The Impact of Transitioning to Shared Electric Vehicles on Grid Congestion and Management

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***Abstract*—The transition towards a sharing economy and the increasing electrification of the transport sector are occurring simultaneously. Consequently, we can expect more car sharing schemes using electric vehicles (EVs) to emerge in coming years. Numerous studies looked into the grid impact of EV charging and its potential to provide ancillary services, but these studies only considered regular EVs. This study compares the charging patterns of regular and shared EVs and creates insight in the grid impact and potential to provide ancillary services with future adoption of shared EVs. Four scenarios for the adoption of shared EVs are proposed, and a method to generate a set of future charging transactions based on historical charging data is presented. The analysis is performed using charging data from an EV sharing company in the Netherlands. Results indicate that charging demand peaks and grid congestion levels decrease substantially with higher adoption of shared EVs. Adoption of shared EVs increases the potential of EVs to provide ancillary services, due to a higher charging flexibility of shared EVs.**

***Index Terms*—sharing economy, electric vehicles, car sharing, grid congestion, ancillary services**

NOMENCLATURE

Indices and sets

$j \in \mathcal{J}$ Set of EV categories (shared EVs and regular EVs)
$n \in \mathcal{N}$ Set of charging transactions

Symbols

$\Delta T_{\text{ch},n}$ Actual charging time of transaction n.
$\Delta T_{\text{con},n}$ Connection time to charging station of transaction n.
$\Delta T_{\text{flex},n}$ Flexibility in charging demand of transaction n.
$d_{\text{arr},n,j}$ Arrival day of the week of charging transaction n of category j.
$E_{\text{ann},j}$ Predetermined annual charging demand of all EV transactions of category j in an LV grid.
$E_{\text{req},n,j}$ Charging demand of transaction n of category j.
$h_{\text{arr},n,j}$ Arrival hour of charging transaction n of category j.
$P_{\text{av},n}$ Average charging power of transaction n.
$P_{\text{max},n}$ Average charging power of transaction n.
$S_{\text{pl},j}$ Set of historical charging transactions of category j of which the charging power is logged.
S_j Set of historical charging transactions of category j.

I. INTRODUCTION

Stimulated by among others battery cost reductions and governmental incentives to decarbonize road transport, the share of electric vehicles (EVs) in the passenger car fleet is growing rapidly [1], [2]. High adoption of EVs can cause power quality and congestion problems in the low-voltage (LV) grid [3], since the extra load of EVs was not considered when designing the grid. At the same time, the battery capacity of EVs can be used to mitigate power quality and grid congestion problems due to the high flexibility in EV charging demand. For this reason, a large number of studies have estimated the future impact of EV charging on grid congestion (i.a., [4], [5]) and have assessed the potential of EVs to mitigate power quality and congestion problems (i.a., [6]–[8]).

In parallel, a paradigm shift towards the sharing economy is emerging in recent years [9]. The application of the sharing economy to the transport sector could result in high market penetration of car sharing schemes [10]. Car sharing is an alternative to car ownership and provides users short-term access to a set of shared cars managed by a third-party organization [11]. The number of car sharing members worldwide has increased with a factor of 40 between 2006 and 2018 [12]. Different studies expect that the market share of car sharing will continue to increase [13]–[15]. Further adoption of car sharing in combination with a market uptake of EVs could result in an increasing charging demand of shared EVs. This increased role of shared EVs could affect the results of previous studies on the future grid impact of EV charging and the potential of EVs to provide ancillary services, since shared EVs are driven by more people, have different arrival times and are used for different functions.

The first aim of this study is to create insights in the impact of a shift towards shared EVs on the electricity grid. This study uses historical charging data from an EV sharing company in the Netherlands to compare the charging characteristics of shared and regular EVs, and proposes a novel method to generate future sets of EV charging transactions. These transaction sets are used to compare EV charging patterns in different adoption scenarios of shared EVs. Second, this study compares the flexibility in charging demand of shared and regular EVs to determine how the potential of EVs in providing ancillary services changes with a shift towards shared EVs. The results of this analysis provide distribution system operators (DSOs) with insights in future grid congestion levels with high adoption of shared EVs, and also indicate whether shared EVs are a suitable technology for the provision of

This study was supported by the European Regional Development Fund 'EFRO Kansen voor West II' through the project 'Smart Solar Charging'.

ancillary services. In addition, the results of this study show policymakers whether a shift towards shared EVs should be stimulated from a grid perspective.

