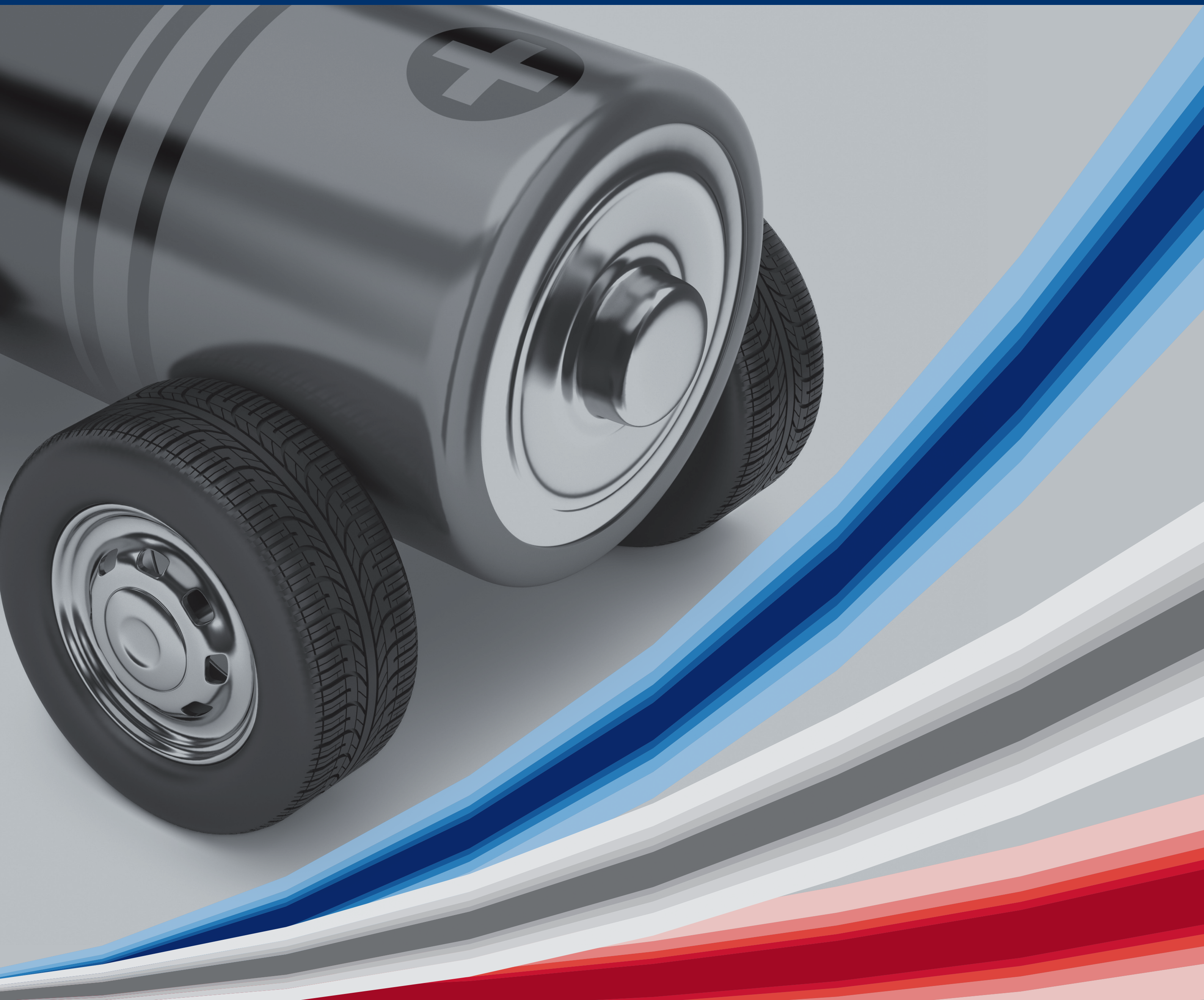
FRAUNHOFER INSTITUTE FOR SYSTEMS AND INNOVATION RESEARCH ISI

MARKET EVOLUTION SCENARIOS FOR ELECTRIC VEHICLES

SUMMARY

MARTIN WIETSCHEL, PATRICK PLÖTZ, ANDRÉ KÜHN AND TILL GNANN



Disclaimer

This study was commissioned by acatech – German National Academy of Science and Engineering and Working Group 7 (AG 7) of the German National Platform for Electric Mobility (NPE). The assumptions, methodology, results and conclusions were discussed extensively with representatives of Working Group 7 and the NPE. The Fraunhofer ISI is solely responsible for the contents of the study. The study does not reflect the opinion of acatech or the NPE.

Contact

Professor Martin Wietschel
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Strasse 48
76139 Karlsruhe
Germany

e-mail: martin.wietschel@isi.fraunhofer.de
Telephone: +49 (0) 721 6809 254

Fraunhofer

ISI

FRAUNHOFER INSTITUTE FOR SYSTEMS AND INNOVATIONS RESEARCH ISI

CONTENTS

1 EXECUTIVE SUMMARY

What share of the market are electric vehicles (EVs) expected to have in Germany by 2020? This was the question tackled by this study. The economic potential for electric cars was ascertained by considering several thousand real-life driving profiles of conventional cars, as well as technical and economic data for different scenarios. Factors which can hinder the diffusion of electric cars, their restricted driving range, for example, or the limited range of models, are integrated as are supporting factors in the form of the willingness to pay more for an innovative technology.

The main results of the study are:

- There is a great deal of uncertainty surrounding the market evolution of EVs because this depends heavily on external framework conditions such as price developments for batteries, crude oil and electricity.
- Under favorable conditions for electric cars, the joint target of the German government and the German National Platform for Electric Mobility (NPE) of one million electric cars by 2020 can be reached without monetary support for the purchase of EVs.
- Even under less favorable conditions, a significant number of electric cars should be able to enter the market by 2020 (about 150,000 to 200,000 in the total stock of cars).
- High electric driving shares (of more than 80 %) and simultaneously high annual mileages (more than 15,000 km) are essential prerequisites for electric cars to be economical. A significant share of driving profiles meets these premises.
- Vehicles with range extenders and plug-in hybrids will probably be able to reach larger market shares than battery electric cars in the near future (approx. three quarters).
- Gasoline-fuelled cars will continue to dominate at low annual mileages in the future under cost-effectiveness aspects, and diesel cars at very high annual mileages.
- The private sector is a relevant market for electric cars. Especially full-time workers from rural areas and small to medium-sized towns or the suburbs of larger cities show high potentials for the switch to electric cars. These make up about one third of private car owners.

- The switch offers more economically to drivers with their own garage (approx. 60 % of private car owners) or with private parking at home, than to so-called “on-street parkers”, because charging infrastructure costs strongly influence the economics. Moreover, the total number of on-street parkers is comparatively small compared to those with garages or private parking at home (depending on the definition, between 3 and 20 %).
- Purely commercial fleets, which make up around 30 % of the market for new cars, show interesting economic potential. This is due to their driving profiles which often feature predictable routes, the specific economic framework conditions applying to commercial fleets such as the elimination of VAT with its positive impact, especially at the higher purchase prices of electric vehicles, and the high relevance of economic efficiency considerations in car purchasing decisions here.
- Different policy measures such as the introduction of special depreciation options, a flatrate subsidy or offering low interest loans could accelerate the market success of EVs. Significant market growth can be achieved in commercial fleets with comparatively modest financial support. Special depreciation allowances seem the most appropriate instrument here. However, a comprehensive evaluation of policy measures requires the analysis of macroeconomic effects, too. These are not taken into account in this study.
- So far, there are not many publicly available empirical data or studies on the group of company car users, which makes up a relevant share of approximately 30 % of the new car market and is particularly important for the large car segment. Not much research has been done on how purchasing decisions are made here. This tends to be a complex process, because it has to balance the interests of both the companies and the car users. The potential to switch to EVs is probably limited here for purely economic reasons because users have partially unfavorable driving profiles often characterized by long distances and individual routes. More research is required on the company car sector.
- There are relevant uncertainties attached to the scenario analyses concerning the assumptions about the willingness to pay more for electric vehicles and the willingness to switch to electrically-powered vehicles despite the currently still limited range of available models. Both aspects have a strong influence on how the market develops. The drawback of the limited model range will be offset to some extent in the next few months since German car makers have announced plans to introduce a wider variety of models (16 models until the end of 2014).

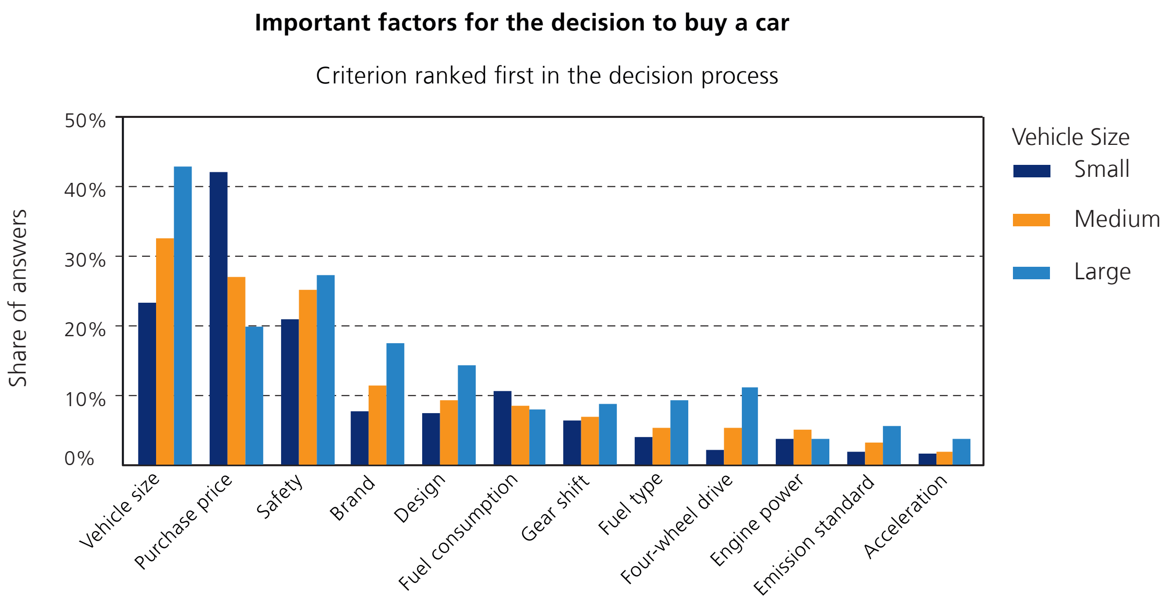
2 INTRODUCTION

Electric vehicles (EV) have been identified as key elements of sustainable transport in Germany's National Development Plan for Electric Mobility. An increasing shift towards electrically-powered cars offers the chance to reduce the dependency of Germany on oil imports, minimize both global (CO_2) and local (pollutants, noise) emissions, contribute to conserving resources and further develop a multimodal transport system.[1] Germany's goal is to become an international lead supplier and lead market for electric vehicles in order to retain its leading role in the automobile and automotive supplier industries as well as in the sciences. As a first milestone, the German government and the German National Platform for Electric Mobility[2] are striving to get one million electric cars onto Germany's roads by 2020. However, the government can only implement targeted and effective support measures if they can build on a well-founded understanding of the possible market evolution of electric vehicles. Here, it is important to develop empirically reliable models of the market evolution.

Building on the previous work of the German National Platform for Electric Mobility (NPE), the overall objective of this research project is therefore to develop a model to calculate the total costs of ownership of electric vehicles in a transparent way. In addition, different obstructive factors (for example charging infrastructure availability or the insufficient range of models) and supportive factors (for instance the willingness to pay more for an innovative and environmentally-friendly vehicle) are considered and different market success scenarios are developed for electric vehicles up to 2020. The scenarios also illustrate several possibilities for how important influencing parameters could develop, including battery and crude oil prices and how these impact the diffusion of EVs. We also analyze the effect of different policy measures on market evolution.

The next chapter outlines the methodology and the model used. The three scenarios are described, and the sensitivity analyses and important model input parameters explained. This is followed by a presentation of the results and their subsequent discussion and then conclusions are derived. A detailed documentation presenting all the calculations, input data and equations is given in the long version of this report, which is only available in German "*Markthochlaufszenarien für Elektrofahrzeuge – Langfassung*".[3]

1 cf. Bundesregierung 2009.
2 cf. NPE 2010.
3 Plötz et al. 2013.



