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Attractiveness and Business Model Potential of the Spot Market Optimized Charging of Electric Vehicles

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Abstract

The spot market optimized charging of electric vehicles supports the integration of renewable electricity generation into the energy system while offering drivers the potential to save charging costs. At the same time, it reduces end consumers' flexibility and increases their price risk. The attractiveness of this use case for drivers is estimated which is the prerequisite to conclude on the business model potential for electricity suppliers and aggregators. The method consists of three steps: First, the required financial compensation is analyzed based on a literature review of acceptance studies. Second, potential charge cost savings are simulated with spot market prices from 2021 and 2022. Third, a final revenue margin is calculated, which ranges between -113.6 to 238.3 EUR per year, depending on the scenario year and tariff. The revenue margin indicates an attractiveness of the spot market optimized charging of EVs with a dynamic tariff and a lack of attractiveness for Time-of-Use tariffs. The business model potential for electricity suppliers and aggregators is therefore inconsistent. Further factors are to be considered when analyzing potential business models in more detail.

Keywords: spot market optimized charging; variable tariffs; acceptance; business model potential

1. Introduction

In the course of the German energy transition, a law that requires electricity providers to offer a variable tariff to household customers has been passed (Electricity and Gas Supply Act, § 41a (2) EnWG). The most common forms of variable tariffs are Time-of-Use (ToU) or dynamic tariffs, where end consumers pay time variable electricity prices according to previously set price levels or hourly spot market prices respectively (Biedenbach and Ziemsky, 2022). The goal of scaling a widespread use of variable tariffs is to incentivize the load-shifting behavior of end consumers

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to stabilize the future energy system. Usually, electricity spot market prices are lowest, when the electricity generation from renewable energy systems (RES) is high. Offering end consumers varying electricity prices at different times of the day or season reflects price fluctuations on the spot market and incentivizes the exploitation of RES electricity generation.

The charging processes of private electric vehicles (EVs) provide a large period for offering load flexibility due to long idle times (Follmer et al., 2010). Whether EV drivers take on a system serving charge behavior depends on incentives and their willingness to adapt (Grahn and Söder, 2011). To financially incentivize load-shifting behavior by reducing EV drivers' costs, EV charging is often combined with a variable tariff (Johnsen et al., 2023). Usually, EV drivers conclude an electricity supply contract with the electricity supplier while an aggregator plans the EV charging processes and provides the charging schedule to the electricity supplier who then trades the respective electricity quantities in the intraday market (Biedenbach, 2022).

Despite the great usefulness of variable tariffs from a systemic point of view, they come with drawbacks for end consumers, such as a restricted flexibility and an increased price risk (Dütschke et al., 2013). To overcome these drawbacks, variable tariffs have to be attractive to users. Several studies researched the influencing factors for the acceptance of using variable tariffs for EV charging, some of which are described in the following section.

1.1. Acceptance factors for smart charging

Various factors define whether smart charging is accepted by EV drivers and whether they are willing to shift their charge load according to schedules, like the integration of renewable energies (Baumgartner et al., 2022; Huber et al., 2019) or contributing to grid stability (Johnsen et al., 2023; Will and Schuller, 2016). Several acceptance studies identify the prospect of lower electricity costs as being one of the most significant motivators to induce load-shifting behavior (e.g., Dütschke and Paetz, 2013; Grahn and Söder, 2011).

On the contrary, some older studies find that the financial factor could be less significant (Paetz et al., 2012; Will and Schuller, 2016). However, these studies were conducted with early adopters of EVs, who are generally more benevolent.

In this paper, it is assumed that financial incentives play the major role in the acceptance of smart charging and that the compensation amount is crucial. German electricity providers promise a possible saving on charging costs of 24 % (Tibber, 2023) and 35 % (Rabot Charge, 2023) to end consumers from using a variable tariff for EV charging. We want to analyze, whether the stated savings potential is sufficient from an end consumer's point of view to accept the implicated flexibility restriction and price risk.

Similar to this paper's approach, Dütschke et al. (2013) compared savings expectations on electricity costs with the actual results of a field test with test participants living in a smart home. Their results reveal that in an optimal electricity usage case, the actual savings just equal the minimum expected savings, leading to a relatively small monetary incentive to induce load-shifting behavior in EV drivers (Dütschke and Paetz, 2013). Different studies tried to quantify the price reductions EV drivers expect to get in reward for their flexibility provision (Dütschke and Paetz, 2013; Ensslen et al., 2014; Hinterstocker et al., 2018; Huber et al., 2019; Scherrer et al., 2019). The results vary depending on the study design and target group.