This study is outlined as follows: Section II introduces the considered car sharing scheme and the investigated case study grid. Section III provides a comparison of the key charging characteristics of shared and regular EVs. Section IV presents a method to simulate future charging transactions and outlines different future adoption scenarios of shared EVs. The aggregated EV charging behavior in a LV grid, flexibility in charging demand and grid impact are presented for all considered scenarios in Section V. Lastly, a discussion and conclusion are presented in respectively Section VI and VII.

II. Case study specifications

We Drive Solar is a car sharing company offering station-based car sharing services using EVs. As of February 2020, it has a portfolio of three Tesla Model 3's (battery capacity 50 kWh) and 72 Renault ZOE's (battery capacity 44-52 kWh). Users need a subscription to drive a *We Drive Solar* EV, and also pay per driven kilometer.

EV charging data is obtained between 8 January 2019 and 10 March 2020 from 230 charging stations with two charging sockets in residential areas in the Netherlands, of which the large majority are located in the city of Utrecht. Each of these charging stations log the arrival time, departure time, car ID and charging volume of each charging transaction. 24 stations also log the charging power over time, which is used to determine the average charging power, maximum charging power and actual charging duration for each transaction. A distinction is made between shared EVs and regular EVs based on the car ID of the *We Drive Solar* EVs. All *We Drive Solar* EVs use one of the logged EV charging stations as their home station. Table I provides an overview of the number of logged charging transactions for regular and shared EVs.

TABLE I: Overview of logged charging transactions in the input data.

	No. of logged charging transactions	No. of charging transactions in which charging power is logged
Regular EVs	28,621	11,570
Shared EVs	8,722	1,963

A residential grid in the Lombok district in Utrecht, the Netherlands serves as a case study grid to analyze the grid impact of EV charging. This grid is connected to the medium-voltage (MV) grid through a 400 kVA transformer and serves 340 grid connections, of which the majority is households. It is assumed that 25% of the households will use a full-electric heat pump (HP) for heating in the future. The assumed future installed photovoltaic (PV) capacity in the grid equals 200 kWp. The profiles of HP demand, residential load and PV generation are created using the methods in [8].

III. Charging characteristics of shared and regular EVs

Fig. 1 compares key characteristics of charging transactions of shared and regular EVs for the selected case study. It shows considerable differences in the arrival times of both EV categories. The arrival hours of regular EVs in Fig. 1a show a distinct peak between 17:00-19:00, induced by EV-owners returning home from work. The minor peak between 8:00-10:00 in the arrival hours of regular EVs are caused by people arriving at work and charging their car in a residential area close to their working location. The majority of charging transactions of shared EVs start in the late afternoon or early evening, but the arrival times do not peak in one or two specific hours, while a substantial share of shared EVs arrive in the late evening. In addition, Fig. 1b shows that the number of charging transactions is substantially higher in weekends for shared EVs. Both trends could indicate that shared EVs are used relatively often for leisure and/or family/friend visits.

While regular EVs charge in some cases up to 75 kWh in Fig. 1c, the charging volume remains below 50 kWh in all charging transactions with shared EVs, due the absence of shared EVs with a battery capacity above 54 kWh in the studied fleet. Regular EVs show a peak between 3 and 8 kWh in the distribution of charging volume in Fig. 1c and between 3 and 4 kW in the distribution of charging power in Fig. 1d, which can be attributed to plug-in hybrids in the fleet of regular EVs, which have a relatively low battery capacity ($<$12 kWh) and a maximum charging power of 3.7 kW [4].

The relatively high share of transactions of shared EVs with a connection time below one hour in Fig. 1e demonstrates high utilization of shared EVs at specific moments. However, the utilization is not always high, as the connection time exceeds 72 hours in a substantial share of the charging transactions.

IV. Scenario development

This section shows how large-scale adoption of shared EVs may affect the aggregated EV charging behavior in a LV grid. This section presents different scenarios for future adoption of shared EVs based on scientific literature, after which a method is provided to generate future EV charging transactions.

