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Can product service systems support electric vehicle adoption?

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ABSTRACT

Plug-in electric vehicles are seen as a promising option to reduce oil dependency, greenhouse gas emissions, particulate matter pollution, nitrogen oxide emissions and noise caused by individual road transportation. But how is it possible to foster diffusion of plug-in electric vehicles? Our research focuses on the question whether e-mobility product service systems (i.e. plug-in electric vehicles, interconnected charging infrastructure as well as charging platform and additional services) are supportive to plug-in electric vehicle adoption in professional environments.

Our user oriented techno-economic analysis of costs and benefits is based on empirical data originating from 109 organizational fleets participating in a field trial in south-west Germany with in total 327 plug-in electric vehicles and 181 charging points. The results show that organizations indicate a high willingness to pay for e-mobility product service systems. Organizations encounter non-monetary benefits, which on average overcompensate the current higher total cost of ownership of plug-in electric vehicles compared to internal combustion engine vehicles. However, the willingness to pay for e-mobility charging infrastructure and services alone is currently not sufficient to cover corresponding actual costs. The paper relates the interconnected charging infrastructure solutions under study to the development of the internet of things and smarter cities and draws implications on this development.

1. Introduction

Increasing awareness of the transport sector's significant contribution to climate change, oil dependency, particulate matter pollution, nitrogen oxide emissions and noise particularly in urban areas has resulted in activities for road transport electrification. Substituting internal combustion engine vehicles (ICEV) with plug-in electric vehicles (EV), i.e. full battery electric vehicles (BEV), range extended electric vehicles (REEV) and plug-in hybrid electric vehicles (PHEV), seems a very promising step to cope with the challenges of individual road transport and fits to the smart city paradigm, which has become one of the most important urban strategies to foster green growth and to improve urban sustainability against the backdrop of climate change (March, 2016). A wide range of definitions for the fuzzy smart city paradigm exist (Cocchia, 2014). Despite the risks accompanying hyper-connected societies (Rifkin, 2014), the common notion is that in smart cities information and communication technologies (ICT) are used to increase citizens' quality of life while contributing to sustainability (Cocchia, 2014; Yeh, 2017). Highly connected information systems providing real-time digital platform services connecting citizens with urban infrastructures are key resources for smart cities.

Policy incentives and car manufacturers' portfolio decisions have a positive influence on EV adoption (Langbroek et al., 2016). Consequently, registrations of EV have been continuously increasing in industrialized countries on the global scale since 2008 (IEA,

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2017). Particularly countries subsidizing EV with pricing incentives and increased access to charging stations, i.e. electric vehicle supply equipment (EVSE), have comparatively higher growth rates (Harryson et al., 2015; Mersky et al., 2016; Ny et al., 2017; Sierzchula, 2014).

However, several barriers to widespread adoption of EV have been observed. Sierzchula et al. (2014) distinguish techno-economic (e.g. prices and range limitations), consumer specific (e.g. consumer mobility patterns and attitudes), as well as contextual factors such as the distribution of EVSE. Thus, further research on decreasing barriers is needed.

The commercial sector in Germany seems particularly promising for EV diffusion (Ketelaer et al., 2014). Vehicles in the commercial sector perform longer trips than private vehicles (on average) and drive more regularly (on average). Both aspects are advantageous for EV usage, as a higher mileage allows a faster amortization and a higher regularity permits to better cope with a limited vehicle range (Gnann et al., 2015a). In addition to that, a large share of annual first registrations, i.e. 65% in Germany (KBA, 2016), are due to commercial owners. Furthermore, in company fleets, which also include ICEV, EV can be easily replaced for extraordinary long distance trips. Therefore, organizational fleets provide an important lever for the integration of EV into the vehicle stock and thus for mass market introduction. Another driving factor is that organizations might be willing to pay somewhat more for EV than for ICEV. As private users (Peters and Dütschke, 2014; Plötz et al., 2014) they might have a willingness to pay more (WTPM) due to the recognized positive impact on their green image (Guth et al., 2017; Nesbitt and Davies, 2013; Nesbitt and Sperling, 2001).

The research question how acceptance of EV can be fostered in order to increase sales numbers of EV have been subject to many research activities during the last years. E.g. reviews are provided by Hjorthol (2013) and Rezvani et al. (2015). More specifically, Wikström et al. (2014) focus on commercial fleets, Koetse and Hoen (2014) on company car drivers and Sierzchula (2014) on fleet managers.

Furthermore, new mobility concepts and business models could transform the technological advantages of EV into value added for the customers (Giordano and Fulli, 2011; Kley et al., 2011; Steinhilber et al., 2013). A function-oriented business model or product service system (PSS) (Tukker, 2004) is a combination of products and services in a system that provides functionality for consumers and reduces environmental impact (Goedkoop et al., 1999). In PSS tangible artefacts and intangible services jointly fulfill specific customer needs (Cook et al., 2006). Supported by the rapid advance of ICT technologies during the last years, many types of PSS became more economical and practical (Roy, 2000). As technology has taken its toll on human life and is present everywhere (Carpanen et al., 2016) the Internet of Things paradigm evolved combining physical and digital components to create PSS and to enable novel business models (Wortmann and Flüchter, 2015). E-mobility business models and therefore e-mobility PSS have experienced increasing attention during the last years (Laurischkat et al., 2016). While business models or services in the automotive industry in general are the subject of many scientific contributions (Williams, 2007), only few authors have focused on business models for EV (see Wells (2013) for a review). EV and corresponding infrastructure increase complexity of business model approaches for multimodal mobility platforms (Willing et al., 2017).

Yet, there are some qualitative studies on business models for EV. Bohnsack et al. (2014) study the evolution of EV business models. Kley et al. (2011) present a systematic instrument describing business models for EV charging. Cherubini et al. (2015) identify the main sub-systems of the PSS in the electric car industry, i.e. vehicle, on-board electronics, infrastructure and energy. They attribute the following actors and roles to these sub-systems: Automobile manufacturers define the PSS value proposition and corresponding product-service bundle pricing strategies. Electronic system companies develop advanced navigation systems. Public institutions are considered being key actors fostering e-mobility infrastructure solutions. They decide on incentive schemes, can push forward implementations of alternative transport systems and can run advocacy campaigns to inform and acquaint citizens. Both, energy providers and public institutions are considered being responsible for the location and availability of charging points, their ease of use and corresponding standardizations. Stryja et al. (2015) provide an overview of existing e-mobility services, classify them and provide a framework to characterize and describe services in the context of EV usage. However, research on PSS is still dominated by conceptual work and additional empirical research is required (Beuren et al., 2013).

Beyond that, specific case studies evaluate costs and benefits of EV. Kosub (2010) applies the technique of cost-benefit analysis to evaluate the choice of an organization to incorporate hybrid vehicles into a vehicle fleet. Piao et al. (2014) compare lifetime net present values of costs and benefits between EV and ICEV to answer the question whether it is beneficial to purchase EV from a private and societal point of view. Costs and benefits of EV compared to ICEV were already studied profoundly, particularly with total cost of ownership (TCO) approaches (ESMT, 2011; McKinsey, 2010; Mock, 2010; NPE, 2011; Peters et al., 2012; Pfahl et al., 2013; Plötz et al., 2012; Thiel et al., 2010). Some approaches are based on individual driving profiles (Gnann et al., 2015a; Gnann et al., 2012; Neubauer et al., 2012) and some were extended by also considering non-monetary factors as WTPM for EV (Gnann et al., 2015b; Plötz et al., 2014). Madina et al. (2016) change the perspective and focus on TCO assessments of EVSE business models instead. In addition to costs Nurhadi et al. (2017) consider sustainability effects in their assessment of current car specific business models (i.e. purchasing, sharing, leasing and taxiing).

