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Combining the Demand for Interim and Opportunity Charging : A Case Study from Stuttgart.

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Combining the demand for interim and opportunity charging – a case study from Stuttgart

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Abstract

The market share of plug-in electric vehicles (PEVs) has been increasing in the last years which comes along with a raising demand for public charging stations. While the operation of low-power charging stations (Mode-3) is far from being profitable, prospects for fast charging stations indicate attractive revenues. This is mainly based on a higher workload (shorter charging times), a higher willingness-to-pay of customers and a higher complementary situation compared to home-based charging [1]. Both also serve for different purposes: Slow charging is performed whenever there is an opportunity while fast charging will also allow short stops to recharge on long-distance trips (interim charging). In this paper, we investigate the potential for combining interim and opportunity charging at one location in order to increase the utilization and decrease the payback time of public fast charging stations. For modeling the operation of Mode-3 charging stations, we applied the ALADIN model [2] and combine it with results from an optimal allocation of fast charging points in Germany (cf. [3]). Results are presented for four fast charging stations around Stuttgart, Germany. Our results show that a combination of long-distance and local customers may increase the occupancy rate and therefore the profitability of fast charging stations. Yet, the willingness to detour of PEV users, the comparably small additional earnings for charging stations together with a joint optimized location modelling might be analyzed in further work.

1 Introduction

The introduction of plug-in electric vehicles is a means to reduce greenhouse gas and local emissions from the transport sector and to become more independent from energy imports. One challenge for their introduction is the setup of an adequate charging infrastructure. Several studies already showed that home and work charging are the most important charging options (e.g. [2,4,5]). Studies for public slow charging points show that a cost-efficient operation with charging when users are already parking close by (“opportunity charging”) might be challenging (also in the future) [2]. However fast chargers that can be used to increase the length of a trip by stopping at the charging point ("interim charging”) seem to provide a positive business case, if they can obtain high occupancy rate [3,6,7]. The aim of this paper is to test whether the two types of demand could be combined at a fast charging station to have a better occupancy rate and shorter payback time.

Models for both types of charging demand are combined for charging locations in the region of Stuttgart. These will be explained in the following section and results are shown and discussed from an energy economical point of view in Section 3. A general discussion and conclusions are presented in Section 4.

Figure 1: Region of Stuttgart (own illustration)

2 Methods and data

The area observed in this paper is the region of Stuttgart, i.e., the six districts Stuttgart, Göppingen, Ludwigsburg, Rems-Murr-Kreis, Esslingen and Böblingen, in the southwest of Germany (see Figure 1).

We apply two models to determine the demand for charging: For slow or opportunity charging, we use the model ALADIN which has been described and applied in several publications [2, 8]. Based on vehicle driving profiles (all trips within one week), the vehicle buying decision and charging at home, work and public charging points are simulated. The charging infrastructure is set up based on the users' demand for it. For fast or interim charging, trips have to be interrupted which is not considered in the ALADIN model. Here, a user only charges in public if his battery state of charge is below 50% and there is a free charging point.

The data used in ALADIN stems from [9], a household travel survey for the region of Stuttgart that was transferred to all households in the region. All modifications and preparations to work for the ALADIN model have been comprehensively described in [3]. The very detailed simulation permits an analysis of occupancy rate of charging points within a geographical granularity of 100x100 m² in the inner city of Stuttgart.

A possible approach for locating fast charging stations is described in [3] and it is also used in this comparison. The model optimally allocates fast charging stations along the German highway (cf. Figure 2) based on a flow matrix that gives the number of cars driving from an origin O to a destination D. It ensures that a certain percentage of these OD-flows can fulfil their trip assuming an average battery capacity. Based on the results, the number of charging points at each station is determined and investigated in a simulation, as presented in [6], also taking the daily driving patterns, charging rates and possible delays into account.

The necessary data for solving the fast charging location model, i.e. the OD flows, the road network and the set of possible locations, was obtained from [10] and [11].

To combine both models, we take a look at the four fast charging locations in the region of Stuttgart in [3] and the demand for opportunity charging from [2] within 5 km around this charging location. These are Esslingen (with 24 charging points (CPs)), Ludwigsburg-Nord (31 CPs), Böblingen-Sindelfingen (40 CPs) and Rutesheim (40 CPs).

For the comparison of costs for charging, we calculate the annual cost of a fast charging point by its investment annuity and the yearly cost, e.g. for maintenance. This annual cost is projected to the kilowatthours that are sold at the charging station to understand how high a surcharge to the electricity price would have to be to cover the charging point.

$$s_l = \frac{I\frac{(1+i)^T * i}{(1+i)^T - 1} + a_{opex}}{365 * 24 * occ_l * P_l} \qquad (1)$$

Here, we use 25,000 EUR as investment , and for simplicity 10% of that as operating cost a_{opex}. The interest rate is set to 5% and the power at location occ_l is always 50 kW. We later vary the investment horizon and receive the occupancy rate at location from the simulations in the previously described models.