A. Scenario Overview

Studies on expected future trends in car sharing show high ambiguity in the future adoption of shared cars. Shaneen & Cohen [16] conducted expert interviews and arrived at a market potential of shared cars of 2-10%, while 70% of the experts interviewed in [15] expected a market potential of shared cars between 11-25%. Other studies estimate the future adoption of shared cars using activity-based models. Martinez et al. [17] estimate that 2.4% of the trips in Lisbon, Portugal will be conducted using shared cars when introducing a car sharing scheme, while the model in [18] estimated a future market share of car sharing services of 1-3.8%. A stated preference study by Namazu et al. [14] in Vancouver, Canada showed that 25% of the inhabitants cannot be convinced to move to car sharing. Liao et al. [13] indicated that 13.9% of the car owners in the Netherlands will use shared cars for all car trips if a car sharing scheme is available, while 63.4% of the car owners will not use a car sharing scheme. Rotaris & Danielis [19] indicated that only 3.7% of the inhabitants in a

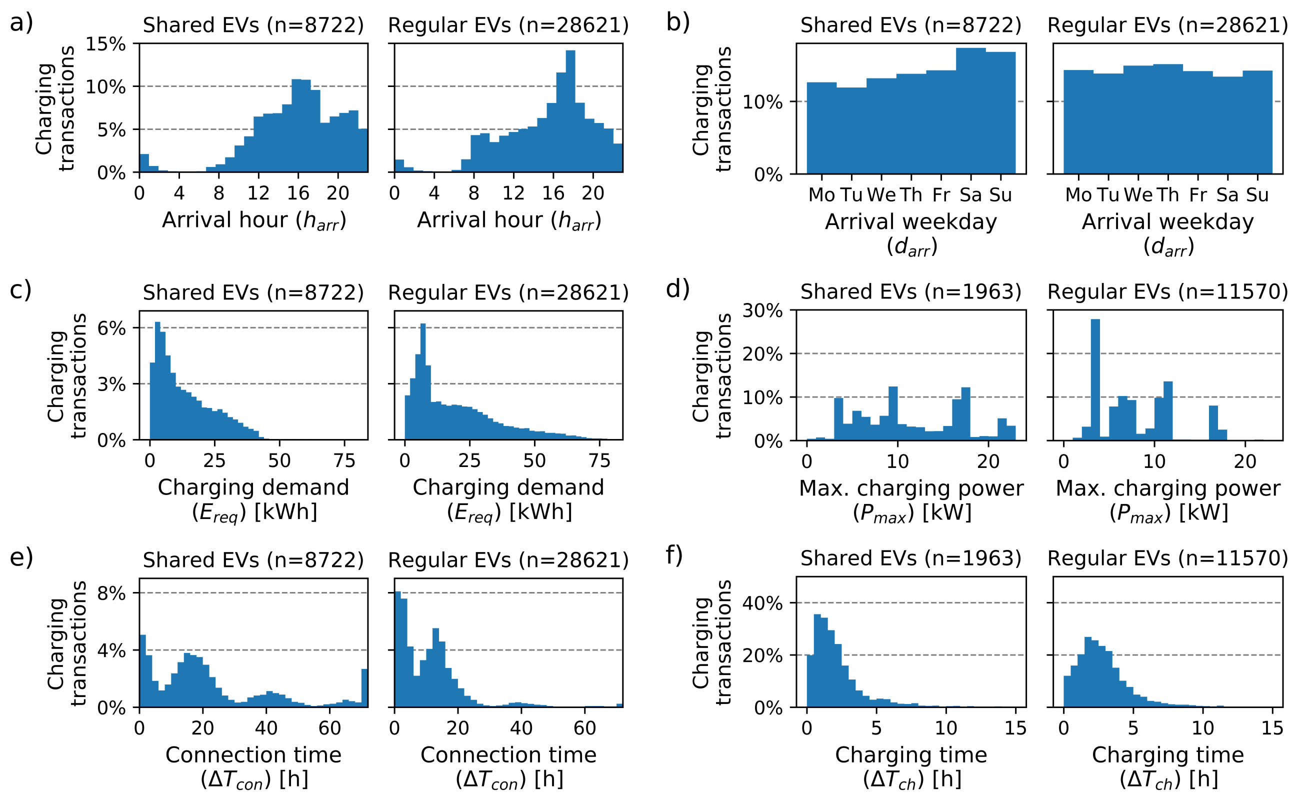

Fig. 1: Histograms comparing key charging characteristics of shared and regular EVs in the input data.

rural area in Italy have a probability of >50% of adopting a shared EV.