However, to the best of our knowledge no studies published so far analyze costs and benefits of e-mobility PSS (i.e. EV, EVSE and services) from a bottom-up user perspective based on empirical data. Consequently, we intend to fill this gap by analyzing actual costs and benefits of organizations who adopted e-mobility PSS in an e-mobility field trial. Based on these results we conclude on the question whether e-mobility PSS can support EV adoption.

This paper is structured as follows: In Section 2 the framework and data used to evaluate costs and benefits of e-mobility PSS is described. In Section 3 the results of the cost benefit analysis are presented. In Section 4 methodological aspects and results are discussed. The article ends with a summary, a conclusion, and an outlook in Section 5.

2. Methods and data

In order to evaluate e-mobility PSS in organizational fleets (i.e. EV, EVSE and e-mobility services) cost-benefit analysis is applied. Organization-specific costs per vehicle for using e-mobility PSS are assessed and compared to the organization-specific WTPM in order to calculate corresponding net benefits. Section 2.1 describes the methodological framework to evaluate costs and benefits of the PSS. Section 2.2 describes the data collected during an e-mobility project in south-west Germany between 2013 and 2015. The project included a large-scale fleet trial with 109 organizations owning 327 EV as well as a regional charging network with 181 interconnected charging points (Sachs et al., 2016).

2.1. Framework to evaluate costs and benefits of PSS

We now turn to the methodology, which is used to evaluate net benefits of e-mobility PSS. As costs for EV and ICEV differ, we analyze the difference of costs and a potential WTPM. Data on costs are combined with data on user perceptions by applying cost-benefit analysis based on the following main Eq. (1):

$$u_i^{PSS} = u_i^{EV} + u_i^{EVSE} + u_i^{CON} + u_i^{SB} + \overline{COE}_i\,, \quad \forall\, i \tag{1}$$

Net benefits of PSS u_i^{PSS} are determined for every organization i by adding net benefits of EV u_i^{EV}, EVSE u_i^{EVSE}, hardware connectivity services u_i^{CON}, service bundles u_i^{SB} (cf. Table 1) and the organizations' average compensation of expenses for participating in the field trial $\overline{COE}_i$ (cf. Section 2.2). Thereby u_i^{PEV}, u_i^{EVSE}, u_i^{CON} and u_i^{SB} represents the average difference of cost and WTPM for EV ($-\Delta\overline{TCO}_i^{EV} + wtpm_i^{EV}$), EVSE ($-TCO_i^{EVSE} + wtpm_i^{EVSE}$), hardware connectivity services ($-c_i^{CON} + wtpm_i^{CON}$) and service bundles ($-c_i^{SB} + wtpm_i^{SB}$). $\overline{COE}_i$ represents the average compensation of expenses for project participation per EV granted to the organization (cf. Eq. (2)).

$$u_i^{PSS} = -\Delta\overline{TCO}_i^{EV} + wtpm_i^{EV} - TCO_i^{EVSE} + wtpm_i^{EVSE} - c_i^{CON} + wtpm_i^{CON} - c_i^{SB} + wtpm_i^{SB} + \overline{COE}_i\,, \quad \forall\, i \tag{2}$$

While all cost parameters are determined by average cost values derived from scientific studies (Plötz et al., 2013), parameters on WTPM are survey based. All parameters have equal weights as WTPM, costs for the vehicles, EVSE and services have monetary units that are directly capable of being totaled.

The average TCO difference between EV and ICEV for a company is calculated in Eq. (3):

$$\Delta\overline{TCO}_i^{EV} = \frac{1}{K}\sum_{k=1}^{K} \min(TCO_k^{BEV}, TCO_k^{PHEV}) - \min(TCO_k^{Gasoline}, TCO_k^{Diesel})\,, \quad \forall\, i \tag{3}$$

Here, the difference between the cheapest EV (BEV, PHEV) and the cheapest ICEV (Gasoline, Diesel) is determined for all vehicles considered of being substituted by EV k of company i, then summed up and divided by their number K (Eq. (3)).

For all vehicles K, TCO is estimated for all vehicle types by Eq. (4).

$$TCO_r = a_r^{capex} + a_r^{opex} \text{ with } r \in \{BEV;\ Diesel;\ Gasoline;\ PHEV\}\,, \quad \forall\, r \tag{4}$$

In Eq. (4) capital expenditures a_r^{capex} and operating expenditures a_r^{opex} are determined for all vehicle types r. Capital expenditures are calculated with the net present value method with residual values (cf. Eq. (5)):

$$a_r^{capex} = (I_r^{veh}\cdot(1+\tilde{i})^{T^{veh}} - SP_r^{veh})\cdot\frac{\tilde{i}}{(1+\tilde{i})^{T^{veh}}-1}\,, \quad \forall\, r \tag{5}$$

Here, I_r^{veh} is the vehicle purchase price and SP_r^{veh} equals the residual value for the vehicle at the end of usage time T^{veh}. The formula is completed by the interest rate $\tilde{i}$. Residual values for the vehicle at end of use T^{veh}, SP_r^{veh} are determined as in Plötz et al. (2014). Operating expenditures are calculated as depicted in Eq. (6).

$$a_r^{opex} = VKT_k\cdot(c_r^{el}\cdot k^{el}\cdot s_{k,r}^{el} + c_r^{conv}\cdot k^{conv}\cdot(1-s_{k,r}^{el}) + k_r^{O\&M}) + k_r^{tax}\,, \quad \forall\, r \tag{6}$$

A part of the operating expenditures is mileage dependent. Annual vehicle kilometers travelled by vehicle k (VKT_k) are derived from vehicle driving profiles collected with GPS-trackers during this study's field trial (all trips of a vehicle within a certain observation period, cf. Section 2.2). The range of an EV determines the feasibility of trips that can be covered by BEV and the electric driving share of PHEV. This largely affects the economics compared to ICEV. It is thus necessary to consider individual driving (e.g. Gnann et al., 2015a). In order to calculate operating expenditures (a_r^{opex}) annual vehicle kilometers travelled (VKT_k), are multiplied with mileage dependent costs such as fuel costs for electricity or conventional fuels (Eq. (6)). Electricity costs consist of the specific electric consumption c_r^{el} [kWh/km], the electricity price k^{el} [€/kWh] multiplied by the share of electric driving $s_{k,r}^{el}$. Conventional fuel costs consist of the specific consumption value c_r^{conv} [liter/km] and the fuel price k^{conv} [€/liter] and are multiplied by the share of conventional driving ($1-s_{k,r}^{el}$). Finally, annual costs for operations and maintenance $k_r^{O\&M}$ are considered. The formula is completed by the mileage independent vehicle registration tax k_r^{tax} (Eq. (6)). While the annual vehicle kilometers travelled are estimated based on an extrapolation of the distance driven in the driving profile, the share of electric driving of a PHEV is determined in an EV simulation (Plötz et al., 2014). All cost parameters considered are taken from Plötz et al. (2014) and Gnann et al. (2015a). We consider an interest rate $\tilde{i}$ of 5% (Pfahl, 2013) and an average vehicle holding time for new vehicles of 3.8 years

Table 1
E-mobility services: Hardware connectivity, charging platform and additional services.

Service category	E-mobility services			Consideration of services	
Hardware connectivity services	Permission to charging network; guarantee of EVSE connectivity and maintenance		s_{CON}	x	
				Service bundle	
				*SB*1	*SB*2
Charging platform services	Map-based display of charging points and display concerning their current availability		s_1	x	x
	Reservation of charging points		s_2		x
	Billing service for charging at the own EVSE		s_3	x	x
	Provision of own EVSE…	… in a regional charging network	s_{4a}	x	x
		… in a supra-regional charging network	s_{4b}		x
	Usage of other organizations' EVSE…	… within a regional charging network	s_{5a}	x	x
		… within a supra-regional charging network	s_{5b}		x
Additional services	Mobility guarantee (a rental car is delivered to the workplace or to the employees if needed)		s_6		x
	EV and infrastructure consulting by …	… different providers	s_{7a}	x	
		… the same provider	s_{7b}		x

(KBA; Gnann et al., 2015a) which will be considered equal to the investment horizon T^{veh}. The assumptions for battery and energy prices are shown in Table A.1, all vehicle parameters in Table A.2.