1.2. Business model potential through the intraday trading of electric vehicle load flexibilities

User acceptance is a main factor for successful business models when it comes to the introduction of new technological developments, like electric mobility. Thus, for large-scale adoption of electricity tariffs and respective business models of electricity suppliers and aggregators, analyzing the attractiveness of variable tariffs and estimating their user acceptance is crucial.

Previous literature described and analyzed business models of aggregators (e.g., Okur et al., 2021). In general, an aggregator's business model consists of trading flexibility of its customers' assets in different electricity markets. In doing so, an aggregator can pursue several strategies when optimizing the charging processes of EVs, like either operating to minimize the aggregator's imbalance cost or operating to arbitrage when trading in the intraday market. When concluding business models of certain actors in the power system, it is important to notice, that the role of the aggregator can be taken over by several different actors. (Okur et al., 2021) In case the aggregator and the electricity supplier are two separate actors they must agree on their business relations and revenue shares as an add-on margin to the spot market price paid by the EV driver.

There is evidence that the mandatory provision of variable tariffs according to § 41a (2) EnWG and the subsequent aggregation of EV load flexibilities offers high market potential. In 2014, Ensslen et al. estimated the German market volume for aggregators based on the probability of households buying an EV to 25.9 to 36.3 EURmn in 2022 and 510.0 to 713.3 EURmn in 2030. Deducting the costs for purchasing electricity leaves aggregators with an estimated contribution margin of 13 to 20.8 EURmn in 2022 and 173 to 294.2 EURmn in 2030.

This paper contributes to the estimation of the business model potential for aggregators and electricity suppliers with a different approach. The revenue margin per EV driver is assessed by comparing user acceptance and simulated savings potentials of the spot market optimized charging.

1.3. Scope of the paper and research questions

This paper is part of the research project Trade-EVs II (Trade of Renewable, Aggregated, and Distributed Energy by Electric Vehicles) which investigates the aggregation and subsequent marketing of the flexibility of EV fleets to reduce their operating costs. Together with the project partners, we investigate the unidirectional spot market optimized charging of EVs (Biedenbach, 2022). Looking at the practical implementation of this use case, two central questions arise:

- Is the annual savings potential of the spot market optimized charging of an EV sufficient for drivers to accept the resulting higher price risk and reduction in flexibility (comfort-loss)?
- How big is the potential revenue margin for electricity providers and aggregators to offer variable tariffs and respective charge load schedules for EV drivers?

The goal of this paper is to quantify EV drivers' acceptance for variable tariffs and to compare it to the simulated cost savings through the spot market optimized charging of EVs. Subsequently, we give an estimation of the business model potential for relevant market actors; aggregators of EV load flexibility, and electricity suppliers as providers of variable tariffs.

The paper's methodological approach is presented in the second chapter, followed by the results section, describing the findings from the literature review of acceptance studies, the quantification of the required compensation, and the simulation results. Next, possible implications for the widespread acceptance of variable tariffs and future business model potential as well as research gaps are discussed, followed by a summary and conclusion.

2. Methodology

We investigated the research questions by comparing simulated charge cost savings from the spot market optimized charging of EVs with the willingness of EV drivers to use variable tariffs and shift their load consumption accordingly. The difference between the required compensation and the simulated charge cost savings potential is defined as revenue margin. The revenue margin allows us to conclude on both the attractiveness of smart charging for EV drivers and the business model potential of participating market actors. The respective shares of the aggregator, electricity provider, and end consumer on the revenue margin depend on the tariff and contract design.

2.1. Required compensation for acceptance

First, a literature review of acceptance studies was conducted to define the required end consumer's annual compensation as a reduction in charging costs to accept the spot market optimized charging of their EV. As the project scope of Trade-EVs II is restricted to Germany, only German data was included. Conclusions on other European countries can be derived in consideration of their respective regulatory framework, electricity price structure, and EV drivers' attitude toward smart charging.

