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The economics of fast charging infrastructure for electric vehicles

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ABSTRACT

By 2011 little is known about the economic rationale of public fast chargers for electric vehicles (EV). This paper aims at providing an insight into the business case of this technology in a case study for Germany. The estimated Return on Investment (ROI) of a public fast charging station constitutes the main contribution. Potential users and organization structures are investigated as well as different tariff types. According to the estimations, the current market outlook seems too uncertain for triggering a large-scale roll-out of fast charging infrastructure. Approximations suggest that investment is hardly profitable at low EV adoption rates, unless investment cost can be severely lowered. Besides competition with alternative charging solutions, the general EV adoption rate is detected as being a main risk factor for investment in public charging infrastructure.

1. Introduction & literature

It is uncertain which charging technology for battery-powered electric vehicles (EV) will become the de facto market standard. Besides home charging, the most prominent and most debated solutions are public charging stations and battery-exchange stations. Whilst the necessity of home-charging solutions is not doubted, little is known about the economic rationale of public fast chargers from an investor's perspective. The present paper aims at providing an insight into the economics of this technology in a case study for Germany.

Fast charging technology for battery EV is hitherto little explored research-wise but is widely debated by the public. It has the benefit of facilitating long-range drives for electric vehicles, and thus could serve as a means to mitigate range anxiety, with EV users having the opportunity to access public charging infrastructure at times and places where they are running low on charge. This factor may be crucial helping push market penetration of EVs toward the goal of 1 million EV in 2020, as set by the German government. Fast charging attracts EV users for it replicates the ease of conventional refueling and it attracts potential operators for it promises interesting business options. Possible disadvantages of this technology are fiercely discussed. These include notably the impact on battery lifetime, electricity grid (Chademo, 2011; Gunderson, 2010) and renewable energy integration. Regarding the latter point, Kempton and Tomic (2005) and Brooks (2002) acknowledge that high power levels facilitate the provision of grid regulation services to support renewable energy integration. With the upcoming nuclear energy phase-out in Germany and further renewable energy expansion, such questions become increasingly urgent.

In-depth research output on EV charging infrastructure can be found on the topics of policy support mechanisms and standardization. Ahman (2006) reviews public efforts to support electric vehicle deployment in Japan, including charging infrastructure, and he finds that both technology progress and policy support are crucial determinants for success. Likewise, Skerlos and Winebrake (2010) describe public policies in the United States that address EV penetration, including charging infrastructure, suggesting that a differentiated subsidy scheme for EV increases EV penetration and social welfare. Brown et al. (2010) delve into EV standards used in the United States pointing to the fact that infrastructure constitutes an important part of standardization. By contrast, there is relatively little research addressing the economics of EV charging infrastructure in detail, particularly when it comes to fast chargers. Important components of any business case evaluation comprise data on cost and demand which can hardly be found in the peer-reviewed literature but are exposed in project reports (NPE, 2011; PlanNYC, 2010; Element Energy, 2009; Wiederer and Philip, 2010; Morrow et al., 2008; Wietschel et al., 2009). Possible charging profiles of public EV stations are developed in Kang and Recker (2009) who conduct an activity-based assessment of EV energy impact and thereby use one-year travel data to derive a typical charging profile of a public charging station. Indications to charging profiles can also be found in a work of Hartmann et al. (2009) on private household travel behavior in Germany and in Markel et al. (2010), who analyze fuel displacement potentials of EV under various use rates of public (fast) charging stations. While none of the mentioned studies investigate business cases specifically for fast charging

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infrastructure in detail, the 2011 report of the German expert group NPE (2011) holds that there is no self-supporting business case for any type of charging infrastructure but expects "new charging technologies" to become a profitable option by 2017.

The work presented here scrutinizes this claim (NPE, 2011) with a special focus on fast chargers for EV. It aims at shedding more light on the economics of public fast charging by carrying-out an economic evaluation for the case of Germany. An estimation of contribution margins and investment cost provides insight into investment decisions while sensitivities with regard to demand, cost markup and different market models are tested. The analysis shall contribute to the general discussion about policy support for public charging infrastructure.

The article is divided into five sections. The introduction is followed by the methodology description, a presentation of alternative models of market organization, and a description of input parameters. Subsequently, results are presented, including their sensitivities. The article closes with a conclusion.

2. Methodology

The business case of charging station operation and investment is influenced by a multitude of factors. Fig. 1 illustrates the composition of cost and revenues arising from the operation of an EV charging station. The key drivers of revenue are the tariff (potentially with markup), the capacity and the utilization rates, which in turn are estimated based on assumptions on EV charging and driving behavior. Cost components include initial capital expenditure (CAPEX) and operational expenditures (OPEX), which, in turn, comprise of electricity cost, maintenance and other operational cost (O&M).

The economic evaluation of charging station operation performed here confines to a 62.5 kW charging socket, conform to the internationally certified DC fast charging standard CHAdeMO. Revenue generated through electricity sales is determined and then cleared with operational cost. Annual net profit of the charging station operation is then compared to its levelized investment cost so as to obtain a Return on Investment (ROI) figure as indicator of profitability. Minimum markups are determined which achieve positive ROI. ROI can be expressed as a percentage value as in Eq. 1.

$$ROI = \left(\frac{Annual\ net\ profit}{Levelized\ investment\ cost} - 1 \right) \times 100 \quad (1)$$

This ROI formulation represents a short-term horizon assessment that indicates what contribution margin a charging station can achieve under various conditions. The ROI concept is a simple measure for it does not require assumptions on the uncertain long-term dynamics of cost and revenue.