The costs for EVSE and services consist of capital expenditures for EVSE TCO_i^{EVSE} as well as operating expenditures for connectivity c_i^{CON} and a service bundle c_i^{SB}. By using the annuity factor a^{EVSE}, EVSE specific capital expenditures are calculated by considering organization specific EVSE investments I_i^{EVSE} and the number of EV per organization n_i^{PEV} as follows (Eq. (7)):

$$TCO_i^{EVSE} = \frac{a^{EVSE}\cdot I_i^{EVSE}}{n_i^{PEV}}, \forall\ i \tag{7}$$

In addition to the hardware connectivity services s_{CON} different e-mobility services compose two different service bundles, *SB*1 and *SB*2 (Table 1). Customized service bundles $SBopt_i$ are constructed in addition, i.e. service bundles consisting only of charging platform and additional services with $wtpm_{i,s}^{SER} - c_i^s > 0$.

Hardware connectivity services s_{CON} grant permission to the charging network and guarantee EVSE connectivity and maintenance.

*SB*1 represents the service bundle which was in addition to the hardware connectivity services s_{CON} provided in the field trial (Table 1). It is composed of the following charging platform services: a map-based display of charging points and display concerning their current availability (s_1), a billing service for charging at the own organizations' EVSE (s_3), a service managing the provision of own EVSE in a regional charging network (s_{4a}) and a service managing charging activities at other organizations' EVSE within a regional charging network (s_{5a}). Furthermore, consultancy services for EV and EVSE (s_{7a}) complete *SB*1. More detailed information is available in Sachs et al. (2016). *SB*2 represents a fictitious, more extensive service bundle that could potentially be provided to e-mobility PSS adopters in the future (Table 1). In addition to the services of *SB*1, this service bundle includes the possibility to reserve charging points (s_2), provides access to a supra-regional charging network (s_{4b} and s_{5b}), includes a mobility guarantee (s_6) and consultancy services by one provider instead of several different providers (s_{7b}). A detailed description on how the relevant services of this study were chosen by Ensslen et al. (2017).

WTPM for the service bundles $wtpm_i^{SB}$ are calculated based on WTPM for single service components $wtpm_i^s$ using linear, additive utility functions (Weddeling et al., 2010). WTPM for single services are aggregated in order to calculate WTPM and net benefits of the service bundles considered.

Operating expenditures are calculated by summing up service costs, i.e. adding cost of service bundle c_i^{SB} and costs for connectivity c_i^{CON}. Parameters and equations for the calculations of costs for EVSE and services are provided in Table A.3.

With the additional information on organizations' benefits available, i.e. the survey-based information on WTPM for EV, EVSE and e-mobility services as well as the data on the compensation of expenses granted ($wtpm_i^{EV}$,$wtpm_i^{EVSE}$,$wtpm_i^{CON}$,$wtpm_i^{SB}$,$\overline{COE_i}$), net benefits of the whole e-mobility PSS can be evaluated.

2.2. Description of datasets

All organizations interested to get involved in the project's field trial were asked to participate in a voluntary fleet analysis involving a detailed analysis of driving patterns by logging driving profiles in order to find out about their fleets' electrification potentials. 45 of the interested 234 organizations volunteered to participate. 109 participated in the field trial, i.e. decided to purchase at least one EV, project specific EVSE as well as additional hardware connectivity services. 26 organizations are represented in both subsamples, i.e. provided driving profile data and participated in the field trial (Fig. 1).

As this study focuses on early EV adopting organizations we did not expect the organizations' distributions concerning industrial

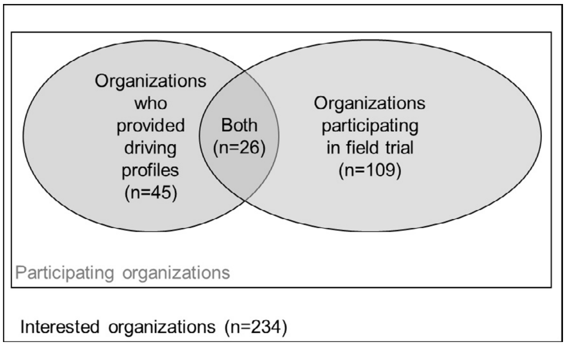

Fig. 1. Overview on subsamples used.

sectors and size to be representative for south-west Germany. We are positively surprised that industrial sector distributions of participating organizations represent the number of employees in the different industrial sectors in Baden-Württemberg fairly well. 38% of the participating organizations belong to the manufacturing sector, 14% to the wholesale and retail sector, 13% to public administration, 8% to information and communication and 6% to the construction sector. Less than 5% of the population are represented in the remaining sectors (Table B.1). Differences can be observed concerning organizations' sectoral distributions compared to Germany's new car registrations (Table B.1). About 80% of the organizations in this study employ less than 250 persons, i.e. are small and medium-sized enterprises. This share is comparably high, as only about 50% of employees in Baden-Württemberg work for organizations employing less than 250 persons (Table B.2).

The fleet managers and decision makers in the participating organizations are on average 45 years old (SD = 12), are predominantly male (about 85%) and are well educated. About half of them have completed academic studies and about 30% have a degree at university entrance level or a master craftsman diploma. 50% have a technical, about 40% a commercial background. On average, the respondents have been employed for 16 years in their organizations (SD = 12) and have an experience level with fleet management activities of 10 years on average (SD = 10). Half of them dedicate more than 10 h per month to fleet management activities, 25% four hours or less and 25% more than 20 h (Ensslen et al., 2017).

Field trial participation came along with a monthly compensation of expenses. Constrained by the real costs for EV the participating organizations received up to 500 Euros monthly (w/o VAT) per BEV or REEV and 350 Euros monthly (w/o VAT) per PHEV in order to compensate for additional costs of project specific EVSE, for the still existent economic disadvantages of EV and for providing data. Due to this setup collecting the substantial amount of high quality organization-specific information was possible.

An overview on the specific datasets used for the assessment of WTPM, costs and net benefits of EV, EVSE and the services considered is provided in Table C.1.

The **vehicle driving profile dataset** is available for the subsample of 45 organizations, who have not necessarily decided to participate in the field trial at the point of time the data was collected. The dataset consists of profiles of all trips of a vehicle within at least three weeks of observation which were collected with GPS-trackers for ICEV to test potential replacements by EV. Several information about the company (such as the number of employees, the main company site or the size of the city) as well as the vehicle (vehicle size, usage type, main overnight parking or number of users) was collected in a short survey. This dataset contains driving profiles of 223 commercially licensed vehicles of 45 organizations participating in the project. The 223 vehicle driving profiles were collected over an average observation period of 23.1 days (SD: 5.8 days) with an average daily mileage of 56.6 km (SD: 39.7 km). At night, the vehicles are mainly parked at the company site (90%) with a dedicated parking spot (54%). Most of the vehicles are fleet vehicles which are used by several users (70%) (Table B.3). Similar to the sample of organizations participating in the field trial, most of the 45 companies which volunteered to provide GPS tracks have less than 250 employees and are mostly located in small cities below 100,000 inhabitants.