Included in the model:
— Vehicle size
— Purchase price
— Brand
— Fuel consumption
— Fuel type
— Emission standard

Assumed to be of **equal value**:
— Safety
— Design
— Acceleration

Not included:
— Gear shift
— Engine power
— Four wheel drive

Figure 3–1: Important factors in private consumers' vehicle purchase decision[4] and their consideration in the ALADIN model

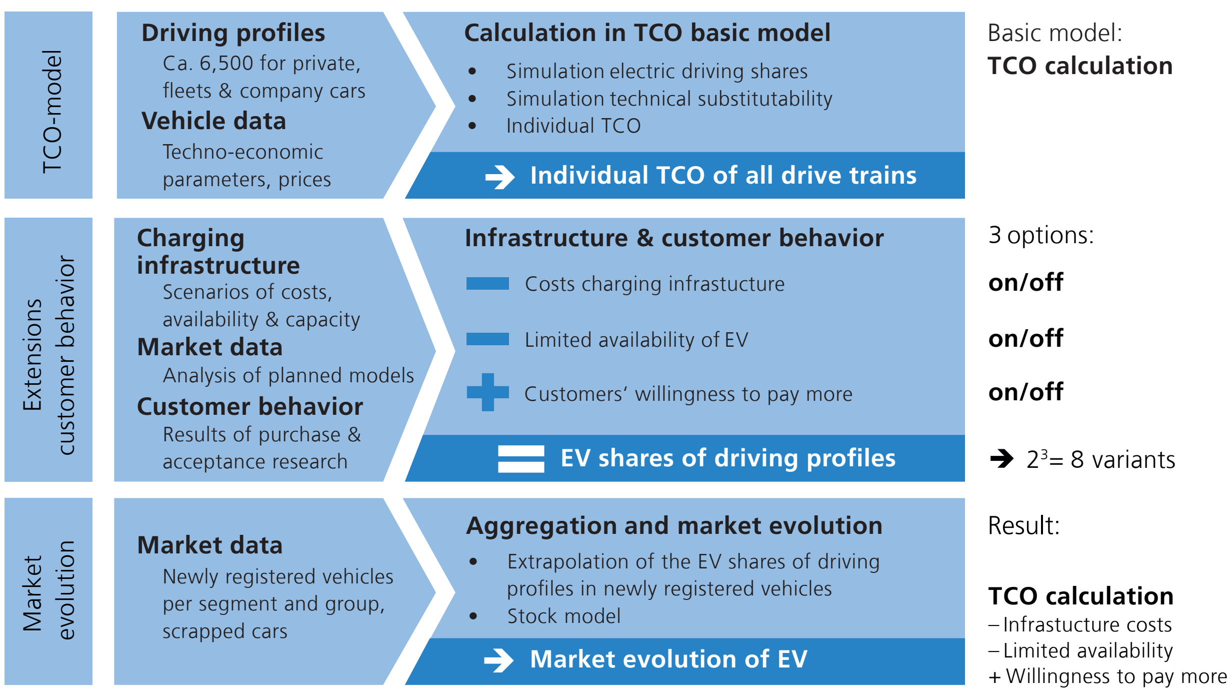


Figure 3–2: Overview of the approach taken in the ALADIN model

3 METHODOLOGY, SCENARIOS AND IMPORTANT INPUT DATA

3.1 METHODOLOGY

This section describes the methodology for calculating the market evolution of electric vehicles.[5] The simulation model ALADIN (**Al**ternative **A**utomobiles **D**iffusion and **I**nfrastructure) is the key element here.[6] The evolution of the market is calculated successively based on a comparison of the economic efficiency of different drive systems and taking obstructive and supportive factors into account for approximately 6,500 driving profiles. One driving profile covers all the trips made by one vehicle in at least one representative week. The successive approach allows the effects of individual influencing factors on market evolution to be plotted separately and thus makes it more transparent.

Figure 3–1 gives an overview of the most important factors which play a role in the decisions of private consumers when buying a vehicle and which of them are considered in the model. Figure 3–2 shows the general approach taken in the ALADIN model.

The costs of buying and using a vehicle obviously play an important role for potential buyers when making a purchasing decision.[7] In commercial fleets, the economic aspects are even more important.[8] Compared to conventional cars, electric cars are generally more expensive to purchase, but they are often cheaper to run on account of lower fuel and maintenance costs, among other things. It is therefore essential to look at costs in terms of the total costs of use, in order to determine for which utilization or driving profiles electric cars are more economical than conventional ones. Total cost calculations for vehicles are correspondingly a common component of models of the market penetration of electric vehicles.[9]

In a first step, therefore, the costs of total use, referred to as TCO (Total Cost of Ownership), are ascertained for electric and conventional vehicles in Germany. The TCO comprise the purchasing and running costs for the respective vehicle and are calculated from the user's perspective. Table 3–1 shows a summary of the economic variables included. Three user groups are distinguished – private, commercial (only fleet vehicles) and company cars – because of their different rates of taxation and depreciation options as well as their deviating patterns of utilization. Because the TCO are also strongly influenced by the size of the vehicle, different car segments are also distinguished. Table 3–2 shows the distribution of newly registered cars by user group and segment.

The drive technologies analyzed included battery electric vehicles (BEV), range-extended vehicles (REEV) and plug-in hybrids (PHEV)[10] as EVs as well as conventional gasoline and diesel cars. For the TCO calculations, the cheapest respective drive technology was selected.

4 Own assessment based on Peters and de Haan 2006.
5 Detailed documentation is found in the full report (Plötz et al. 2013).
6 Although the ALADIN model has not yet been published in its entirety, individual databases and calculations for certain owner groups have been published several times (see among others Wietschel et al. 2012, Gnann et al. 2012a and 2012b, Plötz et al. 2012, Dütschke et al. 2012, Kley 2011).
7 See e. g. Peters et al. 2011 for private owners and Dataforce 2011 for commercial owners.
8 See Öko-Institut 2011a and Dataforce 2011.
9 See Fraunhofer ISI 2012; ESMT 2011; Kley 2011; McKinsey 2011; NPE 2011a, 2011b; Plötz et al. 2012; Wietschel et al. 2009 and 2011; Schmid 2012; Mock 2010, among others.
10 If the option to power the vehicle directly using the combustion engine is realized in hybrid vehicle concepts, these are called Plug-in Hybrid Electric Vehicles (PHEV). Range-extended electric vehicles (REEV) have a combustion engine in addition to the battery with a generator to extend the driving range. This provides additional power for the battery, but does not directly power the vehicle.

Table 3–1: Economic variables considered in the ALADIN model

Parameter	Private	Commercial	Company cars
Purchase price	✓	✓	✓
Discounting of future costs	✓	✓	✓
Residual value at the end of the ownership period	✓	✓	✓
Fuel prices (gasoline, diesel, electricity)	✓	✓	✓
Repair and maintenance costs	✓	✓	✓
VAT	✓		
Vehicle tax	✓	✓	✓
Taxation of benefit in kind[11]			✓
Willingness to pay more	depending on variant		
Charging infrastructure costs	depending on variant		

Table 3–2: Analyzed combinations of user group and car segment

Segment	Private	Commercial	Company cars
Small	✓	✓	✓
Medium	✓	✓	✓
Large	✓	✓	✓
Light-duty commercial vehicles		✓	

One of the key innovations compared to previous TCO analyses is that the calculations are not made based on average annual mileages but are instead based on real-life driving profiles.[12]

A driving profile covers all the trips including the purpose, length of route, departure and arrival time, duration as well as information about the vehicle over an observation period of at least one week. Profiles vary widely by user even within the different groups and have a very strong influence on the economic efficiency of electric vehicles. The barrier presented by BEV's limited range is explicitly considered in the analyses. Each individual driving profile is analyzed according to whether the driver is able to make all the trips with a BEV. In addition, the electric driving share of plug-in hybrids or range-extended electric vehicles is simulated individually for each driving profile. This is important to obtain realistic results for the economic efficiency, which depends on the share of electric driving and is especially relevant for PHEV and REEV. The first step is to make TCO calculations on this basis.

In the second step, the TCO calculations are extended by including the costs of the main charging infrastructure. This is done in order to put the assessment of the economic efficiency in the TCO calculations on a broader basis. Charging infrastructure costs vary widely depending on the charging type and location. For instance, using private charging infrastructure is generally cheaper for drivers with a garage than the use of public charging infrastructure on which on-street parkers have to rely.[13] Because the methodology is a simulation which does not represent spatial modeling but only trip purposes (such as for example "going home", "going to work", "going shopping"), statements about the infrastructure are only possible to a limited extent. The infrastructure assumption made is the same for all users in the respective user group. Depending on the scenario, car users are provided with a different amount of charging infrastructure (for example, only charging at home for private users and only charging at work for commercial users). In terms of costs, however, only the primary charging point (e.g. the private wall box of garage owners) is classified.

11 The scenarios were based on calculations using the former regulation with taxation of benefits in kind for company cars. Towards the end of the project, this regulation was altered and EVs were placed on a better footing tax-wise, but this could no longer be taken into account in the calculations made here. But the current legal status is considered in the calculations for the policy measures (chapter 4.5).

12 The driving profiles used are described in the detailed report (Plötz et al. 2013).

13 See Gnann et al. 2013 and Kley 2011.

The brand and size of a vehicle are also important factors influencing the decision to buy.[14] For instance, many buyers are extremely loyal to a particular brand or, conversely, would not even consider buying other brands. There will continue to be a restricted range of models and brands of electric vehicles available in the near future, which represents a limiting factor for the market evolution of electric vehicles. The restricted choice and availability of brands are therefore taken into account in the model. This is done by analyzing currently offered models of electric vehicles and the announcements made about planned new ones. Logistic growth in the number of available makes with BEV drives or REEV/PHEV is then determined on this basis using ordinary least squares regression. It is also assumed that some buyers decide in favor of an EV of a different brand (if an EV has ideal TCO) and the rest for a conventional vehicle of the original brand.

The most important factors obstructing the market diffusion of electric vehicles are taken into account with the economic efficiency, range anxiety and the limited offer of electric vehicles. The fourth and final step then integrates other aspects of electric vehicles which tend to support their market penetration, for example environmental friendliness, low noise emissions or the allure of an innovative technology. These supportive aspects are integrated in the model for private users via the willingness to pay more.[15] Experiences show that the admission of a willingness to pay a higher price in questionnaires is not the same as actually observed purchasing behavior.[16] Nevertheless, it does provide first indications of the esteem attached to new technologies and the approximate magnitude of the willingness to pay more for them. The approach of taking the willingness to pay a higher price is a common one in market diffusion models of electric mobility.[17] The comprehensive empirical database of the Fraunhofer ISI is employed once again[18] to account for the willingness to pay more in the approach proposed here using the ALADIN model.

It has to be taken into account for the customer segment of company cars which are mainly used privately that these are more strongly regulated as regards vehicle selection and that special taxation rules apply: Among other things, tax has to be paid on the benefit in kind of using a company car. Another restriction is that some companies also pay the maintenance costs of company cars. The drivers therefore do not necessarily profit from low costs in this area. Furthermore, company-internal stipulations play a role. The details can vary widely, but they probably have a large influence on the selection of the vehicle (e. g. exclusive contracts with specific manufacturers, leasing contracts). A company's policy concerning its public image and environmental performance can also influence the provision of vehicles. For this reason, it is necessary to take all the stakeholders' considerations into account: the company's management, its fleet administrator and its drivers. There are no comprehensive publicly accessible surveys available of these complex decision processes and there is the corresponding need for further research here. It was therefore not possible to include the willingness to pay more for company car users.

The existing studies in the commercial transport sector show that some commercial users definitely have the willingness to pay more, but that this is still lower overall in comparison to private users.[19] A willingness to pay more for commercial users is included based on the results of Dataforce 2011.

In the final step, the market evolution is modeled for electric vehicles in Germany up to 2020. The driving profiles at which an electric car becomes economically viable are determined for each year based on the analyses conducted. The evolution of the market is then determined by extrapolating the share of these users in newly registered vehicles.

Monetary policy measures are also integrated into the model such as purchase bonuses, for example, and their impacts on the evolution of the market are quantified. Psychological aspects which can enhance or weaken the effect of measures are not included in the analysis, nor are non-monetary measures such as electric vehicles being able to use bus lanes, which can also have a relevant influence on the market success of electric vehicles. The reason for excluding them is that too few empirical data are available to be able to quantify their influence.

14 See Mock 2010 and Mueller and de Haan 2006.

15 Strictly speaking, this means the "readiness to pay higher TCO". Because this expression is not very common, the expression "willingness to pay more" continues to be used in the following.

16 This phenomenon is well known as "stated preference versus revealed preference", cf. Huang et al. 1997 and Bradley et al. 1991.

17 See for example Mock 2010 and Pfahl 2013.

18 See Wietschel et al. 2012, Peters et al. 2011a and 2011b, but also ADAC 2009, GFK 2010 and FOM 2010.

19 See Öko-Institut 2011a, Dataforce 2011.

Table 3–3: Parameter values for the three scenarios[20]

Parameter	Year	Pro-EV scenario	Medium scenario	Contra-EV scenario
Diesel price [euro/liter]	2013		1.45	
	2020	1.73	1.58	1.43
Gasoline price [euro/liter]	2013		1.57	
	2020	1.79	1.65	1.54
Electricity price private sector [euro/kWh]	2013		0.265	
	2020	0.29	0.29	0.33
Electricity price commercial sector	2013		0.20	
	2020	0.215	0.215	0.25
Battery price [euro/kWh]	2013	470	520	575
	2020	320	335	370

3.2 SCENARIOS

The market success of electric vehicles depends heavily on a series of input variables.[21] These include how the prices for crude oil, electricity, batteries develop over time and consumer acceptance, all of which are associated with great uncertainty. This is why the study develops three scenarios and does not attempt to make a forecast about the market evolution of electric vehicles. The developed scenarios do not imply any evaluations of the underlying assumptions and no assumptions about their likelihood of occurrence.

The three scenarios differ in the definition of their framework conditions as follows: the first scenario makes rather optimistic assumptions with regard to the market success of electric vehicles; the second more pessimistic assumptions and the assumptions made in the third scenario for Germany up to 2020 lie in-between these two. The three scenarios are named as shown below:

- Assumptions in favor of electric vehicles **"Pro-EV scenario"**
- Assumptions not in favor of electric vehicles **"Contra-EV scenario"**
- Assumptions in-between these two **"Medium scenario"**

The most important parameters for the reference years 2013 and 2020 are given in Table 3–3 for the three scenarios.[22]

None of the scenarios makes extreme assumptions; this is why sensitivity analyses are conducted for especially relevant influencing parameters. The objective of these sensitivity analyses is to test the stability of the developments and to identify parameters which have a strong influence on the result.

