RESULTS FROM THE PROJECT "ETAXI FOR VIENNA" CONCERNING THE INTEGRATION OF EVS IN THE DISTRIBUTION GRID

Dominik FASTHUBER
TU-Wien – Austria
fasthuber@ea.tuwien.ac.at

Johannes ASAMER
AIT – Austria
Johannes.Asamer@ait.ac.at

Martin REINTHALER
AIT – Austria
Martin.Reinthaler@ait.ac.at

ABSTRACT

This paper describes the results of the implementation project "eTaxi in Vienna". In this project, the technical university of Vienna (TU Wien) and the Austrian Institute of Technology (AIT) researched the effects of switching from conventional taxis to electric taxis in an urban area. It was analysed in detail whether there are differences in driving distances and driving times of electric taxis compared to conventional taxis with an internal combustion engine. As a result, it can be stated that the operation of a taxi fleet with electric vehicles is already possible under today's conditions. The biggest challenges at the moment, however, are not technical barriers, rather a multitude of organisational, regulatory and economic problems.

INTRODUCTION

Electric vehicles (EVs) are the ideal vehicles for taxi operation in cities [1]. They are quiet for low velocities and do not cause local emissions. For these reasons, the ZENEM [2] research project already started in 2011 to investigate the impact of a high penetration of electric vehicles on the electricity distribution grid including charging station infrastructure under the assumption that a whole Viennese taxi fleet is operated with electric cars. In a follow up project in 2014 important questions concerning legal, organisational, technical and economic issues were addressed. Finally, the implementation project "eTaxi in Vienna" was launched in 2015 and lasted for 39 months. During the project eleven fast charging stations have been installed [3] and, in the end, 40 vehicles could be converted to electric taxis.
One of the biggest challenges in this project was the integration of the rapid charging stations into the electrical distribution grid for the vehicles.

This study reflects the most important results of the project "eTaxi in Vienna" and includes in particular how electric taxis behave as electrical loads in relation to their charging profile and driving profile. In addition, the charging stations are analysed with respect to power output and charged energy. The results and gained knowledge of this project will allow the grid operator to upgrade infrastructures and expand electric grids at minimum costs, because of a better understanding for this new type of electric load.

METHODOLOGY

Eleven rapid charging stations were installed during the project period. Based on previous studies [5, 6, 7, 8], these were planned and constructed at selected locations in Vienna and at the Vienna international airport [3]. In Figure 1 the location of all eleven charging stations are visualized.

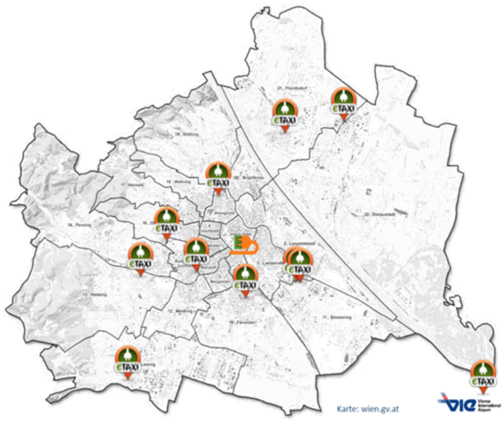

Figure 1: The eleven constructed fast charging stations of the project "eTaxi in Vienna".

Most of these charging stations were so-called "triple chargers" and allow charging with alternating current (AC - Typ2 - Connector with max. 43,5 kW) and direct current (DC - CHAdeMO and CCS[1] connector with 50 kW).
Analysis are based on the backend data of these charging stations, the dataset of the radio taxi provider ("Taxi 31300" and "Taxi 40100". The data contain the periodically recorded GPS location of 60 taxis with internal combustion engine and all available electric taxis (40 vehicles at the end of the project). A detailed description of recorded data can be found in [4]. Moreover, a vehicle status recording the occupation by a customer is available.
Also, data obtained directly from the control area network (CAN) of the vehicle were used for our analysis. This interface provides various information about duration, start and end of the charging processes as well as movement data (mileage, velocity) Furthermore, the energy consumed by the vehicles was recorded and provide via CAN-interface.
The data set recorded by the radio taxi provider enables us to compare the (driving) behaviour of different taxis. From