Survey data on WTPM for EV, EVSE and e-mobility services was collected between five and nine months before the end of the field trial (between April and August 2015). Organizations had experienced e-mobility PSS for quite some time. Survey data includes organization specific information on WTPM for EV $wtpm_i^{EV}$, EVSE $wtpm_i^{EVSE}$, basic hardware connectivity services $wtpm_i^{CON}$ as well as charging platform and additional services s, $wtpm_i^{s}$. The following survey questions were answered by the organizations participating in the field trial:

(i) $wtpm_i^{EV}$: "How much would your organization be willing to pay for a BEV and a PHEV?"
(ii) $wtpm_i^{EVSE}$: "Which monthly extra charge (price reduction) would your organization be willing to pay (expect) for the non-monetary characteristics of a charging station?"
(iii) $wtpm_i^{s}$:" What is the maximum price that your organization is willing to pay for the following services?"

The detailed questions asked in the survey are provided in Appendix E.

Invoices of project specific interconnected EVSE installed were collected between May 2014 and July 2015 by mail.

Information available on organizations' investments for project specific interconnected EVSE (I_i^{EVSE}) is then used to calculate costs of project specific EVSE TCO_i^{EVSE}.

Different cost parameters are used for EV and service specific cost calculations (Appendix A). As the e-mobility services considered were partly tested within the project, actual cost parameters for a large part of the services (s_{CON}, s_1, s_3, s_{4a}, s_{5a}) are used. For the services not actively tested within the project (s_{4b},s_{5b},s_6) or free of charge within the project context (s_2,s_7) plausible assumption were made during a stakeholder workshop (Ensslen et al., 2017).

3. Results

In order to evaluate costs and benefits of e-mobility PSS we first analyze EV (Section 3.1). Second, we analyze EVSE and corresponding connected e-mobility services (Section 3.2). Third, the results concerning costs and benefits of EV, EVSE and e-mobility services are combined in order to calculate net benefits of the whole e-mobility PSS (Section 3.3). Sensitivity analysis are conducted to analyze effects of parameter variations on TCO and overall net benefits (Section 3.4).

3.1. Costs, WTPM and net benefits of EV

We first have a look at the **TCO** differences of the vehicles (Eq. (2)). For this reason, we compare annual TCO for the cheapest EV with those of the cheapest ICEV. We observe that in 2015, annual TCO are about 800 € higher for most users (~70%) and hardly amortizable with current prices and driving behavior (Table E.1). Thus in 2015, based on the driving profiles analyzed EV cannot be paid off. Positive TCO seem only possible in selected use cases (Schücking et al., 2017). These cost differences do not include the costs for EVSE which might be considerable (Section 3.2). However, the significant additional EV specific costs might be compensated by companies' WTPM for an environmental or marketing effect.

We therefore analyze stated **price premiums (WTPM)** organizations are willing to pay for non-monetary values of EV based on survey data described in Section 2.2. $wtpm_i^{EV}$ which is representing annual WTPM for the organizations' EV is calculated by multiplying the organizations' EV specific WTPM with the annuity factor. According to the results, a large part of the organizations participating in the field trial is willing to pay considerably more for an EV than for an ICEV. About 50% of the organizations are willing to pay more than 5000 € additionally for an EV compared to the respective ICEV, i.e. 1477 annually. 75% of them are willing to pay at least a premium of 2000 €, i.e. 591 € annually (Table E.1). These results point out that (early) commercial EV adopters are likely to be willing to pay considerably more for EV beyond what is expected from a pure economic point of view.

Comparing costs and stated WTPM for EV shows that on average WTPM for EV is higher than the additional costs of EV compared to ICEV ($wtpm_i^{EV} > \Delta\overline{TCO}_i^{EV}$) resulting in positive **net benefits** (Table E.1). The advantages of EV seem to outweigh corresponding disadvantages, particularly unfavorable TCO differences, range limitations and high charging times.

3.2. Costs, WTPM and net benefits of EVSE and e-mobility services

Results on organizations' **costs for EVSE and e-mobility services** are presented in Table E.2. Participating organizations' average investments for interconnected EVSE per EV (I_i^{EVSE}) are 4585 € (w/o VAT). Costs for EVSE connectivity and maintenance (c_i^{CON}) amount to 46 €/a on average. Average annual costs per EV for $SB1$ are 884 €/a, costs for $SB2$ 1172 €/a. Average annual costs for organizations' customized service bundles $SBopt_i$ are 323 €/a. As net benefits of different charging platform and additional services are negative for many organizations, they are not considered in $SBopt_i$. TCO_i^{EVSE} represent the major cost component of products and services additional to EV. The costs for connectivity services (c_i^{CON}), charging platform and additional services provided within the project ($SB1$) are comparatively low compared to the annual amortization rates for EVSE. This is also the case for $SB2$. However, according to the results concerning customized service bundles $SBopt_i$, costs for services should be considerably reduced, as only some of the services show positive net benefits for the users.

The results on surveyed **WTPM for EVSE and e-mobility services** (Table E.2) show that the field trial participants are on average willing to pay an annual surcharge of 789 €/a for the non-monetary values of EVSE ($wtpm_i^{EVSE}$). On average organizations are willing to pay 205 €/a for connectivity services ($wtpm_i^{CON}$). Results concerning WTPM for charging platform and additional services composing the service bundles considered show that the organizations are willing to pay somewhat more for $SB2$ (on average 913 €/a) than for $SB1$ (on average 725 €/a) and $SBopt_i$ (on average 763 €/a).

Net benefits of EVSE and e-mobility services are negative for most organizations (Table E.2). Average net benefits of connectivity services (u_i^{CON}) and customized service bundles ($SBopt_i$) are positive. About 85% of the organizations show positive net benefits for the customized service bundles $SBopt_i$. However, net benefits of EVSE and corresponding services ($u_i^{EVSE} + u_i^{CON} + u_i^{SB}$) without considering EV are negative for between 75% and 85% of the organizations (Table E.2). Net benefits of EVSE and organization specific customized service bundles show higher net benefits than the pre-defined service bundles (Fig. 2).

3.3. Net benefits of e-mobility PSS

After analyzing components of the PSS individually, net benefits of e-mobility PSS are now evaluated as a whole. The monetary incentives granted are also considered. According to Table E.3 the organizations participating in the field trial on average received 2050 €/a (SD: 510 €/a) per EV participating. Visual tests show that net benefits of the e-mobility PSS components are

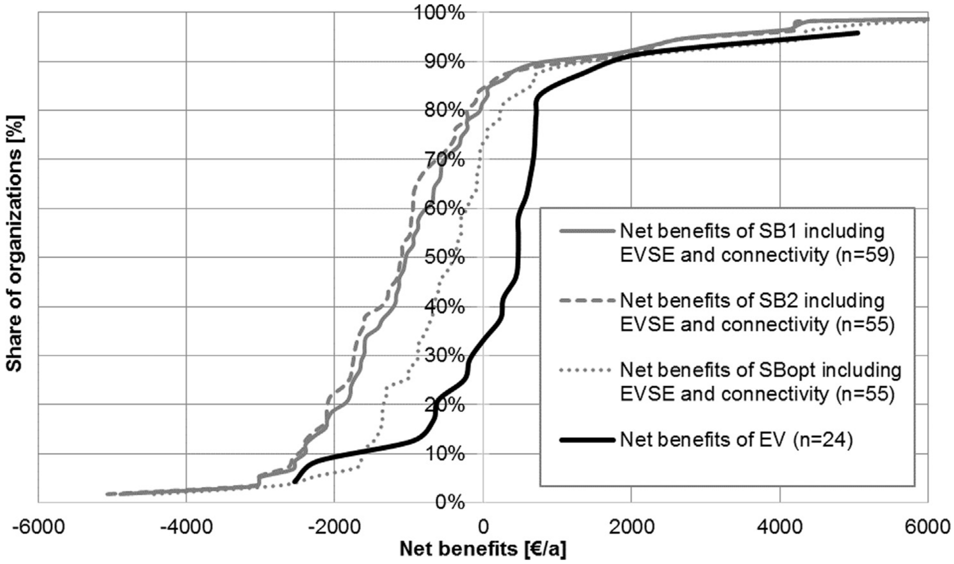

Fig. 2. Net benefits of EV and service bundles including EVSE and connectivity.