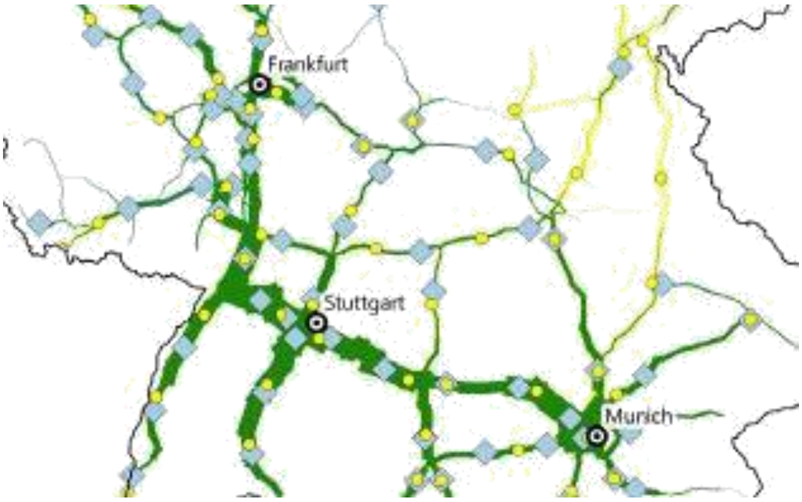

Figure 2: Optimal allocated fast charging stations along the highway around Stuttgart (own simulation)

3 Results

We present results in a threefold way: First, we take a look at the load patterns over one week. Second, the total energy consumed for interim only and combined charging are regarded. And third, we take a look at the economical perspective with necessary surpluses.

Figure 3 shows the weekly course of charging for all four charging stations which may contain multiple charging points. The ordinate holds the total energy consumed in a 15-minute interval in kilowatthours. For all charging stations, the dashed area is the energy charged through interim charging while the additional blue area contains the demand for opportunity charging. For all charging stations, we find morning peak around 7 am and evening peak around 8 pm from Monday to Thursday. On Friday and the weekend, the peaks are varying through the day and the total amount of energy charged is higher.

We also find the energy charged for opportunity charging to occur in the afternoon and evening hours, so the evening peak might be raised through the combination. Furthermore, we can clearly see an additional demand for opportunity charging in the upper panel of Figure 3 (Esslingen), but it is hardly visible anymore at the bottom (Rutesheim). When considering the scale of the ordinate, it becomes obvious that only for smaller charging stations for interim charging, the additional demand for opportunity charging can play a role.

Table 1: Energy, power and occupancy rate of fast charging stations in Stuttgart in 2030

Location	Esslingen	Ludwigsburg-Nord	Böblingen/ Sindelfingen	Rutesheim
Weekly energy charged (opportunity charging) [kWh]	5,490	8,130	6,658	6,658
Weekly energy charged (interim charging) [kWh]	27,024	52,576	69,728	81,584
Weekly energy charged (combined charging) [kWh	32,514	60,706	76,386	88,242
Maximum power for interim charging [kW]	549	1,068	1,416	1,657
Maximum power for combined charging [kW]	602	1,147	1,481	1,722
Occupancy rate for interim charging	13.4%	20.2%	20.8%	24.3%
Occupancy rate for combined charging	16.1%	23.3%	22.7%	26.3%

We may observe these differences in Table 1, too. The total amount of energy charged during the week for interim charging is about five times higher than for opportunity charging in Esslingen and about 10-12 times in Rutesheim. Thus, we may only increase the amount of fast charging by a few kilowatthours. We also observe this when looking at the occupancy rate for interim charging only and combined with opportunity charging. Thus, the occupancy rate can be raised by some percentage and it is even more interesting for charging stations with lower occupancy rate. The increase in power for "interim only" vs. "combined" charging is also negligible, although it will increase the evening peaks.

Lastly, the required surcharge is depicted in Table 2. Here, we find that charging stations with a low occupancy rate for interim charging would really favor the additional demand through opportunity charging. Thus, for Esslingen, the surcharge on the electricity price to cover the cost for the charging station would decrease from 0.14 €/kWh to 0.12 €/kWh if a 5-year payback time was considered. If a 10-year payback time was accepted the surcharge would be around 0.10 €/kWh for interim charging and 0.08 €/kWh for the combined charging approach.

However, also here, we observe that at well occupied interim charging points, the additional demand through opportunity charging is not of great interest and may only slightly decrease the possible surcharge.