1 CCS – Combined Charging System

the GPS locations, recorded approximately every 45 seconds we deduced the chosen routes and estimated the mileage between consecutive locations. Further, the total mileage per day and vehicle was estimated and divided by the time the taxi was in charge that day. As a result, the average hourly mileage for each vehicle was obtained.
From the status regarding the vehicle occupancy, we are informed when a customer trip starts and ends, thus we are able to determine the number of customer trips. Similar to the hourly mileage we divided the number of customer trips per day by the time a taxi was in charge and obtained the average number of customer trips per hour.
To determine whether electric taxis have less customer trips or a higher mileage, possibly caused by charging events, we compared the distribution of mileage and customer trips per hour, visualized as boxplots.
Nevertheless, an electric taxi needs to be charged from time to time and therefore must conduct a trip to a (hopefully) nearby charging station. Since charging stations, especially fast charging stations are not as omnipresent as gas stations, the question is, which average detour an electric taxi has to make in order to reach a charging station. To answer this question, we assume that a vehicle is never charged during a customer trip, but before or after. Therefore, we compared the mileage between two consecutive customer trips for:

- taxis with internal combustion engine,
- electric taxis with no charging event, and
- electric taxis with a charging event.

Whether or not an electric taxi was charged between two customer trips was visible from the recorded backend data of the charging stations. These data contain information about which vehicle was charged when and at which location.
When we compare the mileage between customer trips, the expectation is that electric taxis with a charging event have a higher mileage on average compared to other vehicles. By visualizing the empirical cumulative distribution (ECD) of the mileage for the three different vehicles/situations, we can deduce an average detour length (cf. Section "Results"). The data recorded from the CAN-interface allows a detailed analysis of the energy consumption of each vehicle. For this study we are interested in how much energy per km is consumed and how far this value varies due to different outside air temperatures. I.e. how much energy is required for cooling or heating the vehicle. The energy per km is the total consumed energy divided by the total mileage of a given vehicle and normally expressed in kWh per 100 km. To compare the energy consumption for different temperatures we estimated an average energy consumption per 100km for each day and vehicle. Furthermore, the daily average outside air temperature was recorded for Vienna.

In the result section the energy consumption is visualized together with outside air temperature.

RESULTS

In the following, the results and findings from the project will be processed thematically and discussed.

Analyses based on the travel data of two radio taxi provider

A concern during the implementation of electric taxis in Vienna was whether electrified taxis will have a higher mileage compared to taxis with internal combustion engine due to detours to charging stations and less income because of missed customer trips during charging.
Therefore, we compare the distribution of average mileage and number of customer trips per hour (Figure 2) by using boxplots. The upper and lower limits of the boxes represent the inter-quartile range, while the whiskers (vertical lines) are the 5th and 95th percentile. Median value is represented by a horizontal line within the box. From Figure 2 we see no significant differences of the distribution of the both vehicle types, neither for mileage nor the number of customer trips. This is also confirmed by a statistical test (Kolmogorov-Smirnov test). We therefore conclude that no additional costs (higher mileage) or loss of income are to be expected when switching to an electrified taxi.

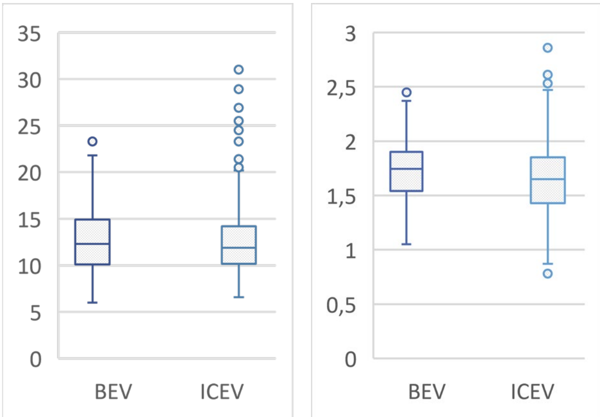

Figure 2: Comparison of average mileage per hour in km (left) and number of customer trips per hour (right) between electrified taxis (BEV[2]) and conventional taxis (ICEV[3]).

In Figure 3 the ECD of the driving distance between two consecutive customer trips is visualized for different vehicle types and situations (with and without charging event). For electric taxis without charging event and taxis with internal combustion engine there is no difference of the ECD visible. However electric taxis, which are charged between two customer trips, have to make a detour of approximately 4 km (median value).