normally distributed. Expected values of the sum of net benefits are calculated by summing up expected values of net benefits of EV, EVSE, e-mobility services and monetary incentives (Eq. (8)).

$$E[u_i^{EV} + u_i^{EVSE} + u_i^{CON} + u_i^{SB1} + \overline{COE_i}] = E[u_i^{EV}] + E[u_i^{EVSE}] + E[u_i^{CON} + u_i^{SB1}] + E[\overline{COE_i}] \quad (8)$$

The standard errors (SE) of the expected values of the whole PSS are calculated as follows (Eq. (9)):

$$SE[u_i^{EV} + u_i^{EVSE} + u_i^{CON} + u_i^{SB1} + \overline{COE_i}] = \sqrt{SE[u_i^{EV}]^2 + SE[u_i^{EVSE}]^2 + SE[u_i^{CON} + u_i^{SB1}]^2 + SE[\overline{COE_i}]^2} \quad (9)$$

Fig. 3 shows that EV specific TCO disadvantages are on average compensated by organizations' WTPM for EV. Expected net benefits of EV $E[u_i^{EV}]$ amount to 716 €/a. Expected net benefits of EVSE are negative for more than 75% of the organizations participating with $E[u_i^{EVSE}] = -589$€/a. Net benefits for connectivity services, charging platform and additional services are rather balanced ($E[u_i^{CON} + u_i^{SB1}] = -2$€/a). Expected net benefits of the e-mobility PSS without considering monetary incentives are 126 €/a. Adding the expected value of the compensation of expenses per EV (2050 €/a) results in expected positive net benefits of 2176 €/a. Hence, negative net benefits of the e-mobility PSS of many organization are largely overcompensated by the monetary incentives provided (Fig. 3).

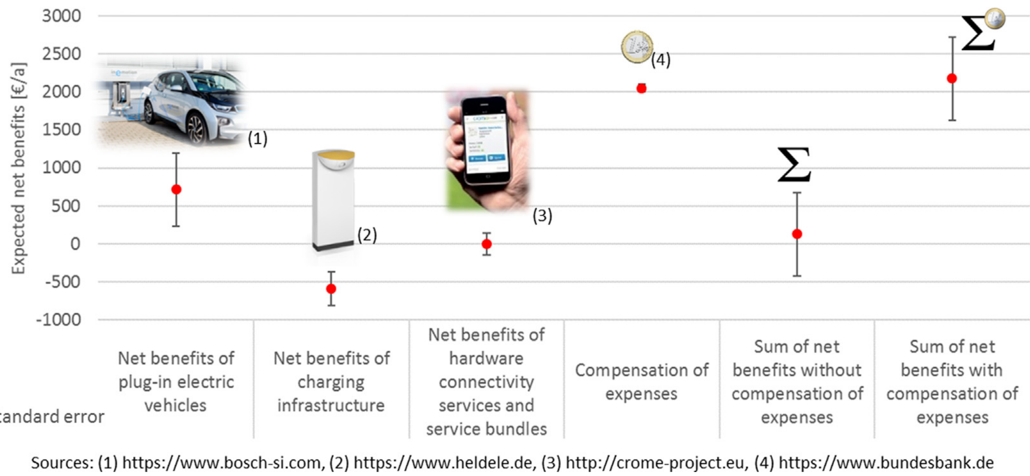

Fig. 3. Average net benefits of the e-mobility PSS provided in the project.

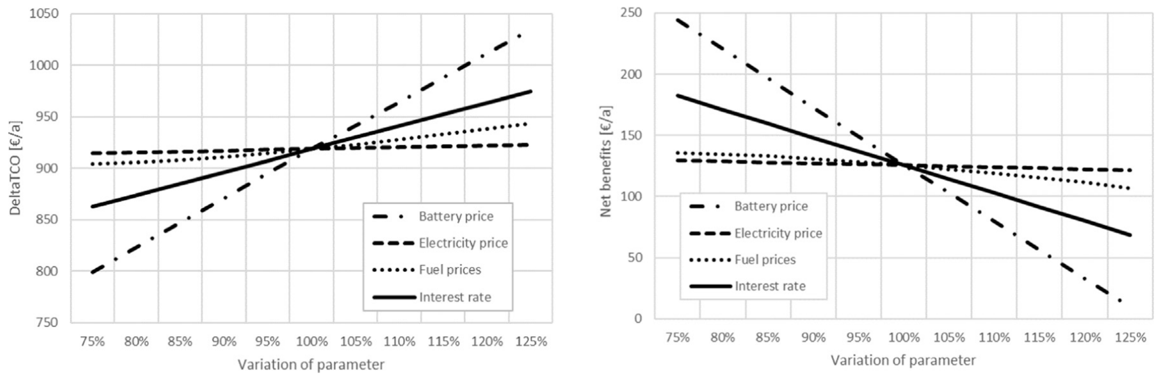

Fig. 4. Sensitivities of parameter variation: Influence of the variation of one parameter on vehicle specific total costs of ownership (left diagram) and overall net benefits excluding project specific compensation of expenses (right diagram).

3.4. Sensitivity analysis

Our sensitivity analysis focuses on parameters potentially influencing TCO calculations as corresponding cost parameters might heavily change in the future and regional aspects might influence some of the parameters.

Fig. 4 shows the effects of parameter variation on TCO calculations and consequently e-mobility PSS specific net benefits. Sensitivities within the range of 25% are highest for battery price, followed by interest rate, fuel prices and electricity price.

4. Discussion

This study deals with the analysis and evaluation of e-mobility PSS based on an approach that combines techno-economic and user-behavioral aspects in order to answer the central research question whether e-mobility PSS in company fleets can support EV adoption. Section 4.1 discusses and critically reflects methodological aspects of our research. In Section 4.2 results are discussed.

4.1. Discussion of methodology

In order to combine the techno-economic analysis of e-mobility PSS with non-monetary benefits, we conducted a survey with participants of a field trial with EV and let them estimate the non-monetary value of e-mobility PSS including different service bundles. The TCO approach is often criticized as being inconclusive for a vehicle purchase decision (ESMT, 2011; McKinsey, 2010; Mock, 2010; NPE, 2011; Peters et al., 2012; Pfahl et al., 2013; Plötz et al., 2012; Thiel et al., 2010), yet it was repeatedly stated by organizations that it is the most important aspect in a commercial vehicle buying decision (Dataforce, 2011). However, this does not necessarily mean that organizations really calculate TCO in their vehicle buying decisions. They might rather use perceived estimates in their decision-making processes. Though the vehicle buying decision is complex (Ensslen et al., 2016) and may include several decision making steps (Klöckner, 2014), the focus of this study is to analyze net benefits of e-mobility PSS as a whole. Therefore, the approach applied combining techno-economic assessments with behavioral aspects seems reasonable.

The design of the questionnaire allowed the fleet managers and decision makers of commercial vehicle users to set non-monetary values of EV, EVSE and e-mobility services in relation to their actual costs. As we asked the fleet managers about WTPM for EV, EVSE, and corresponding services, they tried to monetarize the benefits. However, do these monetarized benefits appropriately represent the real benefits of the e-mobility PSS? The large spread in the net benefits (Fig. 3) shows that corresponding perceptions vary significantly between organizations. Consequently, the results should be interpreted carefully.