3.3 IMPORTANT INPUT VARIABLES

The driving profiles of vehicles form a very important foundation for the calculations. A separate database ("REM2030-Fahrprofile")[23] is used for commercial traffic (fleet users) and the so called "Mobility Panel" for private and company car users (MOP)[24], which also contains information about the driver which can be used to distinguish private users with privately owned vehicles from those with a company car. The influence of the charging infrastructure can also be modeled to a certain extent using the driving profiles, because the driving profiles of the mobility panel contain information about the trips made. As already explained above, no spatially resolved modeling is done.

A willingness to pay more is assigned to each individual private driving profile according to the affiliation to one of four groups in the innovation process (see Figure 3–3). Only 1.5 % of the driving profiles are assigned the willingness to pay more than 10 %, and approximately half of the private driving profiles are given a low willingness to pay 1 % more. The willingness to pay more is assumed to decrease to 60 % by 2020 for both private

20 All prices are real gross prices including VAT (with 2012 as the reference year).

21 The parameters were discussed at great length with the members of the NPE working group, but the ultimate responsibility for setting the parameters lies with the authors.

22 Because in total more than 160 parameters are used as input into the model which vary additionally over the analysis period, only the most important parameters can be addressed in this summary. A detailed documentation of all the parameters is given in the long version of the report "Markthochlaufszenarien für Elektrofahrzeuge – Langfassung" (Plötz et al. 2013).

23 Cf. Fraunhofer ISI 2012; the data can be downloaded at www.rem2030.de.

24 Cf. MOP 1994–2010.

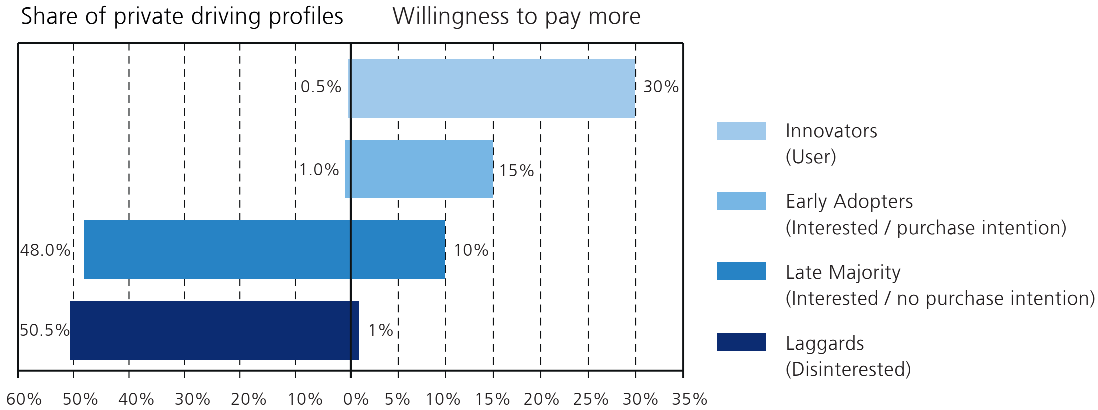


Figure 3–3: Extent and distribution of the willingness to pay more among private buyers in 2013

Table 3–4: Total number of newly registered vehicles by owner group

Segment	Private	Company cars	Commercial	Total
Small	475,300	107,000	233,200	815,500
Medium	694,300	497,600	455,000	1,646,900
Large	143,300	244,600	46,300	434,200
Light-duty commercial vehicles	–	–	204,000	204,000
Total	**1 312,900**	**849,200**	**938,500**	**3 100,600**

and commercial users, because novel technologies become less attractive over time.

Based on a cross-comparison of the different studies, it is assumed that 55 % of commercial users are not willing to pay more. The other 45 % have a willingness to pay 10 % more on the so called Full Leasing Rate.[25] In the market evolution model, this is translated as an extra 7 % on top of the purchase price of the conventional reference model. Again, a decline to 60 % is assumed up to the year 2020. Overall, the assumptions about the willingness to pay more are rather cautious compared to the statements made in the underlying studies. As already stated, company car users are assumed to be not willing to pay more.

Table 3–4 shows the total number of newly registered vehicles by owner groups, which are assumed to be constant for all the years analyzed.

The following monetary policy measures were selected in consultation with the NPE AG 7 and their influence on the market evolution is considered by including them in the TCO:

- *Purchase price reduction*. Target group: all users; a flat-rate, one-off subsidy of the investment; two variants: (a) € 1,000 in 2013, then a linear decline to € 300 until 2020 and (b) € 2,000 in 2013 decreasing to € 600.
- *Lowering the interest rate for private individuals*. Target group: private users; special loans (lowering the interest rates on the investment from 5 % to 4 %).
- *Taxation of company cars*. Target group: company cars; measure of the German Finance Act of 2013; reduction of the gross list price depending on the battery size; linear temporal development 2013: € 500 per kWh, 2020: € 150 per kWh.
- *Special depreciation*. Target group: company cars and fleets; 50 % of the depreciation amount in the first year.
- *Taxation of company cars and special depreciation.* Target group: company cars and fleets; combination of the above two measures.
- *Vehicle tax reduction (PHEV, REEV)*. Target group: all users; BEV already completely tax-exempt; elimination of the base amount based on engine size for REEV and PHEV.

All the parameters were discussed and agreed upon with the members of the NPE AG 7. The final selection, however, was made by the authors. All the other parameters can be found in the long version of the report "*Markthochlaufszenarien für Elektrofahrzeuge – Langfassung*" (Plötz et al. 2013).

25 See Öko-Institut 2011a and b and Dataforce 2011.

4 RESULTS

4.1 TOTAL COST OF OWNERSHIP IN THE MEDIUM SCENARIO

To start with, it should be noted that there a multitude of TCO gaps (differences in the total costs between the drive systems) due to the large number of driving profiles, some of which have very different utilization patterns. To demonstrate this, the TCO gaps in 2020 (accumulated over the total period of use) are illustrated for medium-sized cars in Figure 4–1 for gasoline vehicles compared to diesel vehicles and then for diesel vehicles in comparison to REEV (without including charging infrastructure costs). The left-hand side of the figure shows that, compared to a gasoline-fuelled car, a diesel one only pays off from a specific annual mileage. When comparing diesel with REEV, the influence of the very different electrical driving shares and the associated large scattering is also apparent (right-hand side in Figure 4-1). Despite identical annual mileages, some users have a high electrical share of driving due to more uniform daily driving distances. Such high electrical driving shares have a clearly positive impact on their TCOs on account of the fuel savings made. While studies calculating TCOs up to now have tended to assume an annual average mileage and an average electrical driving share, the scattering here reveals the advantages of analyzing actual driving profiles.

When looking at the various TCO gaps of different user groups and vehicle sizes, it can be stated that electric vehicles are economically efficient for some users already and display a rising tendency to be so from 2013. The annual mileage is decisive here. At low mileages, gasoline cars continue to dominate because EVs are not able to compensate for their higher purchasing costs via their cheaper running costs per kilometer (see Table 4–1). At very high mileages, in contrast, diesel engines are the most cost-efficient option, because PHEV or REEV have to use their combustion engines too often and battery electric vehicles are eliminated because of their limited range. The electric driving share together with the annual mileage is decisive for the difference in TCO of each user. Sufficient annual mileage on its own is not enough (see Figure 4–6).

Table 4–1 shows that the window of annual mileages is the largest for large passenger cars because the consumption savings of EV are the highest here compared to conventional vehicles. Furthermore, considering that large vehicles frequently also tend to have a high annual mileage, large EVs offer the economically most interesting potential. Company cars have no economic potential in the medium scenario.

As already mentioned above, there are many TCO gaps between different drive train concepts and due to the wide range of vehicle utilization. To make the results clearer, the TCO differences between the cheapest conventional and cheapest electrical variant are calculated for an individual driver. This is done for each profile. The TCO gaps are plotted against the shares of vehicles with this or a smaller TCO gap (see Figure 4–2 to Figure 4–4).[26] The figures show these TCO gaps in ascending order on the y-axis with the share of users resp. driving profiles on the x-axis which have this or a smaller TCO gap.

For example, Figure 4–2 shows that the driving behavior of 20% of the private users of small cars in 2013 (dotted orange line) have an overall TCO gap of 6,000 euro or less (over the total ownership period which is assumed to be 6.2 years for private drivers including charging infrastructure costs). This TCO gap decreases up to 2020 so that 20 % of the users of private small cars in 2020 have a TCO gap of around 3,000 euro or less. It can also be seen from Figure 4–2 that a proportion of the users in 2020 has a TCO gap less than or equal to zero. This means that an electric vehicle is more cost-effective in total for some users. The newly registered electric vehicles are extrapolated from these shares (and those for other vehicle size classes and owner groups).

The large span of TCO differences is also visible from Figure 4–2 to Figure 4–4. In addition, it is also apparent that large passenger cars have the highest economic attractiveness in all three user groups. This is higher among private owners than in the

26 The graph corresponds statistically to a relative cumulative frequency distribution or empirical cumulative distribution function (Fahrmeir et al. 2011, p. 49). One advantage of this representation is statistical robustness.

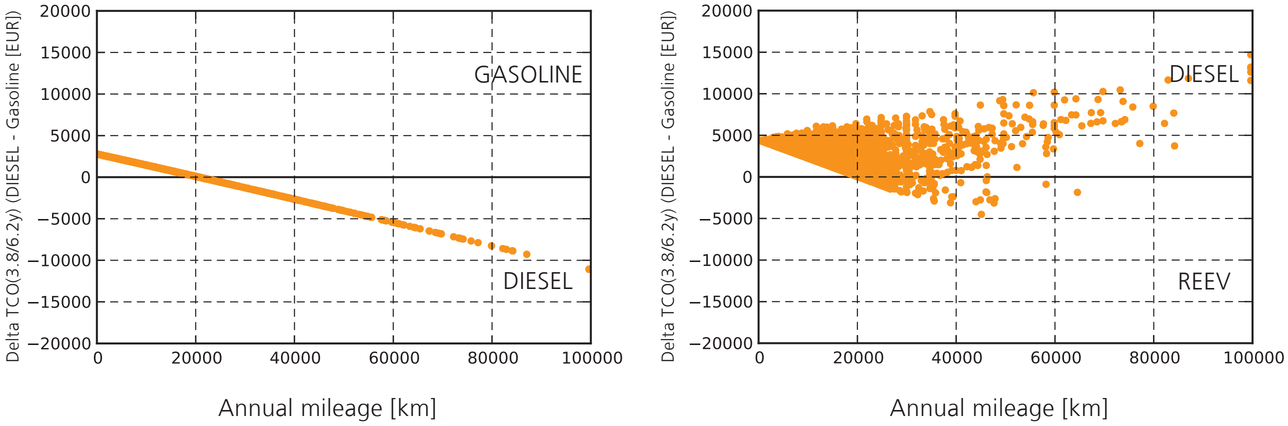


Figure 4–1: Comparison of example TCO gaps for selected drive systems (medium scenario, medium-sized car, private user, 2020) – (each dot represents a driving profile)

Table 4–1: Overview of economically interesting annual mileages (TCO including infrastructure costs) in 2020

Segment	Private	Fleet vehicles	Company cars
Small	20,000 – 25,000 km	about 20,000 km	no window
Medium	18,000 – 35,000 km	about 20,000 km	no window
Large	15,000 – 40,000 km	18,000 – 25,000 km	no window

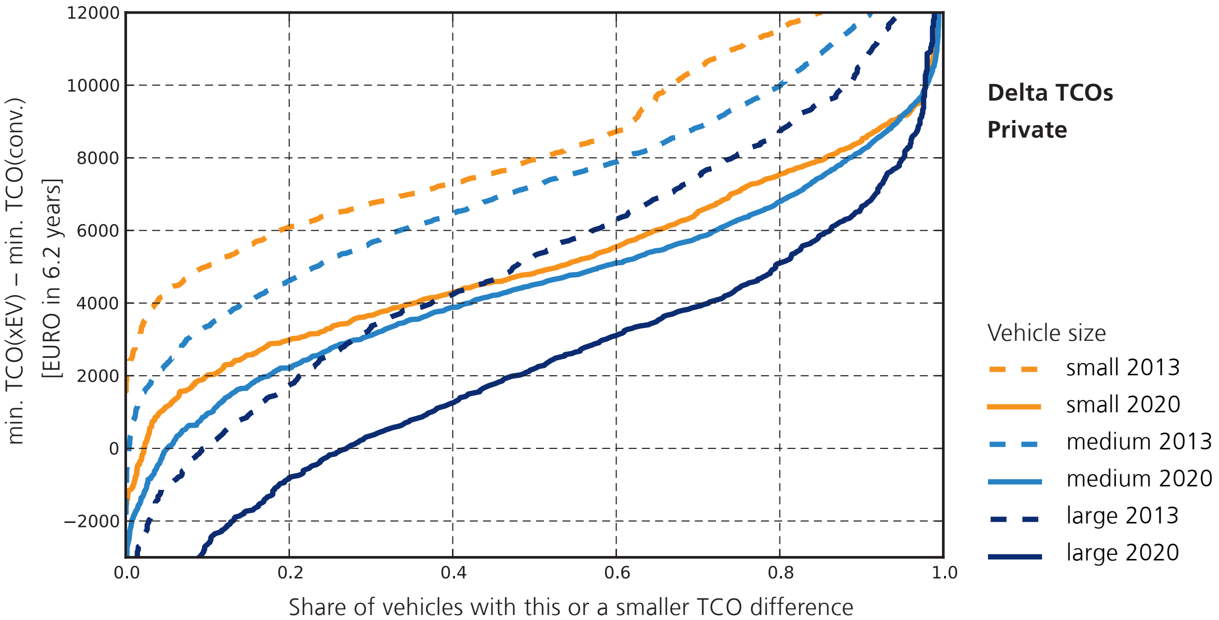


Figure 4–2: TCO differences for private users in the medium scenario in the years 2013 and 2020 including infrastructure costs and willingness to pay more