Sensitivities are tested for different organizational models. In one case, the situation of an independent station operation is scrutinized while electricity generation and station operation are combined in a second case. In order to estimate the profitability of fast charging investment from the viewpoint of an electric utility, the electricity market equilibrium model Esymmetry, developed by Traber and Kemfert (2011), is used to approximate additional profit margins arising through EV load. A detailed model description can be found in Traber and Kemfert (2011). Similiar models have been applied to address the impact of EV and storage on electricity market prices in Schill and Kemfert (2011); Schill (2011). The contribution here consists in updating and re-calibrating the input database as well as including charging of electric vehicles.

3. Market organization

Since an appropriate organizational structure seems important for an economic charging station operation, the business case calculations in this work are differentiated by the type of organizational model. Types of market models can be classified according to the role that individual agents play inside the value chain and their level of integration. Two models are relevant for the analysis here (Fig. 2): In the seperated model, electricity generation and retail are performed by seperate agents. The integrated model pertains to the situation where both, generation and retail, are made by one agent or two perfectly cooperating entities. Basic microeconomic theory suggests that overall profits are not different across market models if the involved markets are perfectly competitive. However, if market power exertion comes into play, organizational models and integration along the value chain can matter.

The German electricity market is characterized by a high concentration of generation capacity (80% owned by the major four players) giving rise to market power (Traber and Kemfert, 2011; Weigt and Hirschhausen, 2008). Regarding the second relevant market – electricity retail at EV charging stations – it is not certain whether this is prone to market failure (for instance oligopolistic structures). When considering charging stations as classical refueling stations – and this seems plausible for public fast charging technology – there is reason to believe that the market is perfectly competitive but with minor local monopolies. If a minumum level of standardization is ensured and all stations must provide universal access (NPE, 2011), there is little room for market power exertion. It is assumed here that there are no

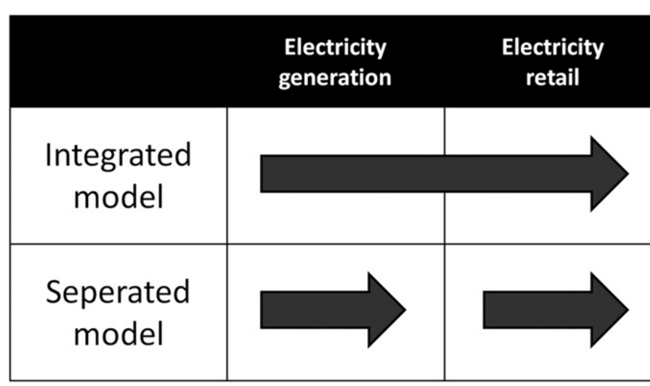

Fig. 2. Market models for charging stations.
Source: Own production.

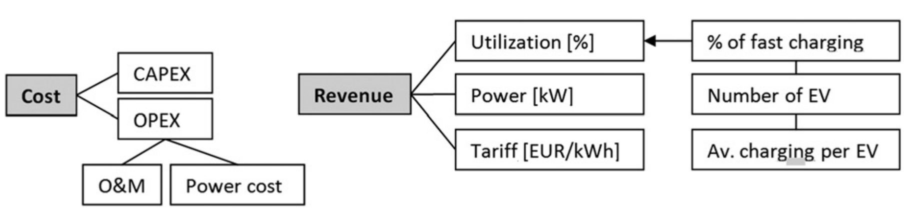

Fig. 1. Parameters affecting cost and revenue stream.
Source: Own illustration.

significant returns to scale when building up a charging station network since every individual station requires roughly the same cost of installation, irrespective of the scale. For the reasons given above, the charging station market is considered here as competitive market while electricity markets are oligopolistic.

4. Input parameters

4.1. Investment cost

Investment cost is compiled for different charging station types in Table 1. While in the United States, the industry distinguishes three charging levels, the International Electrotechnical Commission (IEC) 61851 promotes different charging levels in Europe analogous to the American standard SAE J1772. For the sake of reading ease, the text from here on refers to American standards, although the case study is conducted for Germany. The relevant range for such case study extends from level II chargers (medium-speed) which are commonly used for home-charging to level III chargers (high-speed). Due to cost and thermal limits it is most efficient to deliver high-voltage electricity in direct current (DC) directly to the vehicle's battery pack. Such high voltage and high-current charging is called a DC Fast Charge (level III) in contrast to less powerful 3-phase AC charging. AC connectors supply the EV through a board charger, while DC connectors bypass board chargers to directly supply the EV battery pack.

CHAdeMO is the first international standard for public Level III DC charging solutions. It originates in the Japanese market, is penetrating the United States and may be applied in Europe. A large-scale fast charging station network was not implemented in Germany until 2011 and it is uncertain whether DC or alternatively 3-phase AC power will become the de facto standard for possible applications. By 2011, most EV producers recommend level II charging as the primary charging method for EV.

Cost figures compiled in Table 1 include carefully selected numbers but numbers given here are merely educated guesses. The aim is to provide the model with thorough parameters without any claim for exactness.

Total cost of installation varies greatly depending on the necessity for upstream grid reinforcement. While level II chargers usually require little grid upgrade the high power involved in level III charging is beyond the capacity of most utility transformers serving residential areas. Therefore, grid and transformer upgrades may be required unless installation is done at higher voltage grid levels. Additionally, maintenance of on-street charging equipment may also be significant. As a rule of thumb, annual maintenance and repair figures at 10% of investment cost. The life-length of a charging spot is estimated at 10–15 years for level III chargers (Wiederer and Philip, 2010). The cost of installed recharging posts in Table 1 does not count the expenses required to plan the deployment and to acquire planning permission. Nor is rental cost for parking spaces included. This decision is mainly driven by the largely varying cost per space to be seen across regions and cities. Furthermore, parking space is less of a concern for fast charging stations as opposed to level II on-street chargers.

