Title
Emissions Benefits of Electric Vehicles in Uber and Lyft Services

Author
Jenn, Alan

Publication Date
2019-08-01

DOI
10.7922/G23R0R38

Emissions Benefits of Electric Vehicles in Uber and Lyft Services

August 2019

A Research Report from the National Center for Sustainable Transportation

Alan Jenn, University of California, Davis

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. NCST-UCD-RR-19-01	**2. Government Accession No.** N/A	**3. Recipient's Catalog No.** N/A
4. Title and Subtitle Emissions Benefits of Electric Vehicles in Uber and Lyft Services		**5. Report Date** August 2019
		6. Performing Organization Code N/A
7. Author(s) Alan Jenn, PhD, https://orcid.org/0000-0003-4232-0697		**8. Performing Organization Report No.** UCD-ITS-RR-19-08
9. Performing Organization Name and Address University of California, Davis Institute of Transportation Studies 1605 Tilia Street, Suite 100 Davis, CA 95616		**10. Work Unit No.** N/A
		11. Contract or Grant No. USDOT Grant 69A3551747114
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology 1200 New Jersey Avenue, SE, Washington, DC 20590		**13. Type of Report and Period Covered** Final Report (October 2017 – December 2018)
		14. Sponsoring Agency Code USDOT OST-R

15. Supplementary Notes
DOI:10.7922/G23R0R38

16. Abstract
Integrating electric vehicles (EVs) into vehicle fleets deployed by transportation network companies (TNCs; e.g., Uber and Lyft) is a particularly promising way to realize the benefits of vehicle electrification, due to the greater average miles traveled and passenger occupancy of TNC fleets. In this report, we examine EV use in TNC fleets from 2016 through 2018. We leverage novel datasets from TNCs as well as from charging service providers (e.g., Chargepoint and EVGo) to analyze charging and use patterns of EVs within TNC fleets. These insights allow us to quantify the emissions benefits of EV use within TNC fleets, assess the capability of EVs to perform TNC services, and understand the effects of EV use within TNC fleets on the charging behavior of non-TNC EVs. We find the emission benefits of electrifying a vehicle in a TNC fleet are nearly three times greater than the benefits from electrifying a privately-owned vehicle.

17. Key Words Electric vehicle, transportation network company, emissions, fleet, charging, electrification	**18. Distribution Statement** No restrictions.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 25	**22. Price** N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

NCST

About the National Center for Sustainable Transportation

The National Center for Sustainable Transportation is a consortium of leading universities committed to advancing an environmentally sustainable transportation system through cutting-edge research, direct policy engagement, and education of our future leaders. Consortium members include: University of California, Davis; University of California, Riverside; University of Southern California; California State University, Long Beach; Georgia Institute of Technology; and University of Vermont. More information can be found at: ncst.ucdavis.edu.

Disclaimer

Acknowledgments

This study was funded, partially or entirely, by a grant from the National Center for Sustainable Transportation (NCST), supported by USDOT through the University Transportation Centers program. The authors would like to thank the NCST and USDOT for their support of university-based research in transportation, and especially for the funding provided in support of this project.

Emissions Benefits of Electric Vehicles in Uber and Lyft Services

A National Center for Sustainable Transportation Research Report

August 2019

Alan Jenn, Institute of Transportation Studies, University of California, Davis

[page intentionally left blank]

TABLE OF CONTENTS

List of Figures

Emissions Benefits of Electric Vehicles in Uber and Lyft Services

EXECUTIVE SUMMARY

The use of electric vehicles (EVs) in fleets deployed by transportation network companies (TNCs; e.g., Uber and Lyft) has grown rapidly over the last few years. Coupling EVs with TNCs has enormous potential to mitigate greenhouse gas (GHG) emissions from the transportation sector. In this report, we leverage novel datasets from TNCs as well as from charging service providers (e.g., Chargepoint and EVGo) to analyze charging and use patterns of EVs within TNC fleets. We find that while growth of EV use has been rapid in the last two years, a proportionally small number of EVs use a large share of electricity provided by public charging infrastructure. We also find that concerns regarding the ability of EVs to provide the same level of service as gasoline vehicles have been overstated: we find no statistical difference in the capabilities of the two vehicle types to provide TNC services. Lastly, we find that the potential environmental benefits of TNC electrification are tremendously large. Our analysis suggests that in California, the emissions benefits of electrifying a vehicle in a TNC fleet are nearly three times greater than the benefits from electrifying a privately-owned vehicle.