In some urban areas, the car sharing potential could be much higher. The large future role of car sharing in specific areas is highlighted by the recently published plans for the Merwede district in the city of Utrecht [20]. This to be developed neighborhood will become car-free, meaning that there are no parking spots available for private cars. One shared car will be available to every three households in the district.

TABLE II: Overview of annual EV charging demand of shared and regular EVs per scenario.

	Regular EVs	Shared EVs
Reference scenario	530 MWh	0 MWh
Scenario 1	450 MWh	64 MWh
Scenario 2	0 MWh	285 MWh
Scenario 3	132 MWh	214 MWh

Given this high ambiguity about the role of shared EVs in the future car fleet, this study distinguishes different scenarios for the adoption of shared EVs when determining the future grid impact of EV charging. All scenarios assume that the future car fleet is completely electrified. Each scenario identifies the annual charging demand of all regular and shared EVs in the investigated grid (E_{ann}). These values are used in section IV-B to simulate future charging transactions for both EV groups. Table II presents the assumed annual charging demand of all regular and shared EVs per scenario. The scenarios were generated as follows:

- *Reference scenario* - Shared EVs are not part of the car fleet in this scenario. The total annual charging demand of regular EVs is based on the average mileage per car of 13,000 km/year [21], a driving efficiency of 0.2 kWh/km and the car ownership ratio of 0.6 cars/household [22] in the city of Utrecht.
- *Scenario 1: Limited adoption of shared EVs* - Based on the literature study above, this scenario assumes that 15% of the car-owners adopt a shared EV, corresponding to a reduction in charging demand of regular EVs of 15%. Adoption of car sharing in the Netherlands leads to a reduction of vehicle kilometers travelled (VKT) of around 20% [23]. This has been considered when determining the charging demand of shared EVs.
- *Scenario 2: Only shared EVs* - This scenario is inspired by the newly-developed car-free districts and assumes one shared EV per three households. The average annual charging demand of a single *We Drive Solar* shared EV equals 2519 kWh. It is assumed that the usage of shared EVs in car-free districts is not considerably different than the current usage in other districts. This assumption implies that people living in this district will mostly commute using other means of transport.
- *Scenario 3: Mix of shared and regular EVs* - This scenario assumes 25% of the car owners are non-adopters of shared EVs, based on [14]. The charging demand of regular EVs equals 25% of the charging demand in the

reference scenario. The charging demand of shared EVs equals 75% of the charging demand in Scenario 2.

B. Generating Future EV Charging Transactions

Charging transactions for shared EVs and regular EVs are simulated for one year to obtain insight in EV charging behavior in the different scenarios. A new EV charging transaction $n \in \mathcal{N}$ is created until the total charging requirement of all simulated transactions of a specific category $j \in$ {Shared EV, Regular EV} ($E_{\text{req},n,j}$) equals the predetermined charging demand of all EVs of category j ($E_{\text{ann},j}$):

$$\sum_{n=1}^{N} E_{\text{req},n,j} = E_{\text{ann},j} \; \forall j. \tag{1}$$

The simulated charging transaction set is created using a probabilistic model which considers a set of historical charging transactions S_j for each EV category. In case the charging power over time is not logged at all charging stations, the subset $S_{\text{pl},j}$ of S_j is created with all charging transactions of which the charging power is logged. Charging transactions are simulated using the following steps:

1) The arrival day of the week of charging transaction n ($d_{\text{arr},n,j}$) is determined based on the probability density function of the arrival day of the week in S_j. Subsequently, this transaction is randomly assigned to a date with the specific weekday in the simulation period.
2) The arrival hour $h_{\text{arr},n,j}$ is determined using a probability density function of the arrival hours of all EVs charging transactions in S_j arriving at weekday $d_{\text{arr},n,j}$. The charging transaction is randomly assigned a starting minute in the arrival hour.
3) The required charging volume $E_{\text{req},n,j}$ and connection time to the charging station $\Delta T_{\text{con},n}$ are determined by randomly selecting a charging transaction from all EV charging transactions in S_j arriving at weekday $d_{\text{arr},n,j}$ and arriving at $h_{\text{arr},n,j}$. The charging volume and connection time of this specific charging transaction are assigned to the simulated charging transaction.
4) The average and maximum charging power ($P_{\text{av},n}$ and $P_{\text{max},n}$) of a simulated charging transaction are determined by using the charging power of a randomly selected charging transaction from all charging transactions in $S_{\text{pl},j}$ arriving at weekday $d_{\text{arr},n}$ and at hour $h_{\text{arr},n}$. If the condition in eq. 2 is not met, the steps to determine $P_{\text{av},n}$ and $P_{\text{max},n}$ are repeated:

$$P_{\text{av},n} \geq \frac{E_{\text{req},n,j}}{\Delta T_{\text{con},n}}. \tag{2}$$