When it comes to comparing the cost of fast charging infrastructure versus home charging solutions, there is a clear advantage for the latter. Boxes for garages cost about 500 EUR, are easily installed, are little vulnerable to vandalism and no grid reinforcement is needed. Furthermore, home charging promises to be a good option for controlled charging operation with renewable energy integration as a primary target. Similarly, the cost difference between public level II versus public level III chargers seems huge at first glance. When investment costs are viewed in comparison to charging capacity, both technologies compete on a comparable cost level with approximately 1370–1800 EUR/kW. Note, that a single fast charging station can serve up to 75 users per day or 1500 kWh at (fictive) full-time operation, while a level II charger is designed for a maximum of four users per day and 86 kWh. Hence, almost 20 slow chargers would be needed to equal one fast charging station. Fig. 3 illustrates how an increase in cost of charging infrastructure is compensated by a shortening of charging times.

Table 1
Compilation of information on EV charging station cost.
Source: Comparison of diverse sources, i.e. Wietschel et al., 2009; Wiedener and Philip, 2010; Element Energy, 2009; Morrow et al., 2008; Chademo, 2011; NPE, 2011.

	'Super-fast' DC public	Level III DC public	Level III AC public	Level IIAC public 3ϕ	Level II AC public	Level II AC home
Station lifetime (years)	10	**10–15**	10–15	10–15	10–15	10–15
Load limit (Volt)	2000	**500**	400 (3 phase)	230 (1 phase)	230 (1 phase)	230 (1 phase)
Load limit (Ampere)	125	**125**	96 (3 · 32)	32	16	16
Current	DC	**DC**	AC	AC	AC	AC
Power limit (kW)	250	**62.5**	50	7.3	3.6	3.6
Duration of 20 kWh charge cycle ($_{\text{min}}$)	5	**19**	24	164 (2.74 h)	333 (5.6 h)	333 (5.6 h)
Max. number of 20 kWh charging EV/day	288	**75**	60	8	4	1
Calculation of 3-phase power: $P = U \cdot I \cdot \sqrt{3} \cdot \cos(\varphi)$ with $\cos(\varphi) = 0.7515$ as a standard value used here.						
Material cost (EUR)	60,000	**40,000 (40,000–75,000)**	40,000 (40,000–75,000)	4000 (4000–7500)	2000	500
Grid reinforcement cost/civils (EUR)	20,000	**15,000**	10,000	2000	1000	0
Transformer cost if applicable (EUR)	35,000	**0–35,000**	0	0	0	0
Total CAPEX (EUR)	115,000	**55,000**	50,000	6000	3000	500
Maintenance and repair (EUR/ year) Rule-of-thumb: Up to 10% of material cost	1000	**4000**	4000	400	200	50
Total OPEX (EUR)	10,000	**40,000**	40,000	4000	2000	500
Total investment cost (EUR)	125,000	**95,000**	90,000	10,000	5000	1000
Cost per power unit (EUR/kW)	500	**1520**	1800	1370	1388	278
Approximate number needed for implementation in 1 million EV scenario	4000	**4,000–15,000** [a]	Ca. 15,000	Ca. 125,000	Ca. 250,000	1 million
Total cost 1 million EV scenario, if all EV use this charging technology	0.5 billion EUR	**0.4–1.4 billion EUR**	1.35 billion EUR	1.25 billion EUR	1.25 billion EUR	1 billion EUR

[a] 25–100% of gas stations, each with 1 fast charging post.

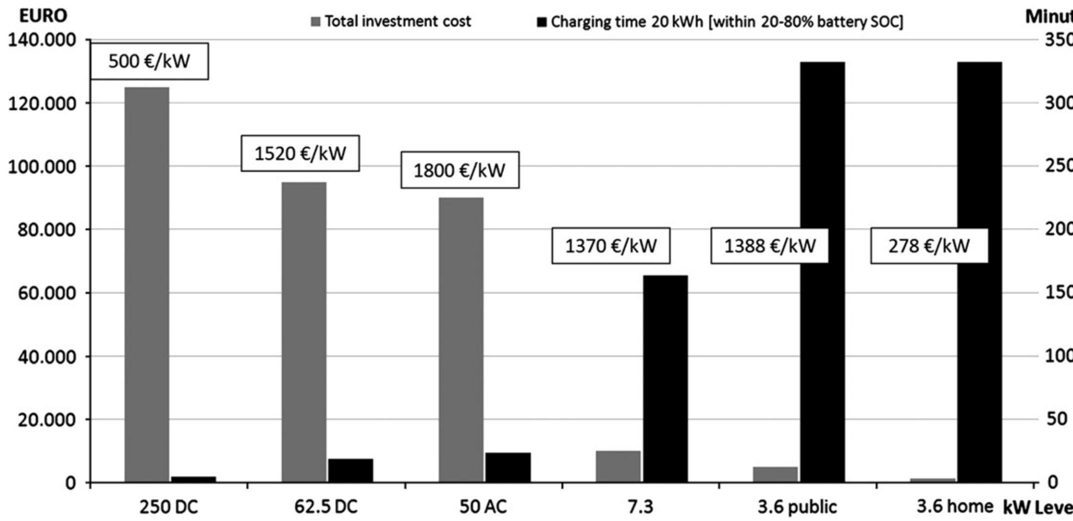

Fig. 3. Cost and average charging times for a 20 kWh charge at different types of stations.
Source: Own illustration based on Table 1.