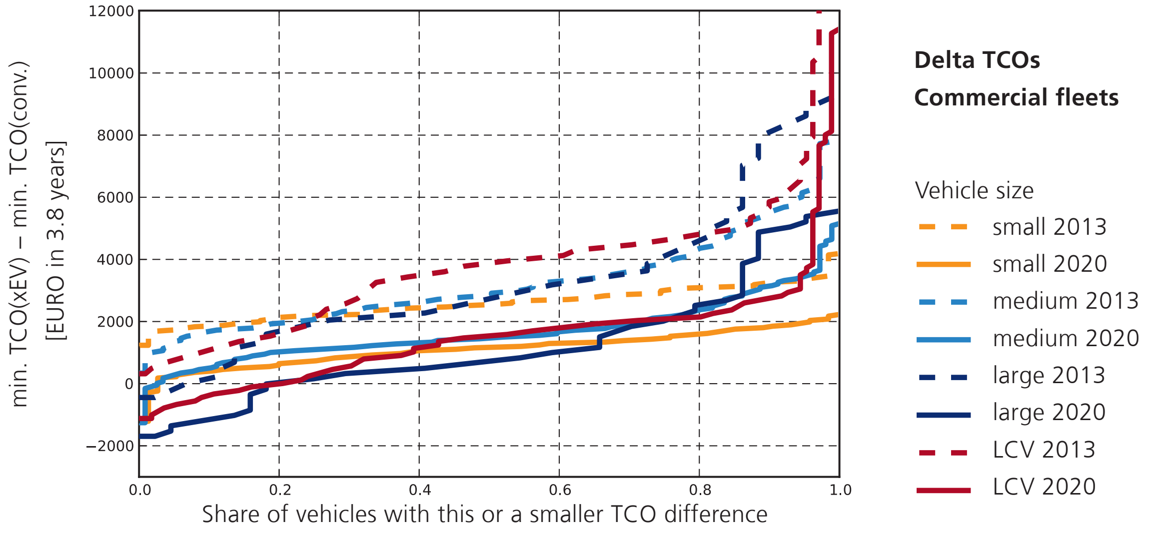


Figure 4–3: TCO differences for fleet vehicles in the medium scenario in the years 2013 and 2020 including infrastructure costs and willingness to pay more

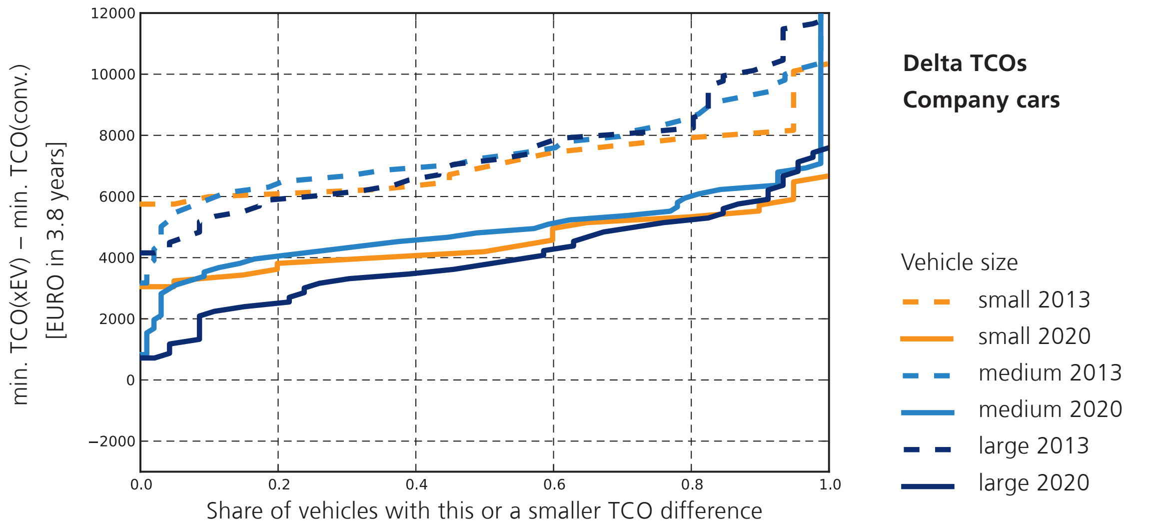


Figure 4–4: TCO differences for company cars in the medium scenario in the years 2013 and 2020 including infrastructure costs and willingness to pay more

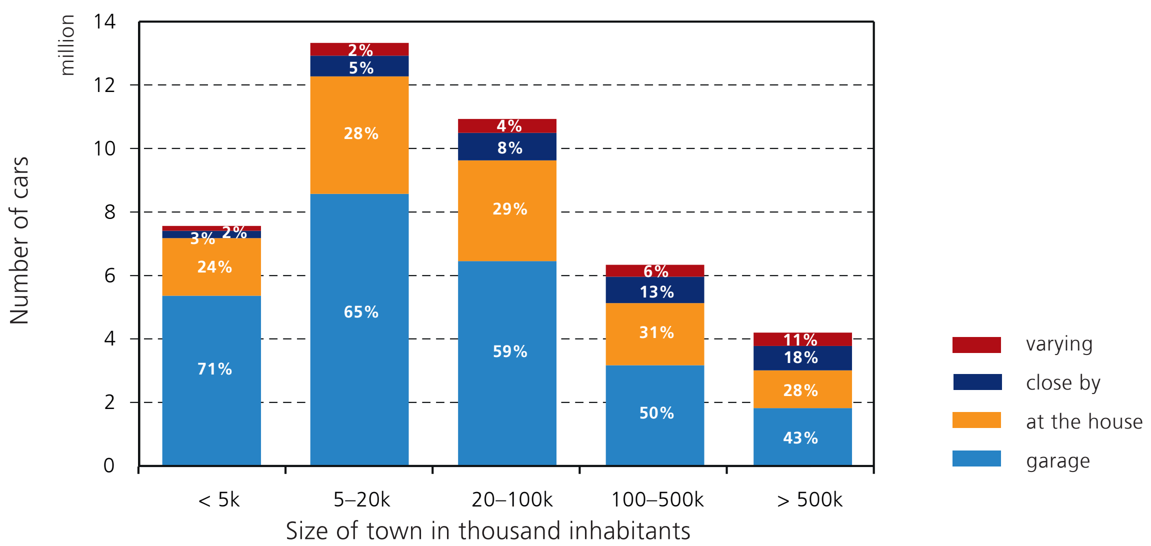


Figure 4–5: Typical distribution of parking places of cars at night in Germany[27]

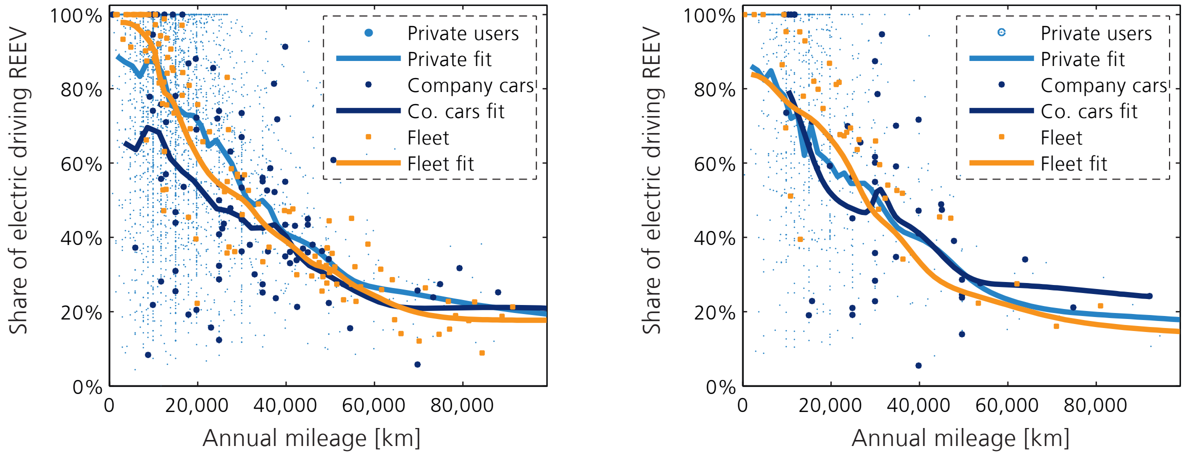


Figure 4–6: Share of electric driving simulated for REEV for different user groups (left: medium-size cars 2020, right: large cars 2020) – (each dot represents a driving profile and the solid lines the regression)

other two user groups because VAT plays a role here alongside driving profiles. Because VAT has to be paid on fuels by private users, the consumption savings between EV and conventional engine systems per kilometer driven are higher among such users than among commercial users.

When comparing the graphs of the three groups, it is noticeable that the curve of private users is the steepest and that of commercial fleets the flattest. There are several reasons for this: first, the effect of VAT, which has already been mentioned. In addition, commercial users tend to have more uniform driving profiles and make long trips more rarely. As a result, the electric driving shares within this group tend to be similar compared to private users, and especially when compared to company car drivers. In addition, the depreciation options for commercial drivers have the effect that the gaps in the TCO shrink on account of the tax savings.

A comparison of the TCO gaps in 2013 with those in 2020 reveals that only a very low potential for EVs exists under the assumptions made in 2013, but that this increases steadily over time.

The costs for charging infrastructure also play an important role for the TCO. It can be assumed for commercial vehicles that simple, weather-protected charging points can be installed on the companies' grounds relatively cheaply (e.g. wall boxes). The same applies to private drivers if these have access to a garage or a private parking place at home (garage availability is given as additional information for each private driving profile). Figure 4–5 shows the distribution of typical night-time parking places of privately owned cars in Germany.

In total, about 60 % of German private car owners have garages.[28] For these and drivers who have private parking at home, it should be relatively cheap to construct infrastructure. Drivers without access to private parking would need charging points which are always useable. This applies primarily to those drivers for whom electric vehicles are an economical option due to their high annual mileages, because these have to be charged over night almost every day in order to achieve high electrical driving shares. Even if these drivers were able to use a comparatively cheap public charging point or another cheap charging point, these driving profiles are hardly interesting economically (see also Figure 4–13).

4.2 ELECTRICAL DRIVING SHARES AND FUEL CONSUMPTION

Because the electrical driving shares have a decisive influence on the TCO results in hybrid designs as shown above and therefore on the market evolution, these are explored in more detail below.

As an example, Figure 4–6 shows the simulated electrical driving shares for REEV of medium-size cars (left) and large cars (right) plotted against the annual mileage for the analyzed driving profiles. The wide scattering of the simulated electrical driving shares is immediately apparent. The shares of electrical driving decline with increasing annual mileage.

In addition, Figure 4–6 illustrates the simulated electrical driving shares of REEV for private cars (light blue), company cars (dark blue) and fleet cars (orange) for medium-size cars (on the left) and large cars (on the right). The plotted lines are moving averages through the point clouds.[29] The electrical driving shares of PHEV have a similar pattern, but are lower than for REEV because of the smaller batteries.

27 Own assessment based on MiD 2002 (refer also to Biere et al. 2009 and Gnann et al. 2013).
28 Independently of this, 70 % of private drivers stated they typically parked on their own property at night, cp. BMVBS 2013, p. 74 based on infas and DLR 2002.
29 More precisely, it is a Nadaraya-Watson kernel regression with the Gaussian kernel to $\sqrt{N}$ nearest neighbor (see Fahrmeir, Kneib and Lang 2009).

In spite of the wide scattering, it is noticeable how the average electrical driving share decreases with increasing annual mileage. The average electrical driving shares are similarly high for all three user groups. However, it can be seen that the simulated electrical driving shares of the fleet vehicles (orange) are scattered less widely around the moving average than those of the other two user groups. The electrical driving shares of company cars are especially widely scattered.

This evaluation raises the question about the electrical and conventional consumption of REEV and PHEV. Effective fuel consumption results are obtained from simulating the electrical driving shares. Values between less than one liter/100 km and more than six liter/100km are possible depending on the electrical driving share. Due to the necessary annual mileages for EV, typical real-world consumption values for REEV and PHEV which make more economic sense than conventional vehicles should be in the range from two to four liters per 100 kilometers.

Besides the purely economic substitutability, the analyses of the driving profiles show that many drivers could achieve comparatively high electrical driving shares. Figure 4–7 shows which proportion of newly registered vehicles would have at least one predetermined electrical driving share as PHEV. Driving profiles are simulated as PHEV and the proportion of vehicles with a minimum share of electrical driving is projected to obtain the share of newly registered vehicles.