If no transaction in $S_{\text{pl},j}$ arriving at weekday $d_{\text{arr},n}$ and at hour $h_{\text{arr},n}$ can meet this condition, $P_{\text{av},n}$ and $P_{\text{max},n}$ are determined using eq. 3:

$$P_{\text{av},n}, P_{\text{max},n} = \frac{E_{\text{req},n,j}}{\Delta T_{\text{con},n}}. \tag{3}$$

Since $S_{\text{pl},j} \leq S_j$, it can occur that there are no or a very limited number of transactions in $S_{\text{pl},j}$ arriving at weekday $d_{\text{arr},n}$ and at hour $h_{\text{arr},n}$. In that case, the set of charging transactions from which a transaction is randomly selected is expanded to all charging transactions arriving at hour $h_{\text{arr},n}$ for all weekdays if $d_{\text{arr},n}$ is a weekday, or all weekend days if $d_{\text{arr},n}$ is a weekend day.

V. Results

A. Charging Patterns

Fig. 2 compares the average EV charging power during week and weekend days for the four considered scenarios. Both in the Reference Scenario and Scenario 1 a charging demand peak occurs around 19:00 on weekdays, caused by EVs arriving home from work. Comparing the charging demand peak between both scenarios indicates that limited adoption of shared EVs reduces the average peak in charging demand on weekdays by 8%, due to a lower overall charging demand and a lower simultaneity in arrival hours in Scenario 1. The average overall charging demand on weekdays decreases from 1433 to 1366 kWh when transitioning from the Reference Scenario to Scenario 1. Despite the lower overall charging demand in Scenario 1, the average charging peak and overall charging demand in weekends are similar in both scenarios due to the large utilization of shared EVs in weekends.

A large scale transition towards shared EVs in Scenario 2 and 3 has substantial impact on the charging peak and overall charging demand on weekdays. The average charging peak on weekdays in Scenario 2 reduces by 75 kW compared to the Reference Scenario, while the average overall charging demand on weekdays reduces from 1433 to 681 kWh. A large share of the charging demand is shifted towards weekends with high adoption of shared EVs; the average overall charging demand on weekend days is 51% higher compared to weekdays in Scenario 2, while this is 4% in the Reference Scenario.

Charging demand peaks and overall charging demand are similar between Scenario 2 and 3, indicating that a limited share of regular EVs in the car fleet still leads to a considerable reduction in the peak charging demand compared to a scenario without shared EVs.

B. Charging Flexibility

TABLE III: Average share of charging demand that can be delayed for at least 6 and 12 hours at different moments of the day in each considered scenario.

	Ref. scenario		Scenario 1		Scenario 2		Scenario 3	
	>6h	>12h	>6h	>12h	>6h	>12h	>6h	>12h
00:00-06:00	24%	7%	26%	9%	45%	25%	35%	16%
06:00-12:00	9%	2%	10%	4%	25%	20%	15%	9%
12:00-18:00	20%	15%	22%	18%	35%	33%	30%	27%
18:00-24:00	36%	13%	37%	16%	47%	36%	43%	28%
Total	27%	11%	28%	14%	41%	31%	35%	24%

Flexibility in charging demand provides insight in the potential of EVs to provide ancillary services, as EVs have more room to alter their charging behavior to provide ancillary services with high charging flexibility. It can be expressed as the difference between the actual charging time ΔT_{ch} and the