For the calculation of contribution margins, one must distinguish total and levelized investment cost. While total cost refers to total CAPEX and OPEX, yearly levelized investment cost distributes total cost over all years and is calculated in Eqs. 2 and 3, with i being the interest rate and n the lifetime of the project.

$$\frac{cost}{year} = cost \cdot annuity\ factor \tag{2}$$

$$annuity\ factor = \frac{(1+i)^n \cdot i}{(1+i)^n - 1} \tag{3}$$

With interest fixed at 6% and a project lifetime of 10 years, an annuity factor of 0.1359 is obtained. This implies a yearly cost of 13.59% of total cost. A fast charging post with total cost of 95,000 EUR would thus require a levelized cost of 12,907 EUR per year.

4.2. EV market penetration

From oil prices to capital markets and electricity cost – A multitude of strategic factors influence the profitability of charging station investment and they are considered here in a single indicator – the EV market penetration. In the scenarios run here, it is assumed that 50,000 pure EV (and 50,000 hybrid EV) hit the road and 245 fast charging stations are installed nationwide, which sums to roughly 15 MW power capacity. Both assumptions stem from a forecast of NPE (2011) for 2014. Thus, 13.2 to 22.8 million EUR are used to build up the network of charging stations. In a second scenario, 1 million EV are on the roads, and 15,000 fast chargers are built, costing from 0.8 to 1.4 billion EUR (Table 1) and making up 0.9 GW power capacity. Note that hybrid EV, scooters and other non-car electric vehicles are excluded as these segments are believed to be marginally relevant for the economics of public fast charging solutions.

4.3. General demand for fast charging

National statistics from household travel surveys in Germany (Wietschel et al., 2009) and the United Kingdom (Element Energy, 2009) indicate that ca. 70% of car owners own off-street parking facilities in suburban areas. This percentage drops to below 30% in metropolitan centers, hence areas where EV are set to spread at the outset. Taking into account hybrid EV and expressed in terms of trips, Kang and Recker (2009) estimate that 70–80% of all hybrid EV trips with 97 km range can be powered by home charging. Consequently, a widespread and comprehensive spread of EV requires public charging options. Estimations in Christensen (2010) imply that roughly 20% of all EV car owners would require fast charging solutions if all cars were EV. Weiller (2011) estimates this percentage at 24–29%. In this analysis here, a 20% rate is used as reference. Naturally, this rate is highly unpredictable and many factors, such as consumer acceptance and infrastructure availability, affect the demand for fast charging. Anegawa (2010) indicates a mutual effect between the need for fast chargers, drivers' behavior and the availability of fast chargers. His study points to a high acceptance of fast charging technology and it reports that the availability of fast chargers remarkably increased EV drivers' mileage in the Tokyo metropolitan area.

4.4. Use pattern

The shape and amplitude of the demand profile is a critical consideration in estimating the profitability of an EV charging station business. Refueling patterns can vary considerably across geographical sites and across the type of customers served. To assist in formulating a demand profile, data were gathered and analyzed from key information sources, including Kang and Recker (2009), Barnes (2008) and Hartmann et al. (2009).

Barnes (2008) shows that normalized profiles are relatively stable irrespective of the fuel station location and type (hydrogen, natural gas, gasoline). The main difference between different types of stations is not the profile but the amount of fuel demand that can be observed with demand at residential stations being roughly double the size of demand at interstate stations, according to data presented in Barnes (2008). Bearing this in mind, the analysis here proceeds with a stylized charging pattern that could possibly be observed at EV fast charging stations independent of their exact geographical location.

Hourly demand data from three different high-volume Conoco Phillips gasoline fuel stations stipulated in Barnes (2008) is used to develop EV load profiles over a period of one average week. Such derivation can be made under the assumption that demand for fast charging has similar characteristics to conventional gasoline demand in terms of its temporal profile. As the defined aim of fast charging solutions is to make electricity charging replicate the convenience of conventional fuel dispensing, the assumption should be reasonable. Fig. 4 sketches a synthetic demand profile. The profile follows an obvious pattern of peak demand during

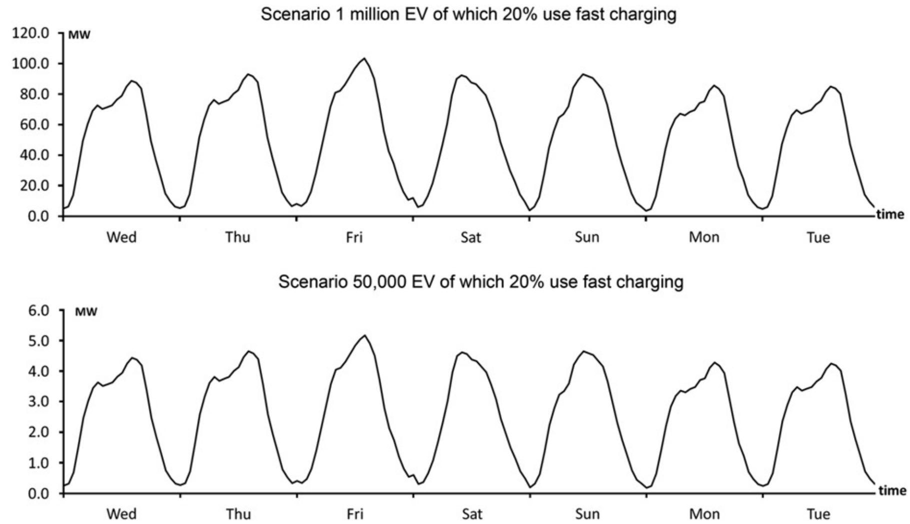

Fig. 4. Synthetic demand profiles in two scenarios.
Source: Based on Barnes, 2008.

day-time and low demand during the night. Mean values feature a consistent pattern for mid-week fueling, with a slight peak early in the morning followed by the highest level of demand around 5 pm. Peak demand occurs on Fridays. The profiles here are relatively similar in shape to a temporal profile of the cumulated share of passenger vehicles en route in Hartmann et al. (2009) with slight deviations on the week-end. A strong correlation between the number of cars on the street and those frequenting gas stations has already been testified in Kitamura and Sperling (1987).