The included acceptance studies assume the financial incentive as being one of the main motivators for using a variable tariff. Their study designs vary, leading to different displays of the actual quantification of the required compensations, mostly as a share of their current electricity bill. Two statistical data inputs were used for converting all compensation amounts into a consistent format of EUR per year and EV: the average annual EV electricity consumption and the mean electricity price. Mean German household electricity prices from 2021 of 32.16 EURct per kWh (BDEW, 2023) were preferred over electricity prices from 2022 as these were influenced by major energy political events. Mean annual EV electricity consumption was calculated using 500 driving profiles from Schmidt-Achert et al. (2021), based on representative data for mobility behavior from the studies Mobility in Germany 2017 and the German Mobility Panel. Finally, we calculated the mean required annual compensation across all studies.

2.2. Simulation of annual charge cost savings potential

The second step comprised the simulation of the annual cost savings of EV drivers who charge according to spot market prices. The charge cost simulations were conducted with the optimization model eFlame (electric Flexibility assessment modeling environment) as described in Biedenbach and Ziemsky (2022). The model optimizes the charging behavior of EVs considering the driving behavior of randomly generated agents using a variable tariff. The simulation scenarios comprised a dynamic electricity tariff using German intraday auction spot market prices for 2021 and 2022. In addition, we calculated the charging costs for the same agent's driving and charging profiles using a ToU instead of a dynamic tariff. In doing so, we could compare the two different tariff designs. The savings were calculated by subtracting the costs for optimized charging with the respective variable tariff from the costs for uncontrolled charging. The uncontrolled charge costs were simulated with a static electricity tariff based on the average spot price.

2.3. Estimating the revenue potential

Third, a margin that determines the revenue (R) was derived by subtracting the required compensation for smart charging with a variable tariff (C) from the charge cost savings (S) described by Equation (1).

$$R = S - C \tag{1}$$

The revenue margin is the amount of charge costs that exceeds or undercuts the required compensation for EV drivers. The final revenue margin indicates, on the one hand, the attractiveness of the spot market optimized charging of an EV (positive or negative revenue margin) and, on the other hand, the volume of the business model potential for electricity suppliers and aggregators.

3. Results

3.1. Financial compensation requirements for the acceptance of variable tariffs

As described in 2.1, we analyzed literature about the acceptance of variable tariffs with the primary focus of quantifying the required annual compensation for the accompanying flexibility restriction and higher price risk. Table 1 provides an overview of the studies. Note that some of these studies directly surveyed EV drivers while others questioned private end consumers in general.

Average electricity consumption of an EV charging unidirectionally and price-optimized amounts to 2,750 kWh per year for frequent drivers driving 16,000 km per year (Schmidt-Achert et al., 2021). With a mean household electricity price of 32.16 EURct per kWh in Germany in 2021 (BDEW, 2023) annual charging costs per EV amount to 884.4 EUR. We used these yearly EV charging costs to calculate the necessary charge cost reduction based on the desired percentage amount stated by the respondents (indicated in the last column of Table 1).

The mean required charge cost reduction above all acceptance studies on variable tariffs amounts to 183.3 EUR per year to compensate end consumers for the restricted flexibility and higher effort. Initial investments in the required technical equipment (e.g., charging station, energy management system, smart meter) were not considered, as we assumed that these costs arise independently of using a variable tariff.

Table 1. Overview of acceptance studies and required annual cost savings to use a variable tariff.

Authors	Method	Target group	Sample size	Type of tariff	Required charge cost reduction	
					Study	Converted [€ / a]
Dütschke and Paetz (2013)	Field experiment with test residents living in a smart home laboratory	consumers already familiar with dynamic pricing programs	4	ToU & dynamic	50 – 150[a]	
Ensslen et al. (2014)	Survey	French and German EV drivers and respondents without EV experience	70	Two-level smart charging tariff	28.5 %[a]	252.1[a]
Will and Schuller (2016)	Survey	Early adopters of EV technology	237	Discount on monthly base price	21.4 %	189.3
Hinterstocker et al. (2018)	Survey	Residential electricity customers	130	ToU	110	
Scherrer et al. (2019)	Survey	EV drivers (early adopters)	432	Variable tariff in general	30 %	265.3

[a] Smart charging service provider controls charging process.

3.2. Simulated charge cost savings potential

Table 2 displays the simulated annual charge cost savings potentials for frequent drivers. The results are given for 2021 and 2022 for the optimization with a dynamic tariff based on the German intraday auction prices and a ToU tariff with three set price levels. To show the range of results, minima and maxima are listed next to the average value. With a dynamic tariff, optimized charging can achieve average savings of 197.5 EUR per EV in 2021 and 421.6 EUR per EV in 2022. The savings with a ToU tariff are significantly lower with 68.7 EUR in 2021 and 122.8 EUR in 2022. The higher savings potential for the dynamic tariff can be explained by a greater possibility to shift loads to times of low price signals. However, the stronger the dynamization of the variable tariff, the higher the price risk for end consumers.