Introduction

Transportation network companies (TNCs) such as Uber and Lyft are a relatively new type of transportation service provider. The general TNC business model is to leverage existing vehicle owners to provide rides through a peer-to-peer "sharing economy". TNC drivers earn money by providing rides for paying users, a portion of which goes to the parent companies. To date, Uber and Lyft have provided a combined 5.5 billion rides with over 50 million customers—a remarkably high figure given that these companies have been around for less than a decade.[1,2] The continued expansion of TNCs presents several opportunities for disruptive change in the transportation sector.

One transition that TNCs may help enable, is a cleaner vehicle fleet through the electrification of vehicles operating in their service. The benefits of the emissions reduction from plug-in electric vehicles (EVs) in TNCs is larger because vehicles driven for these services are driven significantly more than the average vehicle. Electrification can also make economic sense for TNC drivers since EVs cost less than gasoline-powered vehicles to operate and maintain (Pavlenko, Slowik, & Lutsey, 2019). While the up-front costs of purchasing an EV may discourage TNC electrification, emerging options allow drivers to rent shared or fleet vehicles to provide TNC services. For example, in January 2016, General Motors announced a new program called Maven following their acquisition of Sidecar, a TNC founded in 2011. Maven is a car-sharing company that allows its users to rent vehicles within their fleets.

In this study, we examine empirical data on EV use in TNC fleets such as Uber and Lyft. The data allows us to quantify the emissions benefits of EV use within TNC fleets, assess the capability of EVs to perform TNC services, and understand the effects of EV use within TNC fleets on the charging behavior of non-TNC EVs. The remainder of the report is structured as follows. We first briefly review existing studies on TNC electrification. We then present an overview of data and methods used in our analysis, followed by results, discussion, and conclusion.

Literature Review

The benefits of electrifying TNCs have been theoretically discussed in the literature, but there are no examples of empirical work examining its real-world impacts. As early as 2011, Kley et al. identified EVs in the context of products that could be leveraged in different types of mobility services such as "car sharing", "fleet concepts", or "transport services", despite the relative dearth of these services at the time. Kley et al. identify critical issues of charging infrastructure and technological limitations of electric drivetrains as two key obstacles facing the value proposition, value chain configuration, and revenue model of mobility-service electrification (Kley, Lerch, & Dallinger, 2011). This study laid the foundation for future studies investigating opportunities and challenges associated with electrifying emerging transportation modes. In

---

[1] https://expandedramblings.com/index.php/uber-statistics/
[2] https://expandedramblings.com/index.php/lyft-statistics/

2012, the Polytechnic University of Milan in the city of Milan, Italy launched “Green Move”, an EV sharing system, the details and design of which were documented in a peer-reviewed article (Lue, Colorni, Nocerino, & Paruscio, 2012). The project featured a smartphone-based, peer-to-peer approach to EV sharing. Unfortunately, the project was limited in size and duration: it comprised of only four EVs and ended in 2013. Nevertheless, the project was one of the earliest examples of EV use in new mobility services.

As both car-sharing and ride-hailing services have grown in popularity and size, there has been a corresponding increase in research on EVs in new mobility. However, the vast majority of studies have been focused on car-sharing services rather than ride-hailing services. Many studies have focused on optimizing operational aspects of car-sharing (Becker, Ciari, & Axhausen, 2018; Jacquillat & Zoepf, 2018; Mounce & Nelson, 2019; Wang, Liu, & Ma, 2019; Weikl & Bogenberger, 2015; Xu, Meng, & Liu, 2018; Brendel, Lichtenberg, Brauer, Nastjuk, & Kolbe, 2018). Other studies examine specific programs to provide insight into how EVs are being used in regions such as Chicago (Ai, Zheng, & Chen, 2018) and Germany (Burghard & Dutschke, 2019).