It is assumed that average daily demand per EV lies at 6.15 kWh. At standard efficiency of 15 kWh/100km this is equivalent to a 41 km ride, hence the average daily driving distance for cars in Germany (MiD, 2008). This assumption is somewhat debatable since fast charging may be rather attractive not to average users but long-distance drivers. Yet, in absence of real-world data, we hold to this assumption and take comfort in the fact that results happen to be little sensitive to the choice of this parameter.

As explicated before, it is assumed here that 20% of all recharging is done at public access fast charging stations, following Weiller (2011) and Christensen (2010). Hence, 22.4 GWh are consumed annually when 50,000 EV are on the streets and 448 GWh under the 1 million EV scenario. Note that these amounts pale in comparison to over 607 TWh consumed in the national market.

4.5. *Electricity prices and tariffs*

The charging station operator is assumed to have perfect foresight of electricity purchase prices from the energy exchange. This assumption is reasonable in a setting with hourly time resolution since the price spreads and hours with lowest and highest prices are, in general, fairly predictable while other factors, such as charging profiles, are a greater source of volatility than electricity prices in the course of a day, cf. Fig. 4. Previous work (Schill, 2011) has shown that the impact of EV on price profiles is unlikely to be of major magnitude under expected EV adoption rates until 2020.

Two different types of tariffs are investigated: (a) a flat rate; and (b) a time-of-use rate (TOU). The willingness of the customer to pay a markup for fast charging is untested so far. Accordingly, the analysis retrieves to a sensitivity test regarding the allowed markup rate as exogenous model input factor, where the markup is considered as margin over total electricity cost, including taxes and fees. Hence, the electricity cost includes not only spot market prices for Germany from the European Energy Exchange EEX (2010) but also other cost components such as fees and taxes representative for Germany. These comprise all components listed in Fig. 7. Average household prices were 23.69 ct/kWh in 2010 (BDEW, 2011). Note there is an ongoing public discussion on grid tariffs for EV charging stations and, if so, their appropriate rate (Fest et al., 2010; Hoff and Hammerstein, 2010). In Germany, consumers with consumption over 10 GWh yearly and over 7,000 full load hours are generally exempted from grid fee liability (§ 19, Stromnetzentgeltverordnung). It is assumed here that EV charging station operators are levied grid tariffs for they do not exceed the threshold of 10 GWh per year. In a special scenario, it is tested how an exemption from grid fees could help improve the business case.

4.6. *Electricity generation*

The electricity market equilibrium model Esymmetry (Traber and Kemfert, 2011) is used to derive the fictive impact of EV fleets on profit margins in the oligopolistic electricity sector. Margins differentiated by time slice are estimated by the market model and are subsequently used in the business case considerations to scrutinize the economics of fast charging station operation from the viewpoint of an electric utility. Data on yearly average prices, wind and solar output and reference demand in 2010 is gathered from EEX (2010); ENTSO-E (2010). They are used to construct a representative profile for a complete week as in Traber and Kemfert (2011), and shown in Fig. 5. Similar to the analyzed weeks in Traber and Kemfert (2011), strategic behavior improves the replication of plausible price profiles. Table 2 describes marginal production cost and installed generation capacity which is triangulated with Traber and Kemfert (2011), IEA (2010). The capacities are assigned to four dominant players and a fringe so as to be able to simulate the effect of market power exertion on prices in our imperfectly competitive Nash-Cournot framework.

The EV demand and the ordinary electricity demand are considered to be completely separate. EV demand is fixed and inelastic, while ordinary demand is elastic. Since we assume that EV demand from fast charging stations would not occur without the utilities' investments into fast charging networks, the opportunity cost of supplying electricity to EV is equal to marginal