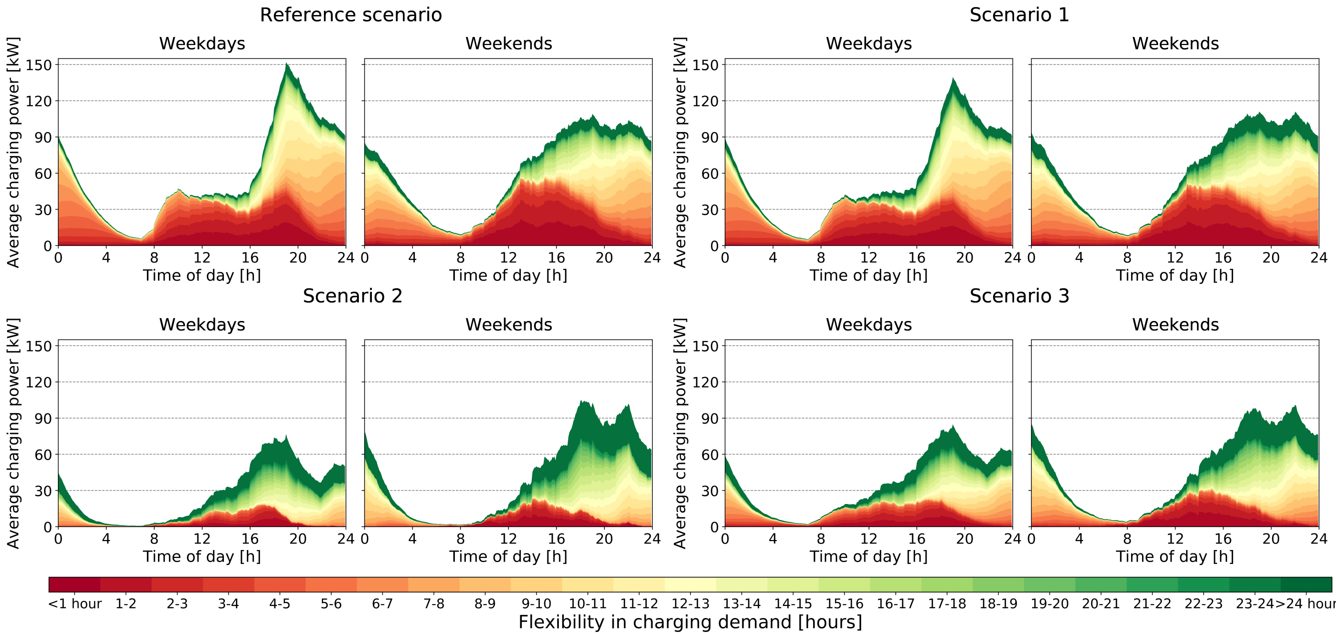

Fig. 2: Average charging power and average flexibility in EV charging demand on weekdays and weekend days in the studied LV grid for the four scenarios introduced in section IV-A.

connection time to the charging station ΔT_{con}, as introduced in [4]:

$$\Delta T_{\text{flex},n} = \Delta T_{\text{con},n} - \Delta T_{\text{ch},n}. \quad (4)$$

Table III and the colors in Figure 2 indicate that charging flexibility is generally high. In all considered scenarios, at least 27% of charging can be delayed with 6 hours or more, at least 11% of charging can be delayed with 12 hours or more, while only up to 12% of charging can be delayed with maximum one hour. EVs parking overnight cause that charging flexibility is highest during the charging demand peak in the evening. Flexibility in charging demand increases with a higher share of shared EVs in the car fleet. Since car sharing companies must guarantee availability of EVs to their customers, there will always be a slight overcapacity of EVs. This results in a high connection time of shared EVs in different cases (see Section III) leading to higher charging flexibility.

C. Grid Impact

Fig. 3 presents the transformer load in the investigated grid for each considered scenario. The grid load exceeds the transformer capacity for more than 2.5% of the year in all scenarios. Transformer congestion levels decrease with higher adoption of shared EVs, as this reduces the overall charging demand in the grid. The difference in transformer congestion levels is minor between the Reference Scenario and Scenario 1 (476 versus 446 hours/year). Large scale adoption of shared EVs can reduce the number of hours with transformer congestion with over 50%, with 235 hours/year of transformer congestion in Scenario 2 and 248 hours/year in Scenario 3.