2 BEV – Battery electric vehicle

3 ICEV – Internal combustion engine vehicle

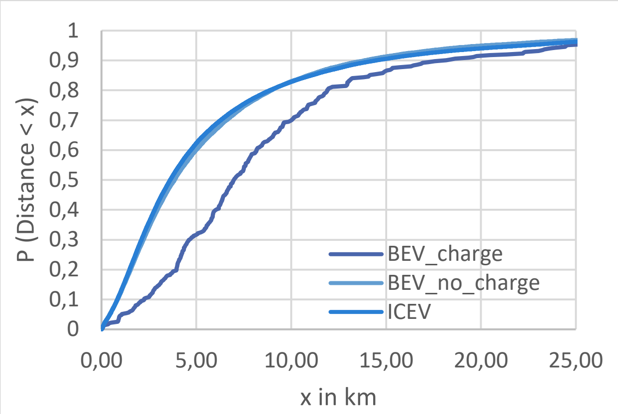

Figure 3: Empirical cumulative distribution of driving distance between two consecutive customer trips.

The analysis of the electric energy consumption with respect to different outside air temperatures is presented in Figure 4. It is visible, that electric taxis consume on average 18 kWh/100km. This value increases as temperature decreases. The highest energy consumption (28 kWh/100 km) is visible for the lowest observed average air temperature (-10°C). On the other hand, an impact of hot air temperatures is not visible. During the summer period (July, August) the energy consumption remains on a rather low level of 18 kWh/100 km. From this analysis we conclude that only heating has a significant impact on energy consumption and thus driving range.

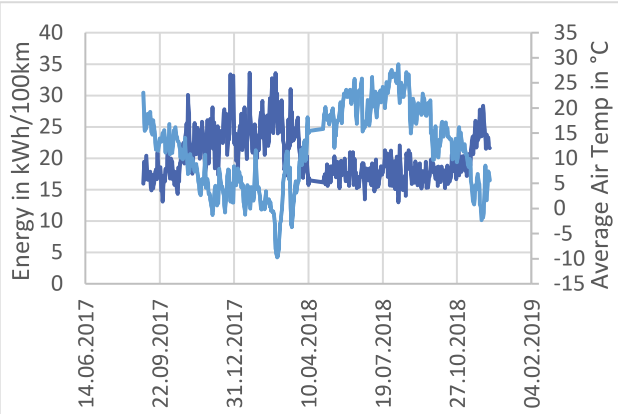

Figure 4: Average energy consumption of electric taxi (dark) and outside air temperature (bright).

Load capacity of the charging infrastructure (number and duration of charging operations per charging point)

In the period from 30th March 2016 to 1st April 2018 (733 days) 42 eTaxi loading cards and 26 loading stations were examined, including the eleven "eTaxi" loading stations as well as further stations where loading was carried out with "eTaxi" cards. 16.868 charging operations were recorded (an average of 23 per calendar day). This corresponds to an average energy output of 14.7 kWh per charging process and an average value of 338.15 kWh per calendar day. The largest amount of energy delivered in a single charging process is 77.1 kWh and was obtained over a day with a maximum power of 44 kW in an AC charging process.

The distributions of the charged energy quantity for the weekdays "Mon. to Fri." and "Sat. and Sun." are shown in Figure 5. Since 75 % of the charging processes carried out account for less than 17 kWh, it can be assumed that the fast charging station is largely used for partial charges (Charge below 90 % SOC[4] completed). A more detailed examination of the proportions of partial and full loads as well as the power and SOC-curves were carried out through additional investigations, but is not part of this paper.

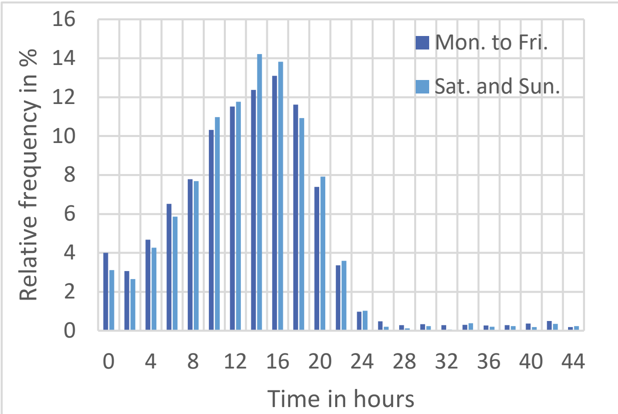

Figure 5: Distribution of the charged energy per charging process.

A breakdown of the average charged energy per weekday is shown in Figure 6. It can be seen that the demand for charging increases from Monday to Friday and is lowest on Saturdays and Sundays. As already described, the fast charging stations have three separate charging connectors.