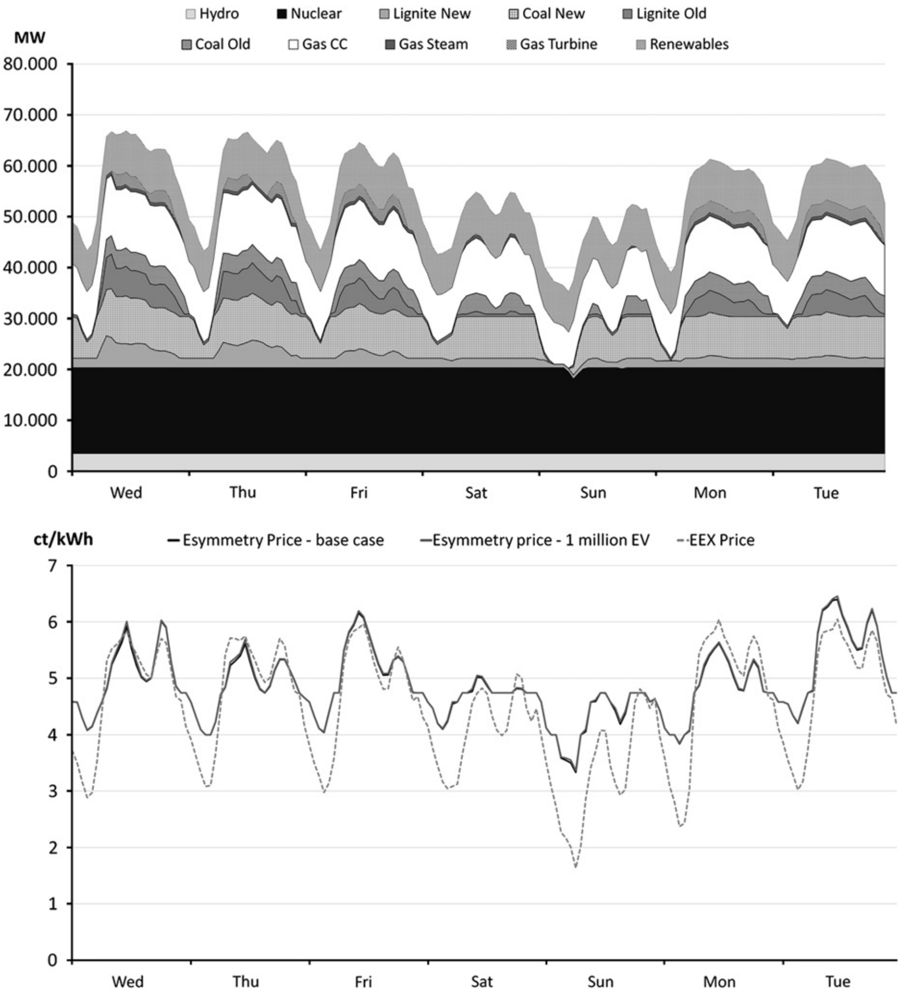

Fig. 5. Electricity generation and price profile. Both profiles are hardly altered with increasing EV demand in our scenarios.
Source: Own illustration.

Table 2
Installed capacities in Germany in MW in 2010 and marginal cost excluding CO_2 and start-up cost.
Source: Compilation based on Traber and Kemfert, 2011; IEA, 2010.

Players	Hydro	Nuclear	Lignite new	Coal new	Lignite old	Coal old	Combi cycle	Gas steam	Gas turbine	Oil steam	Oil turbine
E.on	1507	6696	0	3755	863	2914	1017	14	290	0	0
EnBW	427	3791	0	1652	872	3078	1222	0	0	0	0
RWE	638	4782	4850	3604	1232	3137	939	12	592	0	0
Vattenfall	0	265	1175	1640	7312	945	1360	0	605	0	0
Rest	893	545	660	8155	502	4359	10228	760	2734	250	64
Marg cost (ct/kWh)	0.04	0.92	1.08	2.29	1.21	2.54	3.89	5.57	6.35	14.7	16.75

generation cost and hence does not include the mark-up of strategic firms on the wholesale market.

5. Results

In this section, potential key drivers for the economics of charging station operation are tested upon their impact on investment profitability.

5.1. Use rate and markup

Fig. 6 indicates how the two key parameters markup and demand affect the profitability of a level III charging station when operated by an independent agent. It illustrates how ROI evolves with the markup over electricity prices and thus determines the minimum markup needed to recoup CAPEX and OPEX. For reference, information was included on what tariff rate would correspond to the variable cost level of a 4-liter consuming conventional/hybrid car (here 5–5.50 EUR/100km). It can be argued that this threshold corresponds to the maximum willingness-to-pay of an EV driver. If variable cost is higher than with conventional cars, consumer acceptance of fast charging is likely to vanish. For illustrative reasons, the number of EV calls per station and day is approximated and it is considered that each vehicle recharges 20 kWh per call.

A positive project benefit is fairly unlikely under realistic use rates if total investment cost amounts to 95,000, as depicted on

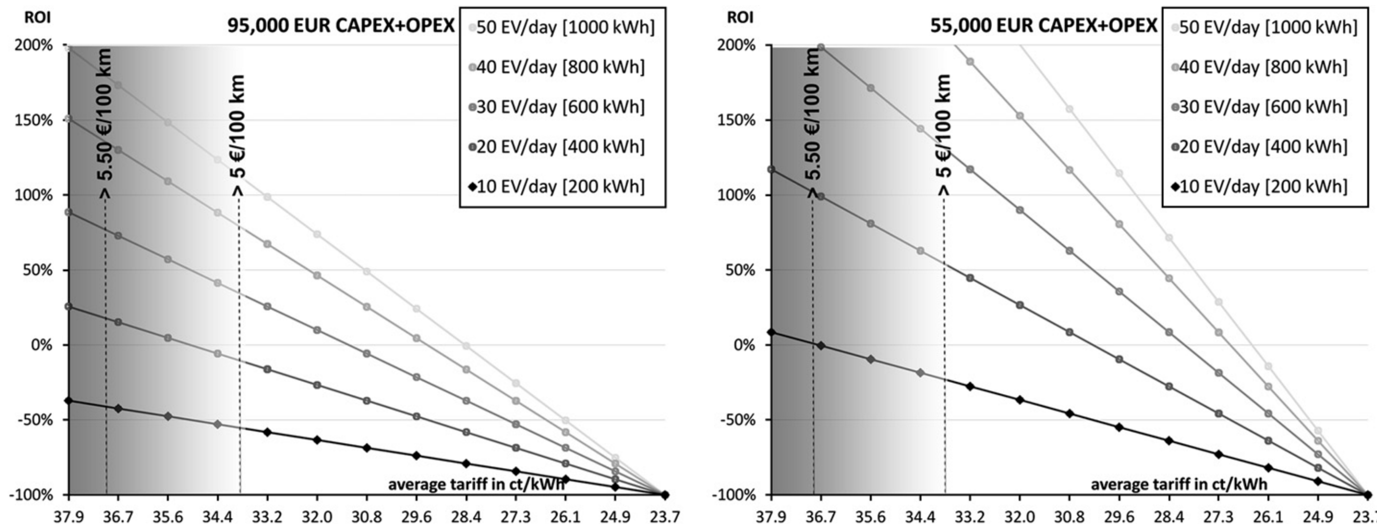

Fig. 6. Return on investment for an independent station operator.
Source: Own production.