The participating organizations represent a very special early adopter group that received expense compensations for participating. The survey sample consists of early EV adopters so it is difficult to draw conclusions about future adopters of EV who will enter the market later and might have different motivations. For example, the average WTPM for e-mobility PSS might be lower when an early majority (Rogers, 1962) is about to enter the market and it is also expected to decrease with increasing market diffusion (Gölz et al., 2015). Hence, results should be considered as an upper estimate. However, some services could potentially increase their attractiveness with increasing market penetrations (e.g. due to a higher number of charging stations) potentially resulting in increasing WTPM.

Furthermore, in addition to incomplete datasets due to the different subsamples of different datasets, missing value problems reduced sample sizes (Appendix C). We controlled for potential errors by additionally calculating net benefit based on the subsample with full data availability. Differences observed between the two approaches are not significant.

Costs for charging infrastructure and services were taken from an early stage e-mobility project. The participating organizations' decisions to adopt and use the interconnected charging infrastructure and services might also be linked to an increased WTPM.

However, the comparably high costs for EVSE and e-mobility services provided within this project might represent the current market situation.

Our TCO and e-mobility PSS net benefit calculations are based on a large set of parameters and assumptions. These are related to values observed in 2015, the observation country (Germany) and the specific observation population (early EV adopting organizations). In the future preconditions for e-mobility PSS specific net benefits might change increasing net benefits of EV. Battery prices are assumed to continue to decline (Berckmans et al., 2017; IEA, 2017). Second hand values of diesel and gasoline cars might decrease quicker than assumed due to governments' plans to ban ICEV from many cities (IEA, 2017). Although the short investment horizon of 3.8 years used in this study represents the average holding time of cars in the commercial sector of Germany, strong variations depending on organizations' commercial sector are possible (Gnann et al., 2015a). According to analyses of other studies, long investment horizons are in favor of EV and sensitivities are comparably low (Palmer et al., 2018). Furthermore, electricity and gasoline prices as well as incentive schemes differ between countries and regions and should therefore be considered when interpreting the results presented.

4.2. Discussion of results

The results presented in Section 3.1 indicate that despite the disadvantages of EV (e.g. range limitations, high charging times) WTPM for EV of organizations participating in the field trial compensate additional EV specific costs. These findings are in line with Plötz et al. (2014) and Peters and Dütschke (2014) showing that private EV users are willing to pay more for EV compared to ICEV. WTPM for EV can be explained by innovative car pool managers benefitting from EV procurements due to technophilia (Globisch et al., 2017). Furthermore, organizations benefit from positive effects on employee motivations (Globisch et al., 2017) and EVs' innovative and environmental image (Guth et al., 2017; Nesbitt and Davies, 2013; Sierzchula, 2014).

The results presented in Section 3.2 indicate that net benefits of individually customized service bundles are higher than net benefits of the predefined ones (Fig. 2). Individual consulting for individual composition of service bundles could increase corresponding net benefits significantly. The market for e-mobility PSS is still highly diversified. Hence, requirements for individual consultancy services are high. There might not be only one e-mobility PSS to succeed in sales activities in organizational fleets. Creating customized e-mobility PSS offers for different types of potential EV adopting organizations might be a convincing strategy for stakeholders and would fit with the smart city paradigm assuming a higher flexibility of services to accommodate individual needs. As interconnected EVSE of other organizations were used only infrequently in our case study, inter-organizational charging activities could hardly be observed. Nevertheless, it seems that the users interpret this service as a kind of insurance against flat batteries and are therefore willing to pay for this charging platform service even without its actual usage. Furthermore, platform-connected EVSE delivers a sound basis for providing smart energy services (Brandt et al., 2017; Ensslen et al., 2018; Goebel et al., 2014; Salah et al., 2017) and multimodal platform services (Willing et al., 2017) including offerings as e.g. ride sharing (Teubner and Flath, 2015) and corporate carsharing (Heinen and Pöppelbu, 2017) in addition to the connected charging platform services considered in this case study. Such additional platform services are co-creating value for EV users and providers by using information exchanged in real-time between EV, EV users, service platforms and other stakeholders. This could contribute to balance the negative benefits of EVSE.

The results presented in Section 3.3 show that today financial support can be an important incentive for EV adoption. If prices for EV, EVSE and e-mobility services are further decreasing, monetary incentives could also be reduced. The findings of this paper show that annual net benefits for most organizations are clearly positive due to the compensation of expenses granted. For about half of the organizations net benefits of the EV are positive without considering the effect of the monetary incentives. However, net benefits of interconnected EVSE and corresponding services are negative for about 80% of the participating organizations. Sierzchula et al. (2014) as well as Harryson et al. (2015) show that financial incentives and availability of EVSE are positively correlated with different countries' EV market shares. The results of this case study point out that the diffusion of EV could be supported not only by providing incentives to vehicle acquisitions but also by incentivizing e-mobility PSS including interconnected EVSE and corresponding platform services being part of publicly accessible charging networks. This could result in positive spillover effects, as additional publicly accessible EVSE offering smart charging services would be put in place that would again positively impact EV sales and developments towards smarter mobility solutions and be in line with the development towards the smart city paradigm.

The results of our sensitivity analysis (Section 3.4) show that EVs' TCO (and therefore overall net benefits of e-mobility PSS) are particularly sensitive to variations of battery prices. Expected fast decreasing battery prices more than halving until 2020 (Berckmans et al., 2017) would significantly increase net benefits of EV (~475 €/a). Effects of electricity and fuel price parameter changes within the range of 25% are comparably low. Despite the high sensitivity potential of future battery price developments, the lever of governments' incentive programs on overall net benefits of e-mobility PSS is comparably high. Incentives amount to more than 2500 €/a in Norway, more than 2000 €/a in France (Harryson et al., 2015) and to more than 2000 €/a in this project's fleet test. These findings are in line with Palmer et al. (2018) showing that government support for low-emission vehicles clearly needs to address financial barriers if EV market share is to break out of the niche market.

5. Summary, conclusions and future work

Recently many field trials with EV intending to counteract climate change, to reduce oil dependency, particulate matter pollution and noise emissions in urban areas by electrifying road transport were carried out in order to develop corresponding technologies. During a field trial with 109 organizations using 327 EV driving profiles, survey data, actual costs for interconnected EVSE solutions as well as information on the compensation of expenses granted to organizations participating were collected. Net benefits for e-mobility PSS, i.e. EV, interconnected EVSE and e-mobility services were evaluated based on fleet managers' perspectives by analyzing costs and WTPM.

The central research question addressed in this article whether e-mobility PSS can support EV adoption can be answered as follows: Currently the costs for interconnected EVSE solutions and e-mobility services outweigh corresponding WTPM. However, e-mobility PSS offerings are more promising if they are adapted to individual needs. They might become even more beneficial to EV users, particularly by considering benefits of smart energy services and multimodal platform services in addition. Consequently, WTPM for e-mobility PSS could increase resulting in a higher probability to adopt. In addition to that it is very likely that interconnected EVSE solutions and corresponding services allocated on the market underlie economies of scale and so will become cheaper in the future. Consequently, positive net benefits of e-mobility PSS might be possible for more organizations in the future without government incentives, particularly if increasing inter-organizational usage frequencies of EVSE are taken into account. Therefore, it is very likely that e-mobility PSS will directly support EV adoption in the future. However, in the current market phase the EVSE and e-mobility services offered rather negatively affected the adoption of EV, the high prices of interconnected EVSE in particular. Although the EVSE and e-mobility services offered did not directly contribute positively to higher net benefits of e-mobility PSS in most organizations, extending the e-mobility charging service offering by further additional smart platform services following the smart city paradigm might positively affect overall net benefits. Smart energy demand response services, billing services permitting to charge private EV with photovoltaic energy produced at the home roof top at the workplace, billing services to charge company cars at home with electricity paid by the employer and multimodal platform services are additional services that could enhance e-mobility PSS offerings. In addition, positive effects of publicly accessible EVSE encountering range anxiety should be considered before conclusions are made concerning the research question whether e-mobility PSS can support EV adoption. Considering positive indirect effects of EVSE availability on EV diffusion should be particularly considered when incentive schemes are designed. The financial incentive program of this study's field trial supported PSS sales activities, i.e. to allocate EV, project specific interconnected EVSE and corresponding charging platform services. This resulted in positive overall net benefits for most of the participating organizations.