Table 2: Surcharge for different payback times of fast charging stations in Stuttgart in 2030

Location	Esslingen	Ludwigsburg-Nord	Böblingen/ Sindelfingen	Rutesheim
Surcharge for interim charging and 5-year payback time [€/kWh]	0.14	0.09	0.09	0.08
Surcharge for combined charging and 5-year payback time [€/kWh]	0.12	0.08	0.08	0.07
Surcharge for interim charging and 10-year payback time [€/kWh]	0.10	0.06	0.06	0.05
Surcharge for combined charging and 10-year payback time [€/kWh]	0.08	0.06	0.06	0.05

4 Discussion and Conclusions

The result for Esslingen shows that a combination of interim and opportunity charging demands can be useful to increase the occupancy rate of charging stations and decrease the cost or payback time when the occupancy rate through interim charging at the fast chargers is low. Above an occupancy rate of 20%, the demand for opportunity charging is negligible in the region of Stuttgart. We consider this result as being transferable to other regions in Germany and even to some other countries. Yet, a further question is whether the increase in occupancy rate is enough to weigh up the additional organizational effort or if users are willing to detour that far for refueling.

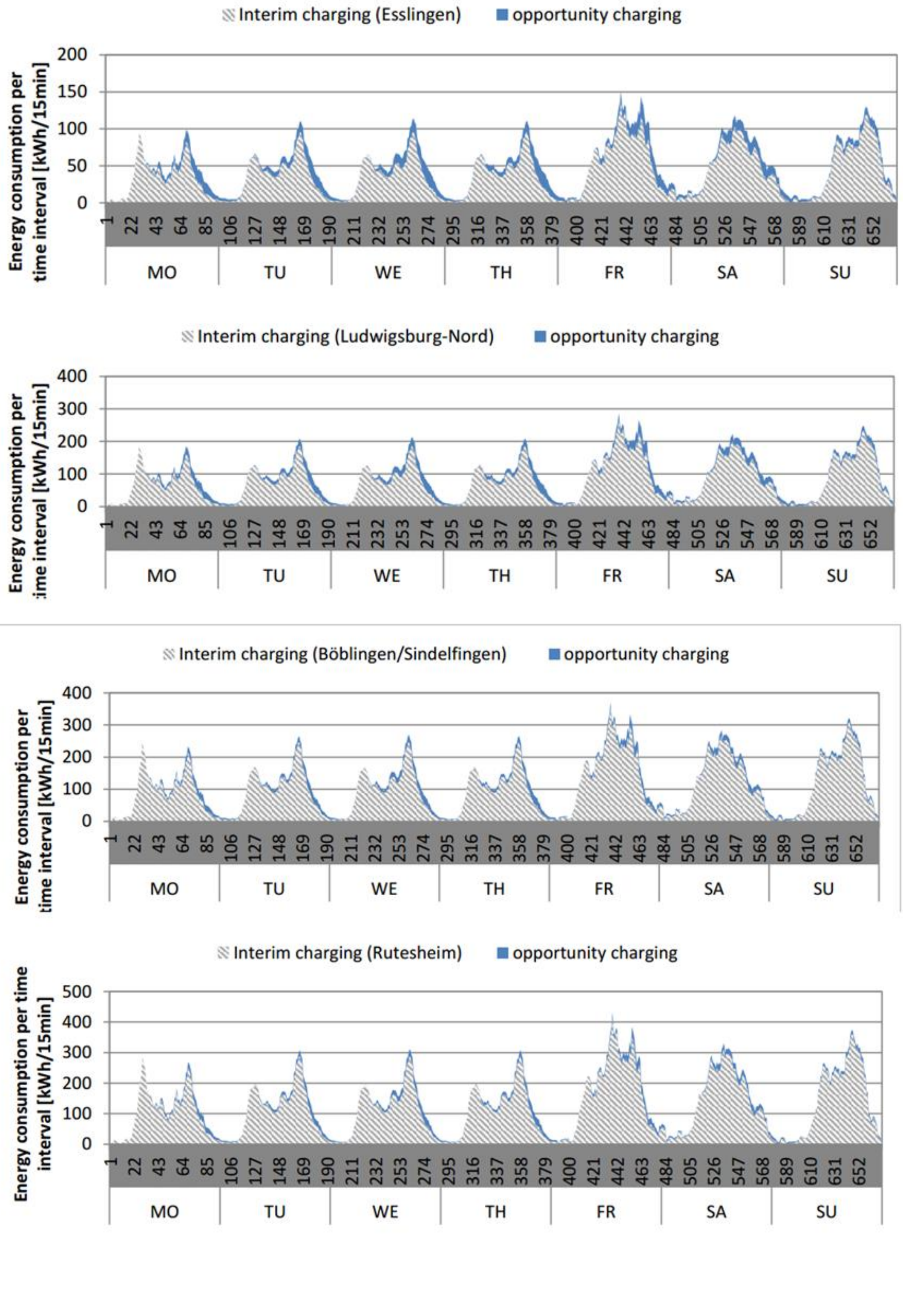

Figure 3: Energy demand for interim and opportunity charging at charging facilities in Esslingen, Ludwigsburg-Nord, Böblingen/Sindelfingen, and Rutesheim in 2030 (own simulation)

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