the left side of Fig. 6. With a markup of 30% over EEX prices (30.8 versus 23.7 ct/kWh), demand at a single station would need to exceed 30 EV/day (600kWh) for the investment to prove beneficial. The calculus indicates that a station costing 95,000 EUR is far from economic for independent operators with ordinary open access stations in 2011. On the right side of Fig. 6, ROI is depicted at life-cycle investment cost of 55,000 EUR. In this optimistic case, a markup of 30% (average tariff 30.8 ct/kWh) yields positive project benefits at demand rates beyond 20 EV/day (27% use rate). Still, this demand rate reflects optimistic projections when considering that sockets in the 2010 RWE fleet trial are solely used at below 10% of their capacity (RWE, 2011). If the independent agent is a fleet operator with permanent refueling demand a 27% use rate may be realistic. A likely demand projection at public stations of 10 EV/day (13% use rate) requires at least 36.7 ct/kWh average tariff. Such tariff would translate into a variable cost of roughly 5.50 EUR per 100 km, hence a value comparable to variable cost of a state-of-the-art gasoline car.

Naturally, the degree of competition and the geographical location of a station matters for demand. However, such particulars are beyond the scope of this analysis, but the situation of a stylized typical station type is assessed. In general, a high local use rate for level III charging can only be attained if EV users do not exclusively rely on restricted access charging facilities at home or at work. Level III chargers may be a losing deal even under high EV adoption rates if too few EV users revert to fast charging facilities. The substitution effect between private solutions and public level III charging is likely to be one of the main risk factors determining investment choices. Level III charging is well located at spots where there is little overlap with private sphere charging facilities. These locations are likely to expose a high share of transit traffic as opposed to commuter traffic, as the latter could mostly rely on inexpensive home charging. Interstate, highway gasoline stations and other stopover locations such as convenience services could ideally fall into this category. As a matter of fact, the electric utility Eon began installing fast chargers along highways in Germany in mid 2011.

5.2. *Tariff type*

While the retail price markup and demand seem to be pivotal for valuing a charging station, the tariff used is also a factor to consider. ROI calculations above were made with an hourly TOU tariff since TOU rating is generally considered as the most efficient pricing scheme. TOU tariffs are found to improve the revenue stream in average by 3–5%. They yield better performance than setting an equivalent flat rate in all scenarios. Consequently, this difference in profits between TOU and flat rate pricing indicates that pricing with temporal price discrimination should be preferred over flat tariffs by a charging system operator. However, simpler tariff structures are likely to be better understood and hence more positively received by consumers than variable prices such as TOU. An intermediate option would be to offer tariffs with at least a two-part structure and a sufficient spread. Night rates at below 20 ct/kWh and daytime rates at around 24 ct/kWh, as used at several level II public charging stations in Germany in 2011, appear too low and not sufficiently differentiated. The same pertains to the 5 EUR fee per call (irrespective of load) charged at fast charging stations owned by Eon in Germany.

5.3. *Organizational structure (integrated versus separated)*

How would the financial results improve if an electric utility was to invest in and operate the charging station? The cooperation between electric utility RWE and the gas station operator AVIA as well as the fast charging investments of the electric utility Eon in 2011 point to the relevance of this question.

Schill (2011) finds that, in general, the introduction of EV increases generator profits and decreases consumer surplus in the power market because of additional (uncontrolled) electricity demand. Market power exertion significantly adds to this effect. Calculations with Esymmetry (Fig. 6) replicate this finding but at a modest scale. They show that additional profits in the electricity market are of very low magnitude, ranging in the order of 1000 EUR/year (50,000 EV scenario) to 80,000 EUR/year (1 million EV scenario) in presence of market power. In a perfectly competitive market, additional profits drop to 200 and 6000 EUR/year, respectively. As in Schill (2011), we thus find a strong effect of market power on profits in the electricity wholesale segment, while the direct effect of additional EV demand on profits is relatively modest. In all scenarios, additional profits would contribute less than 0.1% of nationwide total cost of charging infrastructure. It goes without saying that these amounts are not sufficient to significantly improve the business case. Additional profits are so low that Fig. 6 is hardly different for an electric utility. In the optimistic scenario with 55,000 EUR life-cycle cost, positive returns are achievable at 20 EV/day (27%) use rate and at reasonable markup. When considering conservative cost estimations, profitable station operation would require average tariffs above 32 ct/kWh, resulting in higher specific fuel cost than a concurrent hybrid electric vehicle. It can be concluded that while integrated solutions with electric utilities appear to be superior to any separated market model, returns can be only slightly increased by choosing an organizational model including electric utilities, as testified here. However, in cases where independent charging station operators have no access to electricity at wholesale price, there could be significant advantage when cooperating with electric utilities. This case is not investigated here, for it is highly case-specific and benefits are hard to quantify.

5.4. Fleet operation

Fleet operation is often proposed as business model that can attract a high level of demand for fast chargers. Fig. 7 illustrates the composition of electricity cost and it shows how much markup would be needed to recoup investment and operational cost so as to break even. Charging station fixed and variable cost per kWh add to the electricity wholesale cost and they naturally depend on the overall demand level. Scenario 1 depicts the situation of a fleet operation where permanent demand is ensured at all times. This is the optimal result of operation, but hardly realistic. In this scenario, only a 9% markup is needed to make charging station investment of 95,000 EUR profitable. Clearly, when charging stations are in permanent operation, only little markup is needed to cover cost. The operation of fleets to ensure continuous and high demand at fast charging stations can thus be an attractive business model. Such operation is unprecedented in Germany as large-scale application by mid 2011.