Discussion of EVs in ride-hailing is rarer. Clewlow and Mishra provide an overview of the shared mobility landscape as well as some of the associated impacts of these services (Clewlow & Mishra, 2017). Jenn et al. discuss how exposure to EVs through TNCs can encourage EV adoption more broadly (Jenn, Laberteaux, & Clewlow, 2018). Cassetta et al. demonstrate that EVs and new mobility services (including ride-hailing and car-sharing) have expanded simultaneously, though they do not consider integration of the two developments (Cassetta, Marra, Pozzi, & Antonelli, 2017). Jittrapirom et al. reveal a potentially interesting demand-based incentive for EVs via preferential modes based on cost, time, and CO_2 footprint (specifically from the WienMobil Lab in Vienna, Austria). This incentive favors EVs due to their relative cleanliness (Jittrapirom, et al., 2017). Sarasini and Linder find that linking EVs with new mobility services is a valuable strategy for implementing climate policies that seek to promote low-carbon technologies. The authors also point out that operators of such services are more likely to make vehicle-purchasing decisions based on total cost of ownership. Hence new mobility service drivers are generally more amenable to using EVs which typically have lower marginal costs than conventional vehicles (Sarasini & Linder, 2018). Lastly, Sprei discusses the potential of combining electrification and shared mobility alongside automation. Specifically, Sprei points to the need for regulation to maintain the correct trajectory and ensure that the proper outcomes are met given these large revolutions in the transportation sector (Sprei, 2018).

The topic of electric ride-share is still rather sparse in the existing literature: the remaining studies in this literature review focus primarily on new mobility services that have identified potential for electric vehicles to grow within this realm. The focus of a 2014 study by Barth and Shaheen note that incorporating hybrid and electric vehicles into new mobility services could provide large benefits for costs and emissions. In particular, they point out that the California Air Resources Board (CARB) has an intrinsic interest to link EV technology and demand-management strategies through shared-use vehicle systems (Barth & Shaheen, 2014). Jalali et al. attempt to quantify the potential decrease in emissions (carbon, particulates, and ozone) that could result if ride-sharing were used to replace personal vehicles in Changsha, China. Using big data analytics and machine-learning algorithms, they suggest that ride-sharing could reduce travel intensity by up to 24%, reducing CO_2 emissions by four tons daily (Jalali, Koohi-Fayegh, El-Khatib, Hoornweg, & Li, 2017). The Jalali et al. study is the only study in current literature that quantifies the synergistic emission outcomes from electrifying ride-sharing vehicles. However, the study's conclusions are based strictly on modeled result and may not represent reality if electric ride-share were introduced into Changsha.

There is a gap in the literature when it comes to using empirical evidence to measure the impacts of combining shared mobility services, particularly ride-hailing services, with vehicle electrification. The analysis presented in this study is the first to provide real-world insight into the implications of EV use in TNC services such as Uber and Lyft. Our analysis includes quantifying the travel intensity and energy demand of EVs being used for these services within California. We also measure the comparative emissions savings from EV use in shared fleets relative to EV use among private vehicle owners, as well as the associated charging infrastructure implications from higher-intensity EV usage in shared mobility services.

Data and Methods

Our analysis relies on several high-resolution datasets comprising over 12 million separate charging events within two of the largest DC fast charging network providers: EVGo and Chargepoint, as well as a number of smaller independent charging providers from 2014 to 2018. The data cover more than 87% of all non-Tesla DC fast charging stations in California. Most of these stations operate at approximately 50 kW rated power output, though some operate at as low as 20 kW. The data include the timing and amount of energy transferred, which are key parameters for measuring the emissions associated with EV charging.

Our analysis also draws on over 1.4 million rides provided by EVs operating in TNC services from July 2016 through April 2018. These trips provide insights on the travel behavior of EVs being driven both part- and full-time for companies such as Uber and Lyft. We are able to observe fourteen full battery-electric vehicle (BEV) models and seven plug-in hybrid electric vehicle models being driven for these services. The dataset contains distances of each trip provided, which enables us to characterize the travel demand related to EV use in TNC services.

The combination of charging data and travel demand data from TNC trips allows us to characterize the emissions related to electric vehicle use in these services. We are able to compare the electric vehicle use to a counterfactual world where all TNC drivers using EVs would have used gasoline-powered vehicles instead. Our approach is explained further in the following section.