It can be seen that a significant proportion of newly registered vehicles could have comparatively high shares of electrical driving: almost 25 % of new vehicles would have an electrical driving share of 80 % or more as PHEV, in other words, would mainly drive electrically. Because REEV have a larger battery, the shares of new vehicles with a minimum electrical driving share would be even higher. Apart from a high share of electrical driving, high annual mileages are also required for the use of EV to be economically advantageous. Vehicles which could be electric in the future are generally not those with the highest electrical driving shares, but those with sufficient annual mileages and high electrical driving shares (cp. Figure 4–1). Since the electrical driving share tends to decrease with increasing annual mileages, until 2020, there will only be a limited, but still significant number of drivers, for whom both these conditions are sufficiently met.

Looking only at vehicles which would enter the market according to an analysis based purely on the TCO (without infrastructure costs, limited availability or the willingness to pay more), 84 % of all PHEV and REEV would have an electrical driving share of more than 80 %. 60 % of the users of PHEV and REEV would have an electrical driving share of more than 80 % even if infrastructure costs, limited availability and the willingness to pay more are taken into account when calculating the TCO.

4.3 MARKET EVOLUTION IN THE THREE SCENARIOS

The calculated market evolution for the three scenarios is illustrated in Figure 4–8. Taking all the effects into account (the cheapest respective infrastructure costs, the limited availability of vehicles and the willingness to pay more), around 400,000 to 700,000 vehicles result in the medium scenario in the total stock of cars, while 50,000 to 300,000 EVs would be conceivable in the Contra-EV scenario and 1 to 1.4 million in the Pro-EV-Scenario.[30] The high sensitivity of the results to the framework conditions of the scenario assumptions is apparent here. This can be explained by the relatively flat TCO curves (see also Figure 4–2 to Figure 4–4). Even small changes to the parameters which either enhance or worsen the economic efficiency affect large numbers of vehicle owners. None of the scenarios is considered more probable or more improbable. Nor are they extreme scenarios (see section 3.2).

The question now has to be asked about what influence individual effects have (considering infrastructure costs, considering the limited availability and the willingness to pay more). Figure 4–9 shows the results without uncertainty ranges for the medium scenario. A pure TCO analysis calculates a market evolution of almost 300,000 electric vehicles in the stock of cars until 2020. This potential is reduced by around 50 % if the cheapest variant of charging infrastructure costs is included in the figure. If, in addition, a limited availability of car models of certain manufacturers is included, this only has a minor effect with the given assumptions. In contrast, including the willingness to pay more has a very strong effect, despite the rather conservative estimation made here of private and commercial drivers' willingness to pay more (see section 3.3). It has to be pointed out once again that the willingness to pay more is associated with great uncertainties and slightly different assumptions can significantly influence the result. Nevertheless, the willingness to pay more does represent the esteem attached to a novel technology, which should not be neglected.

30 The ranges represent the uncertainties due to a limited sample of driving profiles and were calculated with confidence intervals and error propagation, see Plötz et al. 2013.

31 The colored areas show the projection of the car stock development for confidence intervals at confidence levels of 10 %, 30 %, 50 %, 70 % and 90 % based on the extrapolation of the share of the respective driving profiles (Fahrmeir et al. 2011). The confidence intervals cover only the uncertainty due to the finite sample. Uncertainties about future price developments, for example, or the availability of brands are not included.

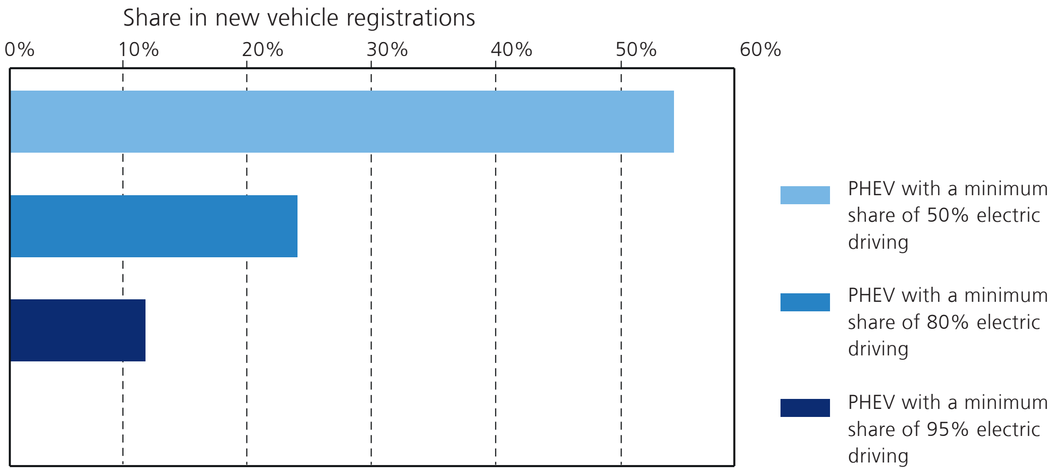


Figure 4–7: Share of new vehicle registrations that have a certain share of electric driving as a PHEV in their driving profile

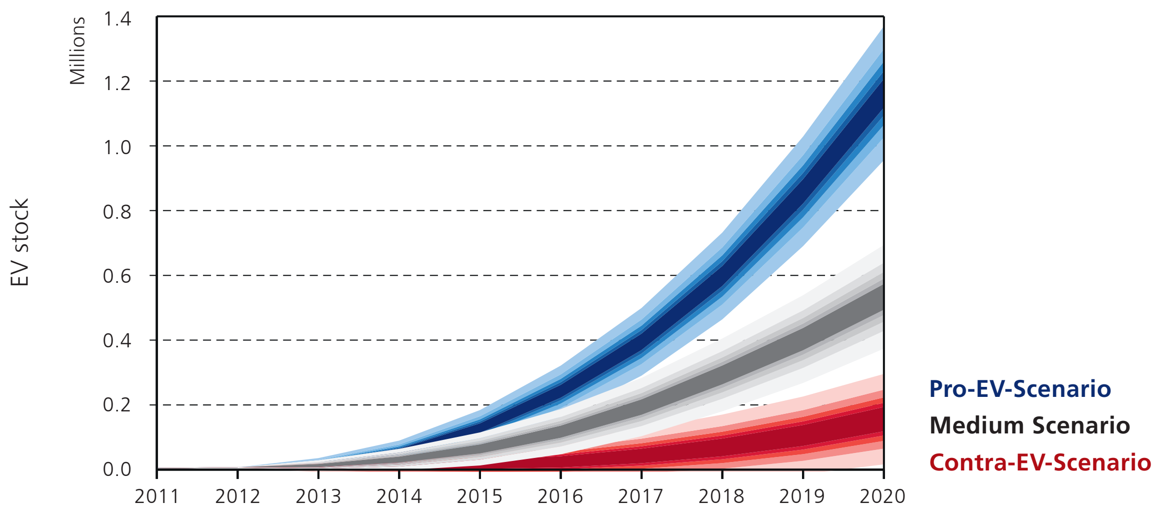


Figure 4–8: Market evolution based on TCO decision incl. cheapest infrastructure costs, limited availability and willingness to pay more in the three scenarios (stock at the end of each year)[31] including confidence band

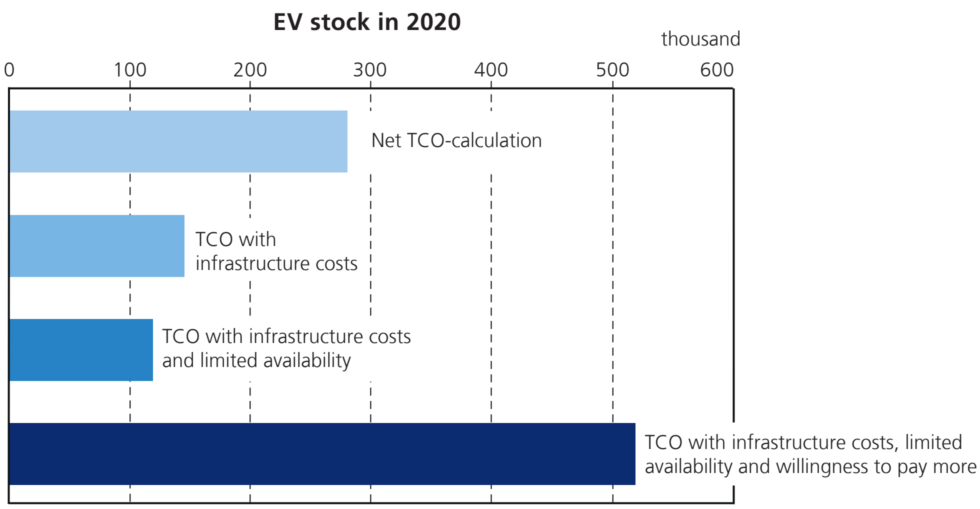


Figure 4–9: EV stock in 2020 including different aspects for the medium scenario without confidence band

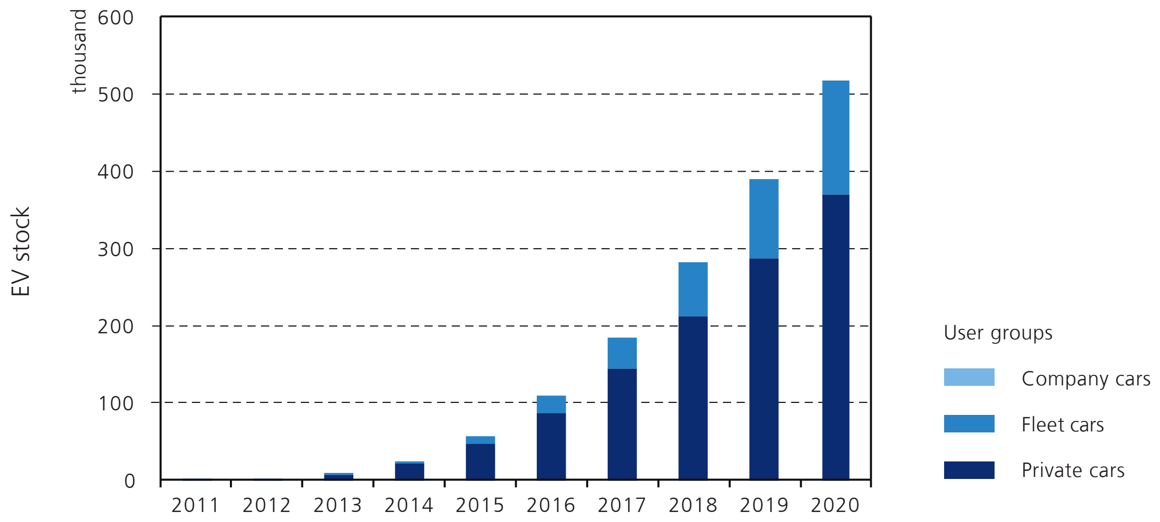


Figure 4–10: Distribution of market evolution into private owners, fleet and company cars in the medium scenario with infrastructure costs, limited availability and willingness to pay more

When splitting the market evolution up into the different user groups of private car owners, fleet and company cars, private owners dominate in the medium scenario followed by the fleet vehicles (see Figure 4–10). Company cars only enter the market in the Pro-EV scenario, but late and with low shares.[32]

As was to be expected based on the TCO analyses, large cars dominate, above all among private owners, and medium-size cars among private and fleet vehicles. Large cars are hardly used at all as fleet cars. Later on, small cars and light-duty commercial vehicles also gain relevance for the market evolution.

Looking at the distribution among the types of EV, REEV and PHEV taken together have a much larger market share than BEV. They enter the market earlier and make up around three quarters of the stock of electric vehicles in 2020. In spite of the lower battery capacities of REEV/PHEV, sufficiently high electric driving shares seem to be attainable for relevant user groups. And the effect, in a few exceptions, of being able to drive longer distances every now and then, also seems to have a positive impact.

It is interesting that the choice of EV drive system differs in the segments. Battery vehicles dominate small cars, which is due to the lower mileages driven in this segment. REEV and PHEV have the upper hand in medium and large cars, although BEV also have a considerable share in the important segment of commercial fleets of medium-size cars. The difference in comparison to private users can be explained by the more uniform, predictable routes and the lower share of outliers regarding very long trips in commercial fleets.

Statements can be made to characterize the private first users of electric vehicles using the socio-demographic information available for the individual driving profiles. Figure 4–12 shows the spread of all driving profiles and the driving profiles for which it makes economic sense to use electric vehicles, differentiated by type of employment and size of the place where drivers live.

It is apparent that, among those for whom the use of electric vehicles makes economic sense, the biggest group comprises full-time workers from small to medium-sized communities. Residents of large cities (with more than 100,000 inhabitants) play only a minor role, contrary to some expectations. The share of this group in EV-compatible driving profiles is smaller than in all other driving profiles. This result is a close match with comparable studies aiming to identify the first users of electric vehicles.[33] It should also be emphasized that the private vehicle stock in cities with more than 100,000 inhabitants is generally "only" about 25 % of all privately owned vehicles (see also Figure 4–12).

Figure 4–13 shows the used charging infrastructure for the option with low charging power and low diffusion. It is assumed that only primary charging points are available. This implies, for example, that private drivers can only charge at home or that on-street parkers need access to public charging. Of course it is likely that there will also be additional infrastructure, for example, semi-public charging points, but these can only be integrated in the model to a limited extent (see section 3.1). This result shows that only a few on-street parkers have reasonable economic potential.