5.5. Grid tariff exemption

As discussed above it might be an option to give charging operators an exemption from grid tariffs or a reasonable reduction. These make out roughly 25% of electricity cost for commercial services according to BNetzA (2011). Scenario 2 shows that when charging station operators are exempted from grid fees, overall cost drops significantly by almost 30%. As Fig. 7 suggests, tariff rates of slightly above 25 ct/kWh would suffice to break even the total investment cost of 95,000 EUR. If cost amounts to only 55,000 EUR, tariffs of around 22 ct/kWh would be enough. The result shows that grid tariff exemption could be an attractive incentive to potential investors. However, it remains arguable, that grid tariffs be waved

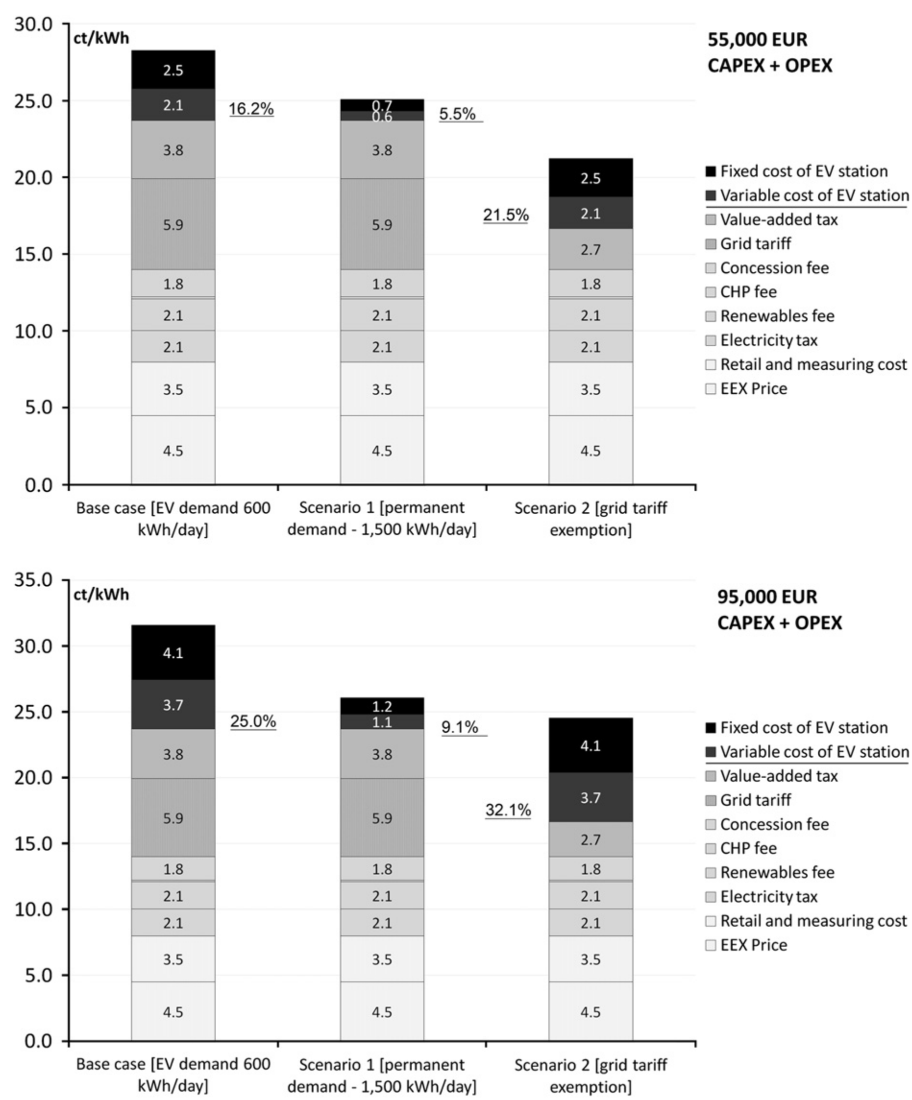

Fig. 7. Cost composition and the tariff needed to break even under varying investment cost.
Source: BDEW, 2011; BNetzA, 2011.

for fast charging installations not the least since these tend to put extra burden on (local) grid system stability.

5.6. Other benefits

The findings of this paper indicate that investment incentives in Germany are hitherto too low for a market-driven roll-out of public access fast chargers. Conversely, there is reason to believe that commitments taken at this premature stage are rather driven by non-financial prospects and by marketing purposes. Electric vehicle stations may be used as a perk to attract consumers while the main revenue is generated from the sale of other products, for instance parking space or commodities. It is pervasive practice for instance at gasoline stations to generate high revenues from non-fuel services. Such aspects are not investigated in this work but further research and business experience should be warranted in the future.

6. Conclusion

A simple but clear message is conveyed by means of a straightforward valuation method applied to EV fast charging infrastructure. Besides the mere cost and benefit estimations given in this paper, the following key insights emerge from the analysis.

A market-driven roll-out of Level III fast charging infrastructure is unlikely to be profitable in Germany at 2011 EV penetration rates. If private investment takes place at this premature stage, it appears to be driven by other than project prospects. Charging stations may be used as a perk to attract consumers with main revenue generated from non-electricity sales, such as commodity sales or to a certain extent parking fees. Integrated organizational structures with electric utilities promise slight improvements in ROI since additional profits on the electricity market side enter the investment calculus. These additional profits are very low, though. Fleet operation and grid tariff exemption can significantly improve returns.

While investment incentives for public fast chargers may turn positive under optimistic circumstances, investment remains fairly risky. The predictability of cost and benefits is low and decisions are thus based on vague estimates. Among the main risk factors are EV adoption rates, local use rates and competition between public and private charging facilities. Naturally, the promotion of other alternative drive train and fuel technology deteriorates investment incentives, as does further promotion of EV home charging boxes.

Tariffs with temporal price discrimination appear to be the most profitable option from an operator's perspective. However, EV users could possibly prefer simpler rates over erratic TOU tariffs.

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