Table 2. Simulated charge cost savings.

Year	Tariff	Savings [€]		
		Min	Max	Mean
2021	ToU	4.3	194.5	69.7
2021	Dynamic	30.6	386.3	197.5
2022	ToU	7.6	343.5	122.8
2022	Dynamic	54	813.1	421.6

The conversion of the electricity supplier's indicated savings potential results in an annual charge cost saving of 212.3 EUR (Tibber, 2023) or 309.5 EUR (Rabot Charge, 2023) respectively, showing that the stated savings potentials are mostly higher than – according to our simulation results – achievable.

3.3. Revenue margin

In the final step, we calculated the revenue margin by deducting the required compensation for EV drivers from the simulated savings potentials from charging an EV using a variable tariff. For a dynamic tariff, the revenue margin results on average in 14.2 EUR per year in 2021 and 238.3 EUR per year in 2022. For a ToU tariff, the revenue margin is negative and amounts to -113.6 EUR per year in 2021 and -60.5 EUR per year in 2022. Fig. 1 and Fig. 2 provide an overview of the average results.

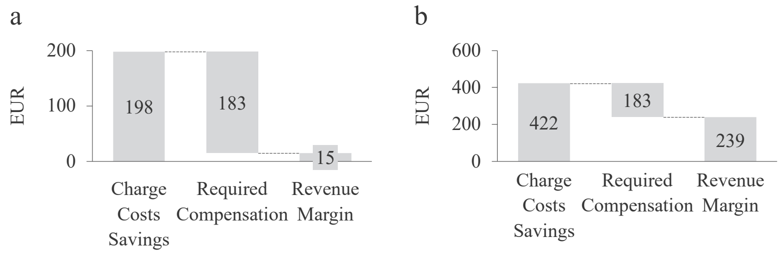

Fig. 1. Revenue margin for a dynamic tariff in (a) 2021 and (b) 2022.

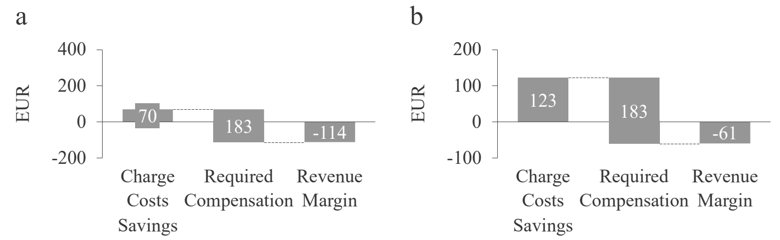

Fig. 2. Revenue margin for a ToU tariff in (a) 2021 (b) 2022.

The results indicate an acceptance of charging an EV with a dynamic tariff and a lack of acceptance of using a ToU tariff. The business model potential for electricity suppliers and aggregators is higher for customers using a dynamic than ToU tariff as in that case the revenue margin allows for a higher revenue share.

4. Discussion

The results have implications for both, the acceptance of using a variable tariff for smart charging as well as on the business model potential for electricity providers and aggregators. In this section, the results and their limitations are discussed, thereby referring to possibilities for further research.

4.1. Implications for acceptance

The revenue margin constitutes a higher potential reward than risk for EV drivers using a dynamic tariff and vice versa for a ToU tariff. For the latter, the charge cost savings potential does not suffice to cover the required compensation from EV drivers. Thus, we predict the acceptance of dynamic tariffs and an aversion to using ToU tariffs for the spot market optimized charging of EVs.

However, the revenue margin might be lower due to EV drivers' change in perception of the required savings on charge costs over time (Ensslen et al., 2018). As some of the included studies were published some years ago, the indicated monetary compensation could be out of date. We do not correct for inflation. This effect is lower for the studies with respondents' indication of percentage values, which were converted to annual values by using recent electricity prices. Moreover, we did not investigate the influence of additional costs for initial investments of EV drivers on the acceptance, like a charge control system.

In 2021, the electricity price constituted only 25 % of the total German electricity price (BDEW, 2023). Still, the required charge cost reductions were calculated using the total electricity price as it was assumed that study participants are not aware of this fact. However, the simulations are based on only 25 % of the household electricity price. Thus, changes in the overall price structure, like lower fixed state-induced price components or variable grid fees, could impact the overall revenue margin.