Increasing the charging power is also simulated in the analyses. Even if it is assumed that no additional costs are incurred for charging infrastructure with higher power output, this has hardly any effect on increasing the number of users of EVs: the charging times of vehicles are generally fully sufficient to be able

32 See footnote 11.

33 See Biere et al. 2009, Wietschel et al. 2012, Plötz and Gnann 2013.

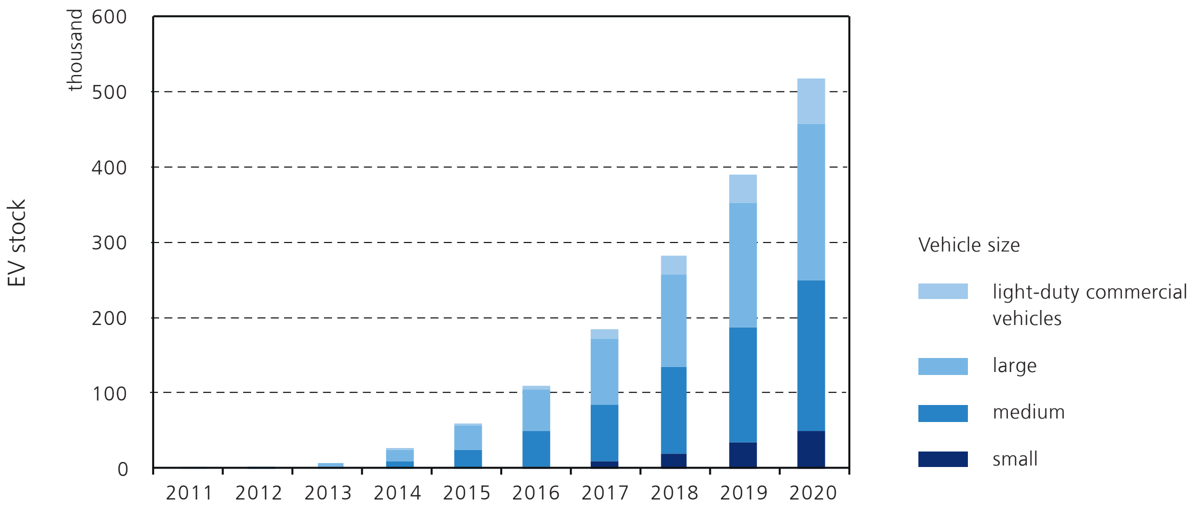


Figure 4–11: Distribution of market evolution into small, medium, large and light-duty commercial vehicles in the medium scenario with infrastructure costs, limited availability and willingness to pay more

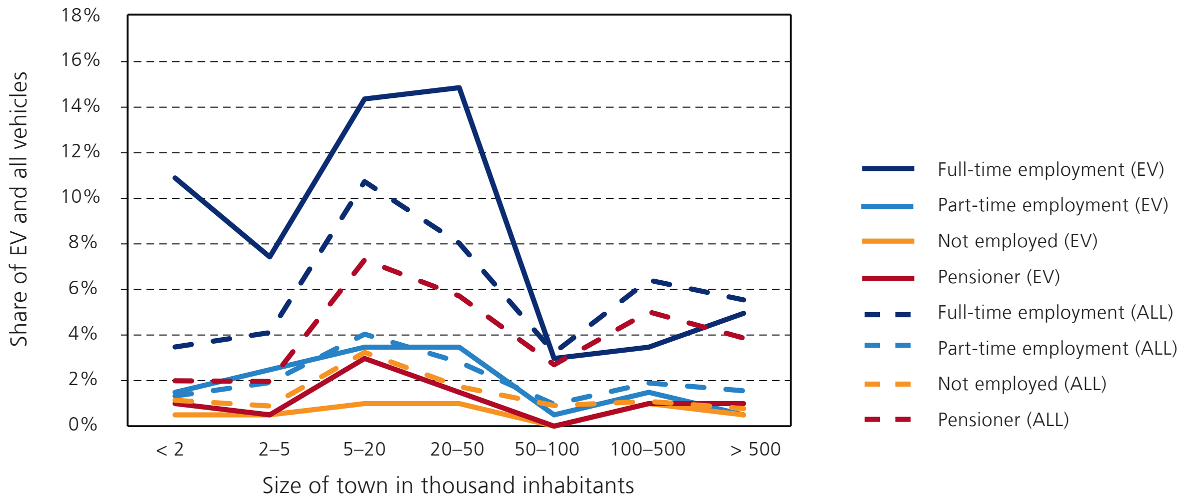


Figure 4–12: Distribution of all driving profiles (ALL) and the ideal TCO driving profiles for electric vehicles (EV) by employment and municipality size in 2020 (medium scenario)

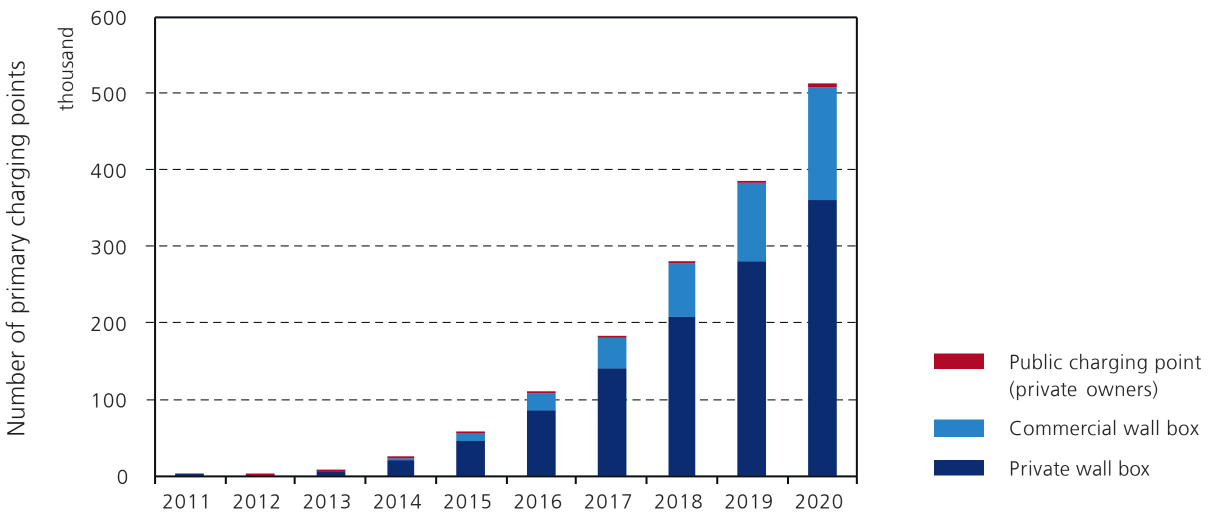


Figure 4–13: Market evolution of the charging infrastructure (only primary charging points) in the medium scenario with infrastructure costs, limited availability and willingness to pay more and cheap charging infrastructure assumptions

to deal with lower charging power.[34] If the costs for a higher charging power are factored in, this even results in a slight decrease in users. Figure 4–14 illustrates these effects for two infrastructure options. It should be pointed out here, however, that the value of being able to charge faster with higher charging power "in an emergency" and the corresponding demand for these kinds of systems cannot be taken into account in the model because of the lack of a data basis among other things.

Further analyses have shown that increasing the availability of charging infrastructure (in other words more charging possibilities in semi-public and public places) results in significantly more users if they themselves do not have to bear the costs for this at all, or only to a minor extent. This might be conceivable if the relevant business models could be realized, e. g. in shopping centers or private car parks or the costs covered by employers. No analysis was made of the individual driving profiles of possible journey breaks during which vehicles could be fast charged because there is no known empirical database concerning the acceptance of such services.

4.4 RESULTS OF THE SENSITIVITY ANALYSES

The high sensitivity of the results to changes in the framework conditions is already obvious when comparing the different scenarios. Separate sensitivity analyses are conducted in this section for the baseline variant (factoring in the costs for charging infrastructure, considering the limited range of vehicles and a willingness to pay more for electric vehicles which decreases by 2020) of the medium scenario. Analyses are made of the sensitivity of electric vehicles in 2020 to changes in electricity prices (private and commercial), fuel prices (gasoline and diesel), battery price and the interest rate for the TCO calculation.

As was to be expected, higher fuel prices, and lower battery and electricity prices lead to much greater numbers of electric vehicles by 2020 in the TCO-based modeling of the purchasing decision. When interpreting the sensitivities, attention should be paid to the fact that the change of electricity and fuel prices cannot be made completely independently of each other from an energy sector perspective. This means, for example, that higher fuel prices may correlate with higher electricity prices.

4.5 IMPACTS OF POLICY MEASURES

The following section shows the effects of different monetary policy measures on the market evolution of electric vehicles. This section aims to reveal free rider effects alongside the costs and benefits of individual measures. Free-rider effects always occur if buyers would have purchased an electric car even without subsidies and therefore profit from additional monetary advantages.

Figure 4–16 summarizes the impacts of the individual measures on the stock of electric vehicles in 2020. It can be seen here that even small financial incentives in the commercial sector can be sufficient to significantly increase the number of EVs in the stock of vehicles. Even with flat-rate subsidies, it is predominantly the commercial fleets that profit. With a flat-rate subsidy of € 1,000, almost 60 % of the market growth is due to commercial fleets. With the special depreciation, it is almost exclusively commercial fleets which demonstrate market growth and company cars hardly at all. The reasons for this are related to the lower TCO gaps (see chapter 4.1). The fact that commercial owners of fleet vehicles attach greater importance to economic efficiency than private owners is another argument supporting the application of possible monetary support measures here.

Changes in the stock of vehicles in 2020 are set against different amounts of support funding. Table 4–2 shows who profits from the individual measures and the necessary amount of funding together with the free-rider effects.

The different measures were integrated into the TCO-based market evolution model. No statements can be made about additional macroeconomic effects (e.g. gross value added or employment) or psychological factors.[36] Further research is required here.

34 Similar results are also presented in detail in Kley 2011.
35 For a detailed description of the assumptions, see Plötz et al. 2013.

36 Refer to TAB 2013, Chapter III.2.4 for possible macroeconomic effects and de Haan, Mueller and Peters 2007 for psychological factors in the application of incentives for car buyers.

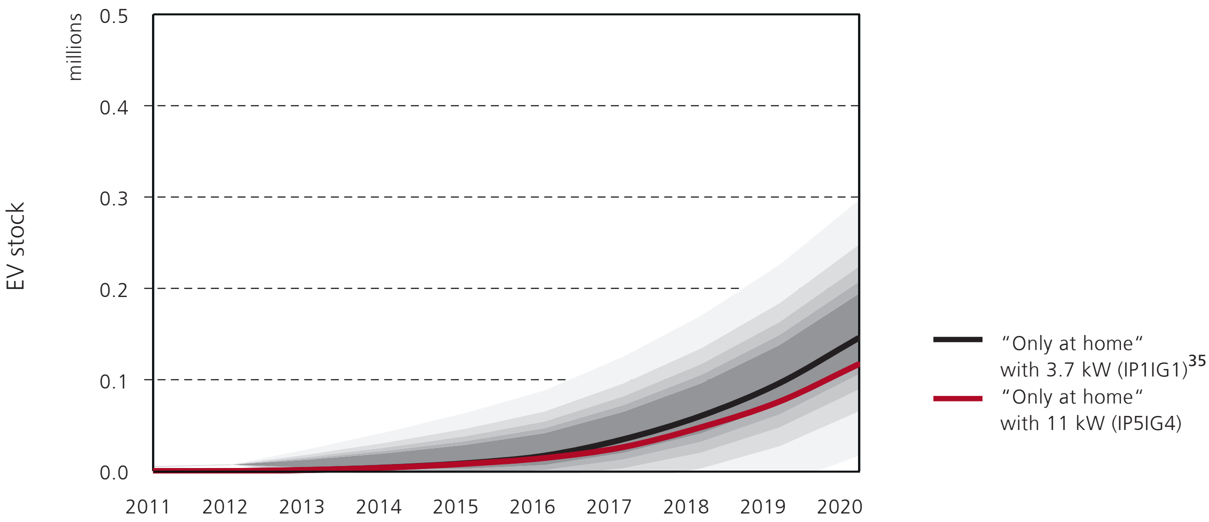


Figure 4–14: Market evolution of EVs in the medium scenario (incl. infrastructure costs, excl. limited availability and willingness to pay more) with two different charging capacities