Future work could in addition to services considered in this analysis focus on further additional, customer-oriented smart services, as interconnected EVSE solutions provide the basis for EV specific EVSE being part of the internet of things fostering possibilities to offer further e-mobility specific charging platform services to organizations and EV users. Future work could focus on evaluating costs and benefits of such advanced e-mobility PSS integrating additional innovative charging platform services forming service bundles supportive to the smart city paradigm.

Acknowledgements

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Appendix A. Cost parameters

See Tables A.1–A.3.

Table A.1
Battery and energy prices (all prices without VAT in $€_{2015}$).

Battery and energy prices	Unit	Value	Reference
Battery price	€/kWh	359	Pfahl (2013)
Gasoline price	€/l	1.274	MWV (2014)
Diesel price	€/l	1.201	
Electricity price private	€/kWh	0.249	Schlesinger et al. (2011), BCG (2009), Leipziger Institut für Energie GmbH (2012), McKinsey (2012)
Electricity price commercial	€/kWh	0.179	

Table A.2
Technical and economic assumptions for vehicle attributes (all prices without VAT in €$_{2015}$).

Vehicle attributes	Unit	Small	Medium	Large	LCV	Reference
Depth of discharge BEV	–	90%				[1]
Depth of discharge PHEV	–	80%				[1]
Battery capacity BEV	kWh	7	10	13	16	[1]
Battery capacity PHEV	kWh	20	24	28	32	[1]
Conventional consumption Gasoline	l/km	0.058	0.071	0.094	0.112	[2]
Conventional consumption Diesel	l/km	0.046	0.057	0.072	0.085	[2]
Conventional consumption PHEV	l/km	0.053	0.066	0.083	0.098	[2]
Electric consumption PHEV	kWh/km	0.170	0.211	0.228	0.335	[2]
Electric consumption BEV	kWh/km	0.185	0.223	0.240	0.360	[2]
Operations & maintenance Gasoline	€/km	0.026	0.048	0.074	0.059	[3]
Operations & maintenance Diesel	€/km	0.026	0.048	0.074	0.059	[3]
Operations & maintenance PHEV	€/km	0.024	0.044	0.069	0.055	[3]
Operations & maintenance BEV	€/km	0.021	0.040	0.062	0.049	[3]
Net list price Gasoline	€	10,747	17,321	30,976	38,689	[4]
Net list price Diesel	€	12,936	19,508	33,208	40,889	[4]
Net list price PHEV (w/o battery)	€	15,356	22,116	35,551	43,371	[4]
Net list price BEV (w/o battery)	€	11,280	18,042	31,432	38,677	[4]
Vehicle tax Gasoline	€/a	62	125	229	161	[5]
Vehicle tax Diesel	€/a	139	226	349	161	[5]
Vehicle tax PHEV	€/a	26	34	46	161	[5]
Vehicle tax BEV	€/a	0	0	0	161	[5]

[1] Hacker et al. (2011), Gnann et al. (2012), Linssen et al. (2012), Pfahl (2013).
[2] Helms et al. (2011)..
[3] Propfe et al. (2012)
[4] Pfahl (2013).
[5] BMF (2014).

Table A.3
Cost parameters and cost calculations for EVSE and services.

			Pricing model	Price	c_i^{EVSE}, c_i^s
EVSE hardware investment for project specific charging infrastructure			One-time payment	Individual organizations' actual investments (I_i^{EVSE})	$c_i^{EVSE} = \frac{a^{EVSE} \cdot I_i^{EVSE}}{n_i^{PEV}}$ [1]
Connectivity services	s_{CON}: Permission to charging network; guarantee of EVSE connectivity and maintenance		One-time registration fee per organization	248.65 € (actual price)	$c_i^{sCON} = \frac{a^{EVSE} \cdot 248.65€}{n_i^{PEV}}$
Charging platform services	s_1: Map-based display of charging points and display concerning their current availability; RFID card		Service fee per month and EV	2.45 €/month (actual price)	$c_i^{s1} = 12 \cdot 2.45€$
	s_2: Reservation of charging stations		Price per reservation	1.00 €/reservation (assumption)	$c_i^{s2} = 12 \cdot f_i^{s2} \cdot 1€$ [2]
	s_3: Charging at own EVSE		Price per charging hour	0.85 €/hour (actual price)	$c_i^{s3} = 12 \cdot f_i^{s3} \cdot 0.85€$ [3]
	s_4: Provision of own charging infrastructure	s_{4a}: Regional		3.10 €/hour (actual price)	$c_i^{s4a} = -12 \cdot f_i^{s4a} \cdot 3.10€$ [3]
		s_{4b}: Supra-regional		3.95 €/hour (assumption)	$c_i^{s4b} = -12 \cdot f_i^{s4b} \cdot 4.10€$ [3]
	s_5: Usage of charging infrastructure of other - organizations	s_{5a}: Regional		3.95 €/hour (actual price)	$c_i^{s5a} = 12 \cdot f_i^{s5a} \cdot 3.95€$ [3]
		s_{5b}: Supra-regional		4.95 €/hour (assumption)	$c_i^{s5b} = 12 \cdot f_i^{s5b} \cdot 4.95€$ [3]
Additional services	s_6: Mobility guarantee (rental car option)		Price per day	40.00 €/day (assumption)	$c_i^{s6} = f_i^{s6} \cdot 40€$
	s_7: EV and charging infrastructure consulting	s_{7a}:By different companies s_{7b}:By the same company	One-time payment	1000.00 € (assumption)	$c_i^{s7a} = c_i^{s7b} = \frac{a \cdot 1000€}{n_i^{PEV}}$

[1] $a^{EVSE} = \frac{(1+\tilde{i})^{T^{EVSE}} \cdot \tilde{i}}{(1+\tilde{i})^{T^{EVSE}} - 1} = 0.295$; $T^{EVSE} = 3.8a$.
[2] f_i^{s2} represents the number of reservations per month.
[3] $f_i^{s3}, \ldots, f_i^{s5}$ represent participating organizations charging hours per month. More detailed information on usage frequencies of connected charging services is provided in Ensslen et al. (2017).

Appendix B. Sample characteristics

See Tables B.1–B.3.

Table B.1
Economic sector distributions.