During our literature review, we found acceptance studies for other European countries that reveal partly higher (Netherlands) (Gardien, 2020), partly lower (Finland) (Ruokamo et al., 2019) required charge cost reductions. However, to further assess the attractiveness and acceptance of the spot market optimized charging for other countries, the different market structures, regulatory frameworks, electricity prices, as well as EV drivers' perceptions toward smart charging are to be considered.

The comparison between the ToU and dynamic tariffs shows that actual charge cost savings as well as financial attractiveness and risk depend on the tariff structure. The more dynamic an electricity tariff the higher the savings potential. In contrast, acceptance studies show that consumers prefer simpler tariff structures, like ToU tariffs, to more complex, dynamic tariffs (Dütschke et al., 2013). Furthermore, survey participants often preferred to stick to their conventional household electricity tariff instead of a dynamic pricing system (Dütschke and Paetz, 2013). Dütschke et al. (2013) therefore suggest heavily promoting variable tariffs for end consumers and ensuring accompanying informatory measures to increase acceptance. Especially since the financial compensation might not be satisfactory for EV drivers, other relevant acceptance factors, e.g., creating a green conscience, environmental protection, or more efficient energy usage (Johnsen et al., 2020), should be included in marketing activities.

4.2. Implications for business models

The revenue margin only exceeds the EV driver's required compensation for accepting a variable tariff for smart charging when a dynamic tariff is applied. This indicates a volatile business model potential for electricity providers and aggregators. The business model potential strongly depends on the electricity price developments as well as EV drivers' individual perception of risk and monetary quantification of their flexibility restriction. In case of a positive revenue margin, EV driver's charge cost savings and attractiveness can be increased, or the profits of the electricity provider and aggregator can be raised.

To comprehensively assess the business model potential for electricity providers and aggregators detailed research of future market and price developments as well as respective trading strategies is necessary, e.g., increasing the revenue margin through arbitrage in the continuous intraday market or countertrades. Ensslen et al. (2014) predict declining future contribution margins for aggregators as their load-shifting activities in the intraday market actively influence the market prices and price spreads, leading to a decline in the revenue margin (Ensslen et al., 2014). Thus, long-term profitability and detailed conclusions for the aggregator's and electricity supplier's business model are to be investigated in more detail considering electricity purchase and other operational costs.

Further acceptance studies on variable tariffs and smart charging, like bidirectional charging (Baumgartner et al., 2022) or semi-public charging at workplaces (Ensslen et al., 2018), were not included due to their slightly different research subject. They point out a larger customer base and additional smart charging use cases, highlighting the potential to expand business models.

5. Conclusion

This paper estimates the attractiveness of the spot market optimized charging of EVs using variable tariffs. The use case has two main goals: To increase the attractiveness of EVs by reducing charge costs and to raise exploitation of RES electricity generation for EV charging processes. EV driver's acceptance of shifting charge loads is crucial for the widespread dissemination of this use case. The attractiveness of variable tariffs determines user acceptance and the associated business model potential.

We analyzed EV drivers' acceptance of the spot market optimized charging by estimating the financial attractiveness from both, a business, and a customer perspective. The required compensation was calculated by reviewing acceptance studies for variable tariffs and comparing them to simulated charge cost savings potentials of the spot market optimized charging of EVs. The resulting revenue margin from the difference between required compensation and savings potential indicates whether user acceptance can be ensured and whether financial leeway for participating businesses exists.

The simulation results reveal an annual charge cost savings potential of 197.5 EUR in 2021 and 421.6 EUR in 2022 for a dynamic tariff and 69.7 EUR in 2021 and 122.8 EUR in 2022 for a ToU tariff. Thus, the required compensation of 183.3 EUR per year to fulfill acceptance is on average exceeded by 14.2 to 238.3 EUR for a dynamic tariff. In the case of a ToU tariff, the revenue margin is undercut by -113.6 EUR to -60.5 EUR. We predict a partial acceptance of variable tariffs and a volatile business model potential for electricity suppliers and aggregators.

Future research should analyze the business model potential of electricity suppliers and aggregators in more detail, especially considering future price developments in electricity markets and additional customer segments. As financial factors alone might not suffice, other influencing factors should be included in marketing and educational activities to ensure the widespread use of variable tariffs and, thus, smooth integration of EVs into the energy system.

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