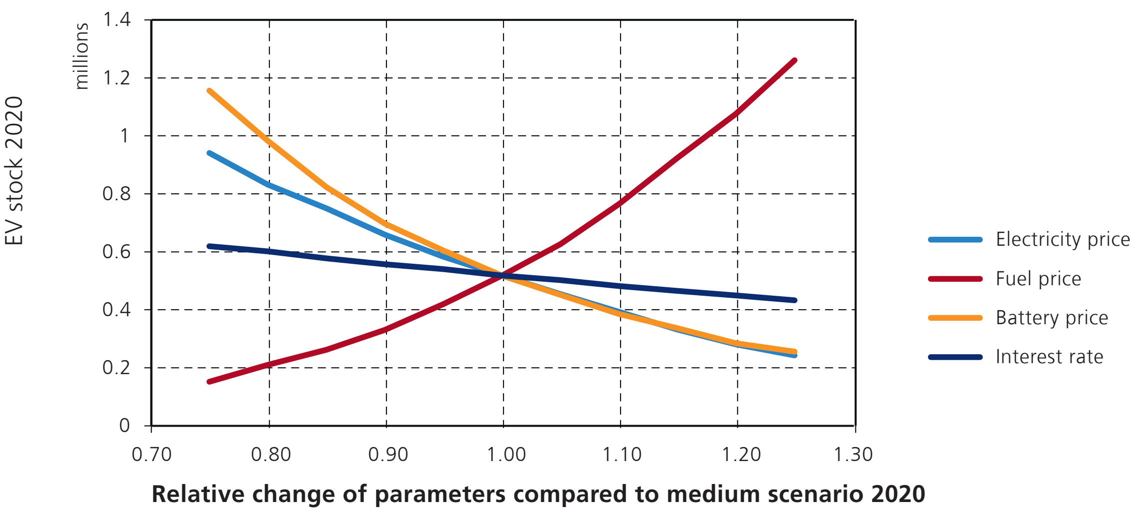


Figure 4–15: Sensitivity of EV stock in the year 2020

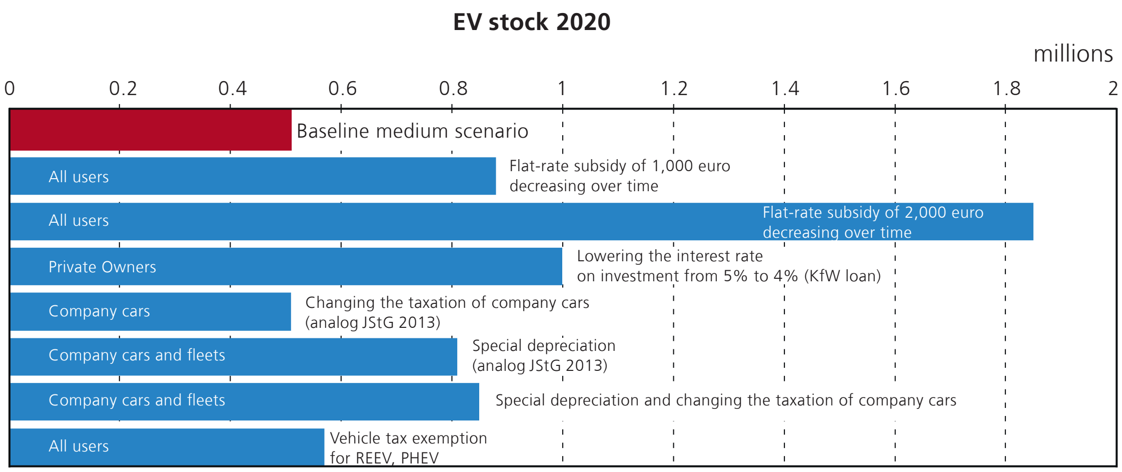


Figure 4–16: Comparison of the effects of policy measures for the medium scenario with infrastructure costs, limited availability and willingness to pay more as well as low charging capacities

Table 4-2: The costs of the individual measures (values in euro 2012) and those who stand to profit from them

Measure	Those who profit	Funding sum required	Free-rider effects
Flat-rate subsidy of € 1,000	Commercial users, small segments	480 million	260 million
Flat-rate subsidy of € 2,000	Commercial users, small and medium-sized segments	2.2 billion	520 million
Lowering the interest rate on investment	Private users, all segments	2.5 billion	710 million
Changing the taxation of company cars	–	–	–
Special depreciation	Commercial users, all segments	540 million	190 million
Special depreciation & changing the taxation of company cars	Commercial users, company cars, all segments	610 million	190 million
Tax exemption for PHEV, REEV	Commercial users, LDV, PHEV, REEV	60 million	45 million

5 DISCUSSION AND CONCLUSIONS

Whether the goal of one million electric cars in Germany by 2020 will be achieved or not is a subject of intense debate. The results of this study show that there is no simple answer. The market evolution of electric vehicles also depends on how external influencing factors develop such as the price of crude oil or electricity, for example. Other factors which are just as decisive are meeting the cost reduction targets, in particular for vehicle batteries, customers' acceptance of this new form of mobility and a sufficient range of vehicles being offered. Predictions here are still associated with a high degree of uncertainty.

The target of one million electric vehicles in Germany by 2020 can be reached under optimistic assumptions regarding the development of the framework conditions for electric mobility. Under such assumptions, there is no need for external incentives to achieve a mass market. The results of the study further show that electric cars can still enter the market even if it assumed that conditions do not favor them: even under difficult framework conditions, a core of 150,000 to 200,000 electric vehicles will be on German roads by 2020. The study did not analyze whether this figure is sufficiently high for automobile manufacturers to enter the market to the extent necessary to achieve the assumed cost reduction potentials for electric vehicles and the charging infrastructure.

Due to the uncertainties regarding market evolution, possible future funding instruments should be characterized by high dynamic adaptability to changes in the technological and economic conditions. It is important that the use of an instrument can also be reversed.

For electric vehicles to be economical, they have to be driven a lot to recoup their higher purchasing costs through their cheaper running and maintenance costs. Low annual mileages (up to about 15,000 kilometers) will continue to be dominated by gasoline-fuelled engines in the future and very high mileages by diesel-fuelled engines (annual mileages from about 30,000 to 40,000 kilometers). In-between, the decision about which car type is most economical strongly depends on whether sufficient shares of driving in a driving profile can be done electrically or if the driving profile can be managed purely electrically. EVs make the most economic sense for relatively uniform daily driving cycles and sufficient annual mileages. A not inconsiderable number of vehicles fulfill these conditions as a detailed analysis of driving profiles in this study shows. The analyses prove that around 12 % of the newly registered vehicles in Germany could achieve an electric driving share of more than 95 % if they were all PHEVs. Possible future funding systems for electric vehicles should therefore be oriented on the electrically-driven kilometers. As other studies[37] have shown, a high mileage is also a prerequisite for a positive environmental assessment of electric vehicles.

Because fuel consumption savings by EVs are the biggest in large vehicles and because these vehicles are often also characterized by high annual mileages, this car segment is actually the most attractive in economic terms. However, this is not reflected at present in either the current range of EV models offered or the announcements concerning planned future models. Instead, so far, manufacturers have tended to specialize in small and particularly medium-sized cars. The reasons for this discrepancy should be analyzed and discussed in more detail.

The analyses further show the fairly high economic efficiency of REEV and PHEV, which together attain a higher market share (approx. three quarters) than BEVs. For many users, the slightly smaller battery in REEV or PHEV compared to BEV seems sufficient to be able to make enough electric trips. And some of these users have to travel longer distances every now and then which require an additional combustion engine. For a more detailed understanding of these fluctuations in the daily trips of individual users, it would be helpful to have access to data recorded over even longer periods of observation, but there are hardly any such data available in Germany up to now.[38] In addition, it is pointed out that range anxiety is one of the main obstacles to the acceptance of BEV, which can only be partially overcome by the positive experiences made with electric vehicles.[39]

37 Hacker et al. 2011, Helms et al. 2011 and Wietschel et al. 2011.
38 See Greene 1985, Lin, et al. 2012, Pearre et al. 2011, Smith et al. 2011 as well as Smith et al. 2010 for longer recording periods outside Germany.
39 See Dütschke et al. 2012.

The private sector, in particular, holds potentials for electric vehicles. This is related to the fact that many “suitable” driving profiles were identified here and that it is assumed – based on empirical surveys – that some customers here have a higher willingness to pay more than commercial customers do. In addition, more large vehicles are found in this segment than among fleet vehicles. The question has to be asked, however, to what extent the purchase decision of private vehicle owners is influenced by the total costs of ownership. The lack of a semi-public and public charging infrastructure could also be a stumbling block to future diffusion.

Users with garages/private parking places, which make up around 60 % of the owners of private cars, are almost always more attractive from an economic perspective than on-street parkers due to their low charging infrastructure costs. The first users of electric vehicles are mainly full-time workers in small to medium towns, because the share of garages is higher here, among other things, and their mileages are better suited to EVs than is the case for drivers in large cities. Only about one quarter of car owners are found in towns with more than 100,000 inhabitants.

Commercial fleets also have high potential. The TCO gaps are small for a comparatively large range of users in this segment in particular. The reasons for this are that these vehicles tend to be driven on regular routes and without sporadic long individual trips. Furthermore, the existing depreciation options and the elimination of VAT have a strong effect on commercial applications and economic calculations play a bigger role here than for private drivers.[40] The construction of public infrastructure is probably less important for these users. Because mainly medium-size vehicles are driven in this segment, the existing range of EV models is a good match. As a result, significant market potentials can be achieved at low cost in commercial fleets. If options are being considered to financially support the market introduction of EVs, the focus should be on the commercial sector. Because commercial vehicles frequently end up on the used car market in the private sector, this segment is also an important door-opener for the spread of EVs. If a special depreciation of 50 % were introduced in the first year, this would significantly accelerate the market evolution (approx. 25 % more cars in 2020 in the medium scenario).

Company cars represent a segment which is less attractive for EVs. One main reason for this was the taxation of benefits in kind, which made EVs economically unattractive to company car users due to their higher purchasing price. A new legal regulation has recently come into force here. Nevertheless, the driving profiles in this sector continue to be characterized by irregular daily trips which result in too low electrical driving shares of many company car users and thus economically smaller potentials. The high share of large vehicles, on the other hand, makes the segment of company cars more attractive on account of the already mentioned high fuel savings – as stated, however, only a few EVs are currently being offered in this vehicle class. Furthermore, it has to be questioned whether low fuel and maintenance costs play any role for company car drivers as these are often covered by the companies. Perhaps the fleet targets set by the companies themselves may give EVs a chance. In the analyses on the market evolution of EVs in company cars, it should be pointed out that, unlike the segments of private owners and fleet vehicles, the lack of data in this segment led to the assumption that there was no willingness to pay more for an EV. Further analyses are needed here for several reasons: because this field is characterized by such high complexity of the decision regarding new cars - what do which companies offer their employees and for what reasons – because there are very few publicly available empirical surveys and even the database of the driving profiles is not very extensive. This is especially relevant given the fact that company cars make up a significant share of newly registered vehicles and play an important role in the large car segment.

Sharing schemes are one aspect which was not considered in more detail in this study. The EV market for car sharing could be especially interesting in large cities according to other studies[41], because of the demand for new transport schemes here and because it might be possible to achieve high capacity use of the vehicles. Schemes combining commercial use and private car sharing are also conceivable. Our current knowledge indicates that the diffusion of electric vehicles can be accelerated via such schemes.

The costs of charging infrastructure have a significant influence on the economic efficiency of EVs. If expensive charging options are necessary for those without private garages or parking spaces, for example, and if users have to cover the costs of the additional charging infrastructure themselves, then EVs are only economical for very few users. High charging power offers hardly any additional benefits because the charging time is only a problem for a very few users with a positive TCO gap, and it is hardly possible to recoup the higher costs of such systems. The psychological aspects of being able to charge "in an emergency" were not considered in the study because of the lack of data. If public or semi-public charging can be offered cost-effectively or for a large number of users, for example in the parking garages of shopping centers or in company car parks,

40 See Dataforce 2011 and Öko-Institut 2011a.

41 See Wietschel 2012 among others.

this has an obvious positive impact on the market evolution. The share of electrical driving can be significantly increased as a result, even for cars with smaller batteries.

Various techno-economic assumptions in the calculations are associated with uncertainties: the future residual value of electric vehicles, for instance, the net list price of new cars and the average battery size of future electric vehicles. Additional calculations showed that the results of this study are not very sensitive to changes in the given assumptions.[42]

The influence of public charging points on the general acceptance of EVs was not investigated in this study. Further research is required here because other studies have indicated that, although drivers often express the desire for such well-developed public charging infrastructure, if such infrastructure is actually available, it is only rarely used.[43] Neither did the study include analyses of locations where trips are interrupted in order to top up the battery at so called fast charging points. In the future, the acceptance of such interim charging should be analyzed, which amounts to around twenty minutes charging time in the 50 kW systems being discussed today. This is probably an elimination criterion for commercial applications because the driver's labor costs during charging cancel out any economic efficiency gained, unless such charging times can be exactly matched to scheduled breaks/appointments. The possible demand for public charging infrastructure due to car sharing and the further use of this infrastructure was not analyzed either.

Another assumption of this study concerns the acceptance of the limited range of BEV. Here, it was assumed that users decide against a BEV if they cannot use one to make all the trips within the period of observation (from one to four weeks). This is plausible because even experienced users of BEV mention their limited range as an important obstacle to the vehicle's attractiveness.[44] However, further studies are necessary here on the real purchasing behavior and the influence, for example, of having a second car.

Finally, it should be pointed out that no changes in mobility behavior were assumed in the study. This assumption is probably legitimate because of the relatively limited time horizon here up to 2020.

42 These variants and results are presented and discussed in detail in the long version of the report available in German "Markthochlaufszenarien für Elektrofahrzeuge – Langfassung" (see Plötz et al. 2013).