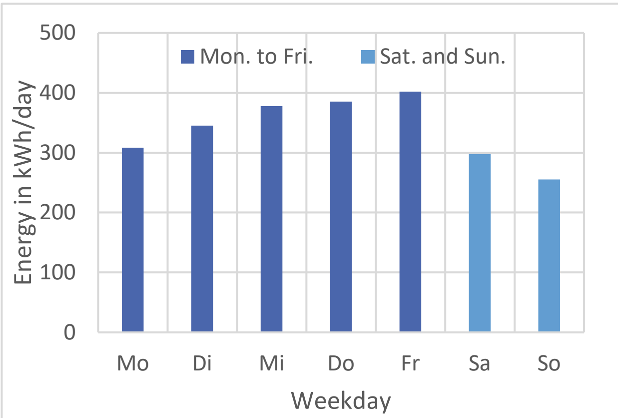

Figure 6: Average sum of charged energy per weekday.

4 SOC – State of Charge

Two for DC charging and one for AC charging. The following values were determined for the percentage frequency of use of the charging processes: 15 % of the charging processes were carried out using AC charging and 85 % using DC charging. From 30 March 2016, the first loading operations of eTaxi drivers were carried out in real operation. The eTaxi fast charging stations will be available 24 hours a day from their commissioning. As expected, the fast charging station was still used cautiously at the beginning due to the small number of eTaxi vehicles. On average, 45.8 charging processes per calendar day were carried out over the observation period.

Figure 7 shows the number of charging processes in the course of the calendar weeks (start 2016, calendar week 14). In the first weeks, less than 40 charging operations were carried out per week. In June there were already almost 100 charging processes per week. After that, a "summer slump" is expected in July 2016. In the winter weeks, the number of charging processes continued to rise, sometimes due to the low temperatures, and finally declined slightly until the end of March, after which it continued to rise. Since the number of charging processes is strongly linked to the number of taxi vehicles, the values per calendar week will tend to rise further in the future.

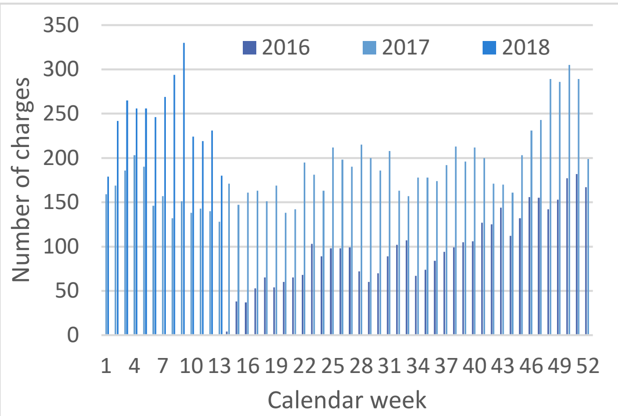

Figure 7: Number of charging operations per calendar week (start 2016, calendar week 14 - all fast charging stations, all charging connectors)

If the start times of the charging processes at the rapid charging stations are considered, a relatively irregular distribution can be seen over all weekdays (Figure 8). With regard to the extreme values, there are clear time differences between working days and weekends. From Monday to Friday, most loading operations are started at midday. At weekends, the start of charging tends to shift towards later times into the early morning. The high frequency values between 0-4 o'clock in the morning can be attributed to eTaxis during the night shift.

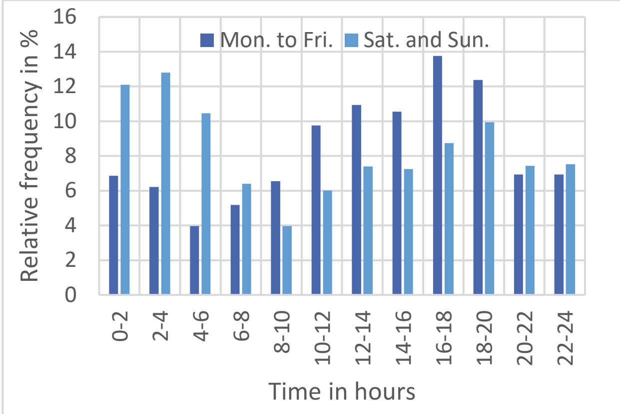

Figure 8: Distribution of the start times of the charging processes of all fast charging stations

The difference between the start and end times is the duration of the charging processes. As you can see in Figure 9, the average charging time during the consideration period is about 29.1 minutes. Fifty percent of all charging processes are between 19.3 and 33.2 minutes (25 % and 75 % quantiles). Shorter charging procedures are carried out especially at weekends. In general, the average values for charging time, charged energy and number of charging processes at weekends are lower.