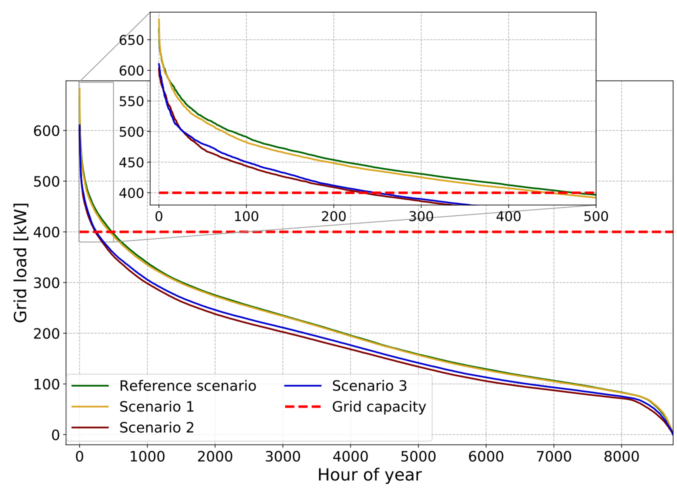

Fig. 3: Load duration curve of transformer load in the investigated grid for the four considered scenarios.

VI. Discussion

This study presented a generic method to use historical charging transactions to get insight in the future charging patterns of shared EVs. However, different methodological considerations should be taken into account when interpreting the results. With higher adoption of car sharing, the utilization of shared EVs could increase and different user groups could adopt shared EVs, potentially leading to different arrival times or to lower connection times. On the other hand, one can expect that there will always be an overcapacity in the number of shared EVs to guarantee availability of shared EVs to users, causing that flexibility values will remain similar in the future.

As there is uncertainty about the departure times of EVs in absence of perfect foresight and not all EV users will allow their EV to be used for the provision of ancillary services, the reported flexibility values will be lower in practice. Shared EVs can only be used through a reservation system, causing that the departure time of a shared EV is more predictable and that a larger share of the charging flexibility of shared EVs can be used for the provision of ancillary services.

Future developments, including increased charging at fast-charging stations or a transition towards autonomous transport or hydrogen vehicles, could reduce the overall charging demand in LV grids, lowering grid congestion levels. Similarly, these congestion levels are affected by different external factors, including the installed PV capacity and the integration of HPs in the grid.

An implication of this analysis is that DSOs can consider lower charging demand peaks in grids with a considerable share of shared EVs in the local car fleet. The high charging flexibility of shared EVs shows that grid operators and market parties should target shared EVs for the provision of ancillary services or for participation in electricity markets.

VII. Conclusions and Future Research

This study compared the charging behavior of EVs in a station-based car sharing scheme with the charging behavior of regular EVs to get insight in the future grid impact of EV charging with a transition towards car sharing. Results of the study indicated that adoption of shared EVs leads to lower EV charging peaks, since shared EVs show less simultaneity in arrival hours than regular EVs. The charging demand peak on week days decreases with 8% with limited adoption of shared EVs compared to a scenario without shared EVs, while the charging demand peak decreases with over 50% with high adoption of shared EVs. Consequentially, the number of hours with grid congestion decreases substantially with higher adoption of shared EVs. The potential of EVs to provide ancillary services is substantially higher with high adoption of shared EVs, in particular during the day, causing that a transition to shared EVs provides grid operators with more flexibility resources for the provision of ancillary services.

Future research could use more sophisticated models (e.g., activity-based models) to get more realistic insight in the utilization of shared EVs by new user groups. This allows for more detailed analyses in the charging behavior and grid impact of shared EVs with high adoption of car sharing. To be able to quantify the potential of shared EVs to provide ancillary services, charging optimization models for the provision of ancillary services should be applied to transaction data of shared EVs in future research.

References

[1] IEA, "Global EV Outlook 2019," Tech. Rep., 2019.

[2] Netherlands Enterprise Agency (RVO), "Statistics Electric Vehicles in the Netherlands (upto June 2019)," Tech. Rep. July, 2019.

[3] E. Ucer, M. C. Kisacikoglu, and A. Cafer Gurbuz, "Learning EV Integration Impact on a Low Voltage Distribution Grid," *IEEE Power and Energy Society General Meeting*, vol. 2018-Augus, pp. 1–5, 2018.

[4] M. K. Gerritsma, T. A. AlSkaif, H. A. Fidder, and W. G. van Sark, "Flexibility of Electric Vehicle Demand: Analysis of Measured Charging Data and Simulation for the Future," *World Electric Vehicle Journal*, vol. 10, no. 1, p. 14, 2019.

[5] S. Habib, M. Kamran, and U. Rashid, "Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks - A review," 2015.

[6] N. Brinkel, W. Schram, T. AlSkaif, I. Lampropoulos, and W. van Sark, "Should we reinforce the grid? Cost and emission optimization of electric vehicle charging under different transformer limits," *Applied Energy*, vol. 276, no. October, p. 115285, 2020.