43 See Gnann et al. 2013, Ecotality & Idaho National Lab 2012 and Bruce et al. 2012.

44 See Dütschke et al. 2012.

6 REFERENCES

ADAC (2009): ADAC-Umfrage: Kaufbereitschaft Elektroautos. Landsberg a. Lech: ADAC

Biere, D.; Dallinger, D.; Wietschel, M. (2009): Ökonomische Analyse der Erstnutzer von Elektrofahrzeugen. Zeitschrift für Energiewirtschaft 33 (Nr.2), pp. 173–181

BMVBS (2013): Mobilitäts- und Kraftstoffstrategie der Bundesregierung (MKS). Bundesministerium für Verkehr, Bau und Stadtentwicklung, Berlin. http://www.bmvbs.de/cae/servlet/contentblob/113880/publicationFile/79485/mks-strategie-final.pdf (July 2013)

Bradley, M. A.; Daly, A. J. (1991): Estimation of logit choice models using mixed stated preference and revealed preference information. In: Les methodes d'analyse des comportements de deplacements pour les annees 1990. 6e Conference internationale sur les comportements de deplacements, Chateau Bonne Entente, Quebec, 22.-24.05.1991, Vol. 1., pp. 116–133

Bruce, I.; Butcher, N.; Fell, C. (2012): Lessons and Insights from Experience of Electric Vehicles in the Community. In: Electric Vehicle Symposium EVS 26, Los Angeles

Bundesregierung (2009): Nationaler Entwicklungsplan Elektromobilität der Bundesregierung. Berlin

Dataforce (2011): Elektrofahrzeuge in deutschen Fuhrparks – Zur künftigen Bedeutung von Elektrofahrzeugen in deutschen Flotten, Dataforce-Studie, Dataforce Verlagsgesellschaft für Business Informationen. Frankfurt a. M.

de Haan, P.; Mueller, M. G.; Peters, A. (2007): Anreizsysteme beim Neuwagenkauf: Wirkungsarten, Wirksamkeit und Wirkungseffizienz. Forschungsbericht zum Projekt Hybridfahrzeuge. Berichte zum Schweizer Autokaufverhalten Nr. 14. ETH Zürich, IED-NSSI, Report EMDM1161. http://www.nssi.ethz.ch/res/emdm/ (July 2013)

Dütschke, E.; Schneider, U.; Sauer, A.; Wietschel, M.; Hoffmann, J.; Domke, S. (2012): Roadmap zur Kundenakzeptanz. Zentrale Ergebnisse der sozialwissenschaftlichen Begleitforschung in den Modellregionen. Karlsruhe: Fraunhofer ISI

Ecotality and Idaho National Lab (2012): The EV Project Q1 2012 Report

ESMT (European School of Management and Technology) (2011): Marktmodell Elektromobilität. Teil 1: Ansatz und Ergebnisse. ESMT Berlin

Fahrmeir, L.; Kneib, T.; Lang, S. (2009): Regression (Statistik und ihre Anwendungen). Zweite Auflage, Springer

Fahrmeir, L.; Künstler, R.; Pegeot, I.; Tutz, G. (2011): Statistik – Der Weg zur Datenanalyse. Siebte Auflage, Springer

FOM (2010): FOM-Umfrage: Elektromobilität Kauf- und Mobilitätsverhalten in Bezug auf Elektroautomobile. Hochschule für Ökonomie und Management

Fraunhofer ISI (2012): REM2030 Driving Profiles Database V2012. Karlsruhe

GFK (2010): Hohe Kaufbereitschaft für Elektroautos. Studie der GfK Panel Services Deutschland zu Einstellungen und Akzeptanz von Elektrofahrzeugen. http://www.gfk.com/imperia/md/content/presse/pressemeldungen2010/20100921_pm_elektroautos_dfin.pdf (May 2012)

Gnann, T.; Plötz, P.; Kley, F. (2012a): Vehicle charging infrastructure demand for the introduction of plug-in electric vehicles in Germany and the US. In: Electric Vehicle Symposium 26 (EVS26). Los Angeles

Gnann, T.; Plötz, P.; Zischler, F.; Wietschel, M. (2012b): Elektromobilität im Personenwirtschaftsverkehr – eine Potenzialanalyse. Working Paper. Sustainability and Innovation. Karlsruhe: Fraunhofer ISI

Gnann, T.; Plötz, P.; Haag, M. (2013): What is the future of public charging infrastructure for electric vehicles? – A techno-economical assessment of public charging points for Germany. In: Proceedings of the 2013 ECEEE summer study, Hyeres

Greene, D. L. (1985): Estimating daily vehicle usage distributions and the implications for limitedrange vehicles. Transportation Research Part B, vol. 19B, no. 4, pp. 347–358

Hacker, F.; Harthan, R.; Kasten, P.; Loreck, C.; Zimmer, W. (2011): Marktpotenziale und CO_2-Bilanz von Elektromobilität – Arbeitspakete 2 bis 5 des Forschungsvorhabens OPTUM: Optimierung der Umweltentlastungspotenziale von Elektrofahrzeugen. Anhang zum Schlussbericht im Rahmen der Förderung von Forschung und Entwicklung im Bereich der Elektromobilität des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit. Freiburg, Berlin: Öko-Institut

Helms, H.; Jöhrens, J.; Hanusch, J.; Höpfner, U.; Lambrecht, U.; Pehnt, M. (2011): UMBReLA Umweltbilanzen Elektromobilität. Ergebnisbericht. Heidelberg: ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH. http://www.emobil-umwelt.de/images/ergebnisbericht/ifeu_%282011%29_-_UMBReLA_ergebnisbericht.pdf (July 2013)

Huang J.; Haab, T. C.; Whitehead J. C. (1997): Willingness to Pay for Quality Improvements: Should Revealed and Stated Preference Data Be Combined? Journal of Environmental Economics and Management, Volume 34, Issue 3, November 1997, pp. 240–255

infas und DLR (2002). Mobilität in Deutschland (MiD) (2002): Bonn, Berlin: infas Institut für angewandte Sozialwissenschaft GmbH, Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR)

Kley, F. (2011): Ladeinfrastrukturen für Elektrofahrzeuge – Entwicklung und Bewertung einer Ausbaustrategie auf Basis des Fahrverhaltens. ISI-Schriftenreihe Innovationspotenziale, Fraunhofer-Verlag

Lin, Z.; Dong, J.; Liu, C.; Greene, D. L. (2012): PHEV Energy Use Estimation: Validating the Gamma Distribution for Representing the Random Daily Driving Distance, in TRB 91st Annual Meeting. Transportation Research Board, 2012, pp. 1–14

McKinsey (2011): A portfolio of power-trains for Europe: a fact-based analysis – The role of Battery Electric Vehicles, Plug-in Hybrids and Fuel Cell Electric Vehicles. Study by McKinsey & Company. http://www.zeroemissionvehicles.eu/ (July 2013)

Mock, P. (2010): Entwicklung eines Szenariomodells zur Simulation der zukünftigen Marktanteile und CO_2-Emissionen von Kraftfahrzeugen (VECTOR21). Universität Stuttgart

MOP (1994–2010): Mobilitätspanel Deutschland (MOP). Projektbearbeitung durch das Institut für Verkehrswesen der. Datenzugang durch die Clearingstelle Verkehr des DLR (Deutsches Zentrum für Luft- und Raumfahrt). www.clearingstelle-verkehr.de (July 2013)

NPE (2010): Nationale Plattform Elektromobilität (NPE): Zwischenbericht der Nationalen Plattform Elektromobilität. Berlin: Gemeinsame Geschäftsstelle Elektromobilität der Bundesregierung

NPE (2011a): Nationale Plattform Elektromobilität (NPE): Zweiter Bericht der Nationalen Plattform Elektromobilität. Berlin: Gemeinsame Geschäftsstelle Elektromobilität der Bundesregierung

NPE (2011b): Nationale Plattform Elektromobilität (NPE): Zweiter Bericht der Nationalen Plattform Elektromobilität – Anhang. Berlin: Gemeinsame Geschäftsstelle Elektromobilität der Bundesregierung

Öko-Institut e.V. (2011a): Betrachtung der Umweltentlastungspotenziale durch den verstärkten Einsatz von kleinen, batterieelektrischen Fahrzeugen im Rahmen des Projekts "E-Mobility Berlin“. Status-Seminar Elektromobilität, Berlin-Brandenburg, Hacker, F., Berlin: Öko-Institut

Öko-Institut e.V. (2011b): CO_2-Minderungspotenziale durch den Einsatz von elektrischen Fahrzeugen in Dienstwagenflotten. Ergebnisbericht im Rahmen des Projektes "Future Fleet“. Kasten, P.; Zimmer, W., Berlin: Öko-Institut

Pearre, N. S.; Kempton, W.; Guensler, R. L.; Elango, V. V. (2011): Electric vehicles: How much range is required for a day's driving? Transportation Research Part C, vol. 19, no. 6, pp. 1171–1184

Peters, A.; Agosti, R.; Popp, M.; Ryf, B. (2011a): Electric mobility – a survey of different consumer groups in Germany with regard to adoption. Proceedings to ECEEE Summer Study, June 2011. Belambra Presqu'île de Giens, France

Peters, A.; Agosti, R.; Popp, M.; Ryf, B. (2011a): Elektroautos in der Wahrnehmung der Konsumenten: Zusammenfassung der Ergebnisse einer Befragung zu akzeptanzrelevanten Faktoren. Karlsruhe: Fraunhofer ISI

Peters, A.; de Haan, P. (2006): Der Autokäufer – seine Charakteristika und Präferenzen. Ergebnisbericht im Rahmen des Projekts „Entscheidungsfaktoren beim Kauf treibstoff-effizienter Neuwagen". Berichte zum Schweizer Autokaufverhalten Nr. 11. ETH Zürich. http://www.nssi.ethz.ch/res/emdm/ (July 2013)

Pfahl, S. (2013): Alternative Antriebskonzepte: Stand der Technik und Perspektiven – Die Sicht der Automobilindustrie. In: Jochem, P.; Poganietz, W.-R.; Grunwald, A.; Fichtner, W. (Hrsg.): Alternative Antriebskonzepte bei sich wandelnden Mobilitätskonzepten, Tagungsband vom 8. und 9. März, Karlsruhe: KIT Scientific Publishing

Plötz, P.; Gnann T. (2013): Who should buy electric vehicles? – The potential early adopter from an economical perspective. In: Proceedings of the 2013 ECEEE summer study. Hyeres 2013

Plötz, P.; Gnann, T.; Wietschel, M. (2012): Total Ownership Cost Projection for the German Electric Vehicle Market with Implications for its Future Power and Electricity Demand. Enerday, 7th Conference on Energy Economics and Technology Infrastructure for the Energy Transformation, 27.04.2012. Dresden

Plötz, P.; Gnann, T.; Kühne, A.; Wietschel, M. (2013): Markthochlaufszenarien für Elektrofahrzeuge – Langfassung. Studie im Auftrag der Acatech und der Nationalen Plattform Elektromobilität (AG7). Karlsruhe: Fraunhofer ISI.

Schmid, S. (2012): Marktperspektiven zukünftiger Fahrzeugkonzepte – Wettbewerb technischer Lösungen, der Kunde und die Rahmenbedingungen. Vortrag 7. März 2012, DLR Energiespeichersymposium Stuttgart

Smith R.; Blair, D. (2010): Notes on GPS Data Quality, 2010. http://auto21.uwinnipeg.ca/data.html (May 2012)

Smith, R.; Shahidinejad, S.; Blair, D.; Bibeau, E. (2011): Characterization of urban commuter driving profiles to optimize battery size in light-duty plug-in Electric Vehicles. Transportation Research Part D: Transport and Environment, vol. 16, no. 3, pp. 218–224

TAB (2013): Konzepte der Elektromobilität und deren Bedeutung für Wirtschaft, Gesellschaft und Umwelt, Autoren: Peters, A., Doll, C., Kley, F., Plötz, P., Sauer, A., Schade, W., Thielmann A., Wietschel, M., Zanker, C. TAB-Arbeitsbericht Nr. 153, Berlin: Büro für Technologiefolgen-Abschätzung beim Deutschen Bundestag

Wietschel, M.; Kley, F.; Dallinger, D. (2009): Eine Bewertung der Ladeinfrastruktur. ZfAW Zeitschrift für die Wertschöpfungskette Automobilwirtschaft 3, pp. 33–41

Wietschel, M.; Dallinger, D.; Doll, C. et al. (2011): Gesellschaftspolitische Fragestellungen der Elektromobilität. Karlsruhe: Fraunhofer ISI

Wietschel, M.; Dütschke, E.; Funke, S.; Peters, A.; Plötz, P.; Schneider, U.; Roser, A.; Globisch, J. (2012): Kaufpotenzial für Elektrofahrzeuge bei sogenannten ‚Early Adoptern'. Bericht für das Büro für Technikfolgenabschätzung des Deutschen Bundestags. Karlsruhe: Fraunhofer ISI, IREES GmbH

IMPRINT

Fraunhofer Institute for
Systems and Innovation Research ISI
Breslauer Strasse 48 | 76139 Karlsruhe,
Germany

Authors
Martin Wietschel
Patrick Plötz
André Kühn
Till Gnann

Layout, typesetting and illustrations
Renata Sas
Sabine Wurst
Assistance: Julia Emmler

Translation
Gillian Bowman-Köhler

Study commissioned by acatech – German National Academy of Science and Engineering and Working Group 7 of the German National Platform for Electric Mobility (NPE)

Karlsruhe, September 2013

The Fraunhofer Institute for Systems and Innovation Research ISI analyzes the origins and impacts of innovations. We research the short- and long-term developments of innovation processes and the impacts of new technologies and services on society. On this basis, we are able to provide our clients from industry, politics and science with recommendations for action and perspectives for key decisions. Our expertise is founded on our scientific competence as well as an interdisciplinary and systemic research approach.

With a current workforce of more than 230 staff members from science, technology and infrastructure, we offer a highly motivated team. The success of our work is documented by the increase in our annual budget to over 21 million euros in 2012, which was generated in more than 350 projects.