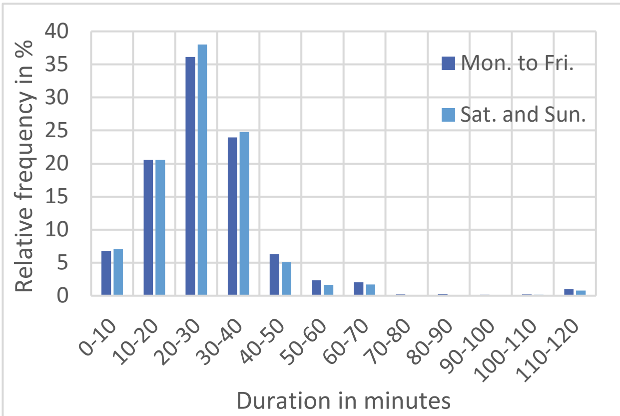

Figure 9: Frequency distribution of charging durations

CONCLUSIO

In summary, it can be said that the operation of battery electric vehicles as taxis is already possible today. The following findings can be recorded about the operation:

- Over the entire observation period, the current power values at the PCC[5] are low at several kW. Nevertheless, isolated peak power values of up to 55 kW occur. On average, an output of 40 kW is called up at the considered fast charging stations.
- The resulting energy quantities amount to an average of 15 to 20 kWh at the respective charging locations. This value could rise further in the future due to increased battery capacities.
- The average charging time at the charging stations is between 25 and 35 minutes. Isolated outliers occur, which can be explained by lower power outputs.
- No significant differences of hourly mileage and hourly number of customer trips is visible between electric taxis and taxis with internal combustion engine. Therefore, we conclude that operating an electric taxi comes with no additional costs or financial penalties.
- The average detour length to an electric charging station is 4km. This value could be reduced if density of fast charging network is increased.
- Energy consumption is approximately 50% higher during winter times due to heating. Cooling has no visible effect on energy consumption for electric taxis.

ACKNOWLEDGMENTS

The project “eTaxi in Vienna” was funded through a subcontract of the "bmvit" and is carried out in the context of the programme "E-Mobilität für alle: Urbane Elektromobilität".

REFERENCES

[1] Cai, H., Jia, X., Chiu, A.S., Hu, X., Xu, M., Siting public electric vehicle charging stations in Beijing using big-data informed travel patterns of the taxi fleet. Transportation Research Part D: Transport and Environment, Volume 33, Pages 39-46, 2014

[2] W. Gawlik, M. Litzlbauer, A. Schuster, et al.: ZENEM - Zukünftige Energienetze mit Elektromobilität, FFG-Forschungsprojekt, NE2020, 4. AS, Projektnummer: 829953, Final Report, Wien 2013

[3] J. Asamer, M. Reinthaler, M. Ruthmair, M. Straub, J. Puchinger, Optimizing charging station locations for urban taxi providers, Transportation Research Part A: Policy and Practice, Volume 85, Pages 233-246, 2016

[4] W. Toplak, J. Asamer, M. Straub, M. Dragaschnig, J. Puchinger, M. Prandtstetter: Route Analysis And Planning For Urban Transportation On Basis Of Floating Car Data And Emission Estimates; 90th TRB Conference, Washington DC, 2011

[5] R. Sellmair, T. Hamacher, Method of optimization for the infrastructure of charging station for electric taxis, Proceedings of the 93rd Annual Meeting of the Transportation Research Board, 2014

[6] M. Andrews, M. Dogru, J. Hobby, Y. Jin, G. Tucci, Modeling and optimization for electric vehicle charging infrastructure, Proceedings of Production and Operations Management Society (POMS), 2013

[7] H. Cai, X. Jia, A.S. Chiu, X. Hu, M. Xu, Siting public electric vehicle charging stations in Beijing using big-data informed travel patterns of the taxi fleet. Transportation Research Part D: Transport and Environment, Volume 33, Pages 39-46, 2014

[8] Y. Gao, Y. Guo, Optimal planning of charging station for phased electric vehicle. Energy and Power Engineering, Volume 5, Pages 1393-1397, 2013

5 PCC - Point of common coupling