[7] M. Raoofat, M. Saad, S. Lefebvre, D. Asber, H. Mehrjedri, and L. Lenoir, "Wind power smoothing using demand response of electric vehicles," *International Journal of Electrical Power and Energy Systems*, 2018.

[8] N. Brinkel, M. Gerritsma, T. AlSkaif, I. Lampropoulos, A. van Voorden, H. Fidder, and W. van Sark, "Impact of rapid PV fluctuations on power quality in the low-voltage grid and mitigation strategies using electric vehicles," *International Journal of Electrical Power & Energy Systems*, vol. 118, 2020.

[9] K. Frenken, "Political economies and environmental futures for the sharing economy," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 375, no. 2095, 2017.

[10] D. Wosskow, "Unlocking the sharing economy: An independent review," 2014, no. November, p. 43.

[11] S. A. Shaheen, N. D. Chan, and H. Micheaux, "One-way carsharing's evolution and operator perspectives from the Americas," *Transportation*, vol. 42, no. 3, pp. 519–536, 2015.

[12] S. Shaheen, A. Cohen, and M. Jaffee, "Innovative Mobility: Carsharing Outlook," Tech. Rep., 2018. [Online]. Available: http://innovativemobility.org/?project=innovative-mobility-carsharing-outlook-spring-2018

[13] F. Liao, E. Molin, H. Timmermans, and B. van Wee, *Carsharing: the impact of system characteristics on its potential to replace private car trips and reduce car ownership*. Springer US, 2018, vol. 47, no. 2.

[14] M. Namazu, D. MacKenzie, H. Zerriffi, and H. Dowlatabadi, "Is carsharing for everyone? Understanding the diffusion of carsharing services," *Transport Policy*, vol. 63, no. January, pp. 189–199, 2018.

[15] F. Zhou, Z. Zheng, J. Whitehead, R. Perrons, L. Page, and S. Washington, "Projected prevalence of car-sharing in four Asian-Pacific countries in 2030: What the experts think," *Transportation Research Part C: Emerging Technologies*, vol. 84, pp. 158–177, 2017.

[16] S. A. Shaheen and A. P. Cohen, "Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends," *International Journal of Sustainable Transportation*, vol. 7, no. 1, pp. 5–34, 2012.

[17] L. M. Martínez, G. H. d. A. Correia, F. Moura, and M. Mendes Lopes, "Insights into carsharing demand dynamics: Outputs of an agent-based model application to Lisbon, Portugal," *International Journal of Sustainable Transportation*, vol. 11, no. 2, pp. 148–159, 2017.

[18] S. Le Vine, M. Lee-Gosselin, A. Sivakumar, and J. Polak, "A new approach to predict the market and impacts of round-trip and point-to-point carsharing systems: Case study of London," *Transportation Research Part D: Transport and Environment*, vol. 32, pp. 218–229, 2014.

[19] L. Rotaris and R. Danielis, "The role for carsharing in medium to small-sized towns and in less-densely populated rural areas," *Transportation Research Part A: Policy and Practice*, vol. 115, no. August 2017, pp. 49–62, 2018. [Online]. Available: https://doi.org/10.1016/j.tra.2017.07.006

[20] Municipality of Utrecht, "Omgevingsvisie Merwedekanaalzone," Tech. Rep. december, 2018. [Online]. Available: https://www.utrecht.nl/fileadmin/uploads/documenten/bestuur-en-organisatie/beleid/omgevingsvisie/_deelgebied_Merwedekanaalzone/2018-03-MWKZ-Omgevingsvisie–deel-1-ruimtelijke-agenda_01.pdf

[21] CBS Statline, "Verkeersprestaties personenauto's; kilometers, brandstofsoort, grondgebied," 2019. [Online]. Available: https://www.cbs.nl/nl-nl/cijfers/detail/80428ned

[22] CBS Statline, "Kerncijfers buurten en wijken 2017," 2017. [Online]. Available: https://www.cbs.nl/nl-nl/maatwerk/2017/31/kerncijfers-wijken-en-buurten-2017

[23] H. Nijland and J. van Meerkerk, "Mobility and environmental impacts of car sharing in the Netherlands," *Environmental Innovation and Societal Transitions*, vol. 23, pp. 84–91, 2017.