	Interested organizations	Participating organizations	Organizations providing driving profiles	Both – Participating organizations providing driving profiles	Employees in Baden-Württemberg in 2013 [1]	New registrations in Germany in 2014 [2]
Sample size	234	109	45	26	4,476,072	1,935,175
A – Agriculture, forestry and fishing	0.00%	0.00%	0.00%	0.00%	4.06%	0.14%
B – Mining and quarrying	0.43%	0.00%	0.00%	0.00%	0.10%	0.06%
C – Manufacturing	31.20%	37.61%	31.11%	46.15%	32.30%	20.33%
D – Electricity, gas, steam and air conditioning supply	1.71%	2.75%	0.00%	0.00%	0.65%	0.39%
E – Water supply; sewerage, waste management and remediation activities	0.43%	0.00%	0.00%	0.00%	0.39%	0.19%
F – Construction	5.56%	5.50%	4.44%	3.85%	4.61%	1.59%
G – Wholesale and retail trade; repair of motor vehicles and motorcycles	12.39%	13.76%	11.11%	15.38%	14.28%	35.51%
H – Transportation and storage	0.85%	0.92%	0.00%	0.00%	2.79%	1.46%
I – Accommodation and food service activities	0.43%	0.00%	0.00%	0.00%	2.29%	0.30%
J – Information and communication	6.84%	8.26%	6.67%	3.85%	3.16%	0.77%
K – Financial and insurance activities	3.42%	2.75%	2.22%	0.00%	2.69%	1.10%
L – Real estate activities	0.85%	1.83%	4.44%	7.69%	0.57%	0.34%
M – Professional, scientific and technical activities	9.83%	3.67%	8.89%	0.00%	5.60%	0.81%
N – Administrative and support service activities	3.42%	4.59%	8.89%	7.69%	4.63%	19.20%
O – Public administration and defence; compulsory social security	11.54%	12.84%	13.33%	11.54%	6.96%	1.42%
P – Education	3.85%	3.67%	0.00%	0.00%	2.30%	0.13%
Q – Human health and social work activities	5.56%	1.83%	6.67%	3.85%	9.57%	1.86%
R – Arts, entertainment and recreation	0.00%	0.00%	0.00%	0.00%	0.64%	0.20%
S – Other service activities	1.71%	0.00%	2.22%	0.00%	2.40%	14.19%

[1] Number of employees based on Statistisches Landesamt Baden-Württemberg (2016a), Statistisches Landesamt Baden-Württemberg (2016c) and Tanzmann (2016).
[2] KBA (2015).

Table B.2
Economic sector distributions.

	Interested organizations	Participating organizations	Organizations providing driving profiles	Both – Participating organizations providing driving profiles	Employees in Baden-Württemberg in 2013 [1]
Sample size	234	109	45	26	4,476,072
n/a	79	31	14	6	0
Subsample without missing values	155	78	31	20	4,476,072
More than 250 employees	20.65%	20.51%	16.13%	20.00%	47.54%
Less than 250 employees	79.35%	79.49%	83.87%	80.00%	52.46%

[1] Statistisches Landesamt Baden-Württemberg (2016b).

Table B.3
Statistics on the vehicle driving profile data.

Attribute	Items	N
Vehicle size	Small	65
	Medium	107
	Large	26
	LCV	25
Vehicle usage	Fleet vehicle	131
	Company car	88
	Not reported	4
Number of users	One	67
	Several	156
Parking spot	Own parking spot on company's estate	120
	Differing parking spots on company's estate	81
	No parking spot on company's estate	22

Appendix C. Data used

See Table C.1.

Table C.1
Overview on the datasets used.

(Sub) Sample	Interested organizations	Organizations participating in the field trial			Cost parameters	Sample size
Dataset	Driving profiles (n = 45)	Survey data (n = 109)	Copies of EVSE invoices (n = 109)	Invoices concerning compensation of expenses (n = 109)		
$\Delta\overline{TCO}_i^{PEV}$	x				x	n = 45
$wtpm_i^{PEV}$		x				n = 96
TCO_i^{EVSE}			x			n = 109
$wtpm_i^{EVSE}$		x				n = 94
c_i^{CON}					x	n = 108
$wtpm_i^{CON}$		x				n = 87
c_i^{SB}		x			x	$n^{SB1} = 67$; $n^{SB2} = 61$; $n^{SBopt_i} = 56$
$wtpm_i^{SB}$		x				$n^{SB1} = 63$; $n^{SB2} = 56$; $n^{SBopt_i} = 56$
$\overline{COE_i}$				x		n = 108
u_i^{PEV}	x	x				n = 24
$u_i^{EVSE} + u_i^{CON} + u_i^{SB}$		x	x		x	$n^{SB1} = 59$; $n^{SB2} = 55$; $n^{SBopt_i} = 55$
u_i^{PSS}	x	x	x	x	x	$n^{SB1} = 13$

Appendix D. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.tra.2018.04.028.

Appendix E. Summary statistics

See Tables E.1–E.3.

Table E.1
EV specific summary statistics.

Summary statistics		N	[in €/a]							
			Mean	Std. Devi-ation	Std. Error	Mini-mum	Maxi-mum	Quantiles		
								25	50	75
TCO difference for an EV compared to an ICEV	$\Delta\overline{TCO}_i^{EV}$	46	944	216	32	668	1654	771	914	1041
WTPM for an EV compared to an ICEV	$wtpm_i^{BEV}$	96	4837	6282	641	−10,000	35,000	2000	5000	7000
	$wtpm_i^{PHEV}$	93	4321	5302	549	−22,500	25,000	2000	5000	5500
	$wtpm_i^{EV}$	96	1460	1878	192	−2955	10,341	591	1477	2068
Net benefits of EV	u_i^{PEV}	24	716	2353	480	−2540	9509	−232	477	716

Table E.2
EVSE and service bundle specific summary statistics.

Summary statistics			N	[in €/a]							
				Mean	Std. Devi-ation	Std. Er-ror	Mini-mum	Maxi-mum	Quantiles		
									25	50	75
Costs for EVSE and e-mobility services	I_i^{EVSE}		108	4585	3430	330	0	16,075	2164	3655	5731
	TCO_i^{EVSE}		109	1342	1017	97	0	4749	637	1066	1678
	c_i^{SCON}		108	46	25	2	2	73	24	37	73
	c_i^{SB}	$SB1$	67	884	923	113	4	6223	381	580	1123
		$SB2$	61	1172	1251	160	134	6523	462	708	1247
		$SBopt_i$	56	323	961	128	−1411	6449	0	29	346
WTPM for EVSE and e-mobility services	$wtpm_i^{EVSE}$		94	789	2067	213	−1200	16,800	0	296	600
	$wtpm_i^{CON}$		87	205	259	28	2	1518	57	126	235
	$wtpm_i^{SB}$	$SB1$	63	725	1545	195	−42	10,860	60	222	683
		$SB2$	56	913	1759	235	−137	11,235	108	326	1029
		$SBopt_i$	56	763	1678	224	−24	11,235	44	138	660
Net benefits of EVSE and e-mobility services per PEV	u_i^{EVSE}		94	−589	2145	221	−4438	15,951	−1357	−680	−227
	u_i^{CON}		87	158	250	27	−61	1444	7	77	204
	u_i^{SB}	$SB1$	63	−166	995	125	−2936	4637	−560	−192	103
		$SB2$	56	−256	1074	144	−2939	4712	−619	−299	−1
		$SBopt_i$	56	441	898	120	0	4786	28	91	431
	$u_i^{EVSE} + u_i^{CON} + u_i^{SB}$	$SB1$	59	−584	2580	336	−4894	14,842	−1731	−1028	−214
		$SB2$	55	−661	2674	361	−5064	14,842	−1794	−1088	−369
		$SBopt_i$	55	43	2732	368	−4443	15,939	−1011	−367	58

Table E.3
Average compensation of expenses per EV.

Summary statistics		N	[in €/a]							
			Mean	Std. Deviation	Std. Error	Mini-mum	Maxi-mum	Quantiles		
								25	50	75
Average compensation of expenses per EV	$\overline{COE_i}$	108	2050	510	49	834	3285	1773	2068	2364

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Glossary

BEV: Battery electric vehicle
EVSE: Electric vehicle supply equipment (i.e. charging infrastructure)
ICEV: Internal combustion engine vehicle
EV: Plug-in electric vehicle, i.e. full battery electric vehicle, range extended electric vehicle or plug-in hybrid electric vehicle
PHEV: Plug-in hybrid electric vehicle
PSS: Product service system
REEV: Range extended electric vehicle
TCO: Total cost of ownership
WTPM: Willingness to pay more compared to a combustion engine vehicle alternative