Counterfactual Emissions Calculator

We calculate the greenhouse gas (GHG) emissions associated with each of the charging events from the charging data data, which enables us to understand the impact of electrifying ride-hailing services on reducing emissions. The emissions are calculated as follows:

$$emissions_i = kWh_{it} \times gridEmissions_t \tag{1}$$

where *i* is an index for each individual observation, *t* represents an hourly time index, and each *i* has a corresponding element in *t*. The *gridEmissions* parameter values are derived from the California Independent System Operator (ISO)'s historical hourly load data and corresponding hourly emissions data from 2014 through 2018. The values are obtained by dividing load by the emissions to provide an emissions rate [kg CO_2/MWh]. These values provide the average hourly emissions for the grid across the full span of charging and TNC trip data. We find that the hourly emissions rate ranges from 270–350 g CO_2/kWh during nighttime hours (6:00 p.m. to 6:00 a.m.) and drops to 150–200 g CO_2/kWh during daytime hours (6:00 a.m. to 6:00 p.m.). Values for the *kWh* parameter are obtained directly from the charging dataset.

We can also estimate the counterfactual emission savings from electrifying the ride-hailing vehicles. Because drivers can actually use gasoline vehicles in the TNC service, it is not unreasonable to assume that the service they would have provided and the travel intensity of those vehicles would not be drastically different from the electric vehicles being used in TNCs. In fact, we observe in our data that the service provisions between electric vehicles and gasoline vehicles in TNCs are identical in terms of miles travelled and number of trips provided in a given day. However, it is important to note that some of the travel behavior would likely differ because gasoline vehicles would not have to travel to charge their vehicles (though they would need to drive to gas stations), this is not something we observe in our data. The emission savings of replacing a gasoline-powered vehicle in a TNC fleet with an EV can be calculated by taking the difference between the emissions associated with EV charging (calculated using Equation (1)) with the theoretical emissions generated associated with operation of a gasoline-powered vehicle. This calculation is:

$$em.savings_i = kWh_i \left(\frac{em.rate^{\mathrm{Gas}}}{efficiency^{\mathrm{PEV}} \cdot MPG} - gridEmissions_t \right) \tag{2}$$

The EVs in our analysis are assumed to have an $efficiency^{\mathrm{PEV}}$ value of 28 kWh per 100 miles (the miles-weighted average efficiency of electric vehicles in our data using EPA efficiency labels). The *MPG* parameter for the theoretical gasoline-powered vehicle is calculated at 29.4, based on distance-weighted fuel efficiency of a representative sample of gasoline-powered vehicles serving TNCs. Note that vehicles in ride-sharing services are generally more fuel efficient than average vehicles. We use EPA values for the emissions rate of gasoline vehicles, $em.rate^{\mathrm{Gas}}$, of 8,887 g CO_2/gallon.[3]

[3] https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

We also consider the savings from switching an ordinary gasoline vehicle (not involved in ride-hailing services) to understand the relative emission savings for targeted EV adoption policy. The process to calculate the emissions can be seen below in Eq. (3)–(5).

$$emissions_j^{\mathrm{ord.gas}} = \frac{em.rate^{\mathrm{Gas}} \cdot VMT_j}{MPG} \tag{3}$$

$$emissions_j^{\mathrm{ord.PEV}} = VMT_j \cdot efficiency^{\mathrm{PEV}} \cdot gridEmissions_t \tag{4}$$

$$em.savings_j^{\mathrm{ord}} = emissions_j^{\mathrm{ord.gas}} - emissions_j^{\mathrm{ord.PEV}} \tag{5}$$

The set *j* describes the index for individual observations of travel behavior from a separate dataset: the California Household Transportation Survey.[4] We focus primarily on estimating emissions savings as a bounding exercise, particularly related to the emission savings from the TNC electrification, and therefore estimate an optimistic scenario for the emission savings from switching a regular (non-ride hailing service) vehicle to an electric vehicle ($em.savings^{\mathrm{ord}}$). Therefore, the *MPG* parameter is assumed to be 27 MPG (approximately the average for privately owned gasoline-powered vehicles in California) and the *gridEmissions* parameter is assumed to be 186 g CO_2/kWh, the lowest average emissions rate as calculated using the CAISO data.

Characterizing the Use of Electric Vehicles in TNCs

We begin our analysis by comparing travel behavior between privately owned EVs and gasoline-powered vehicles in California with travel behavior of EVs in TNC services in California. Figure 1 displays the distribution of daily miles traveled for several groups of vehicles in California. For the average driver (non-TNC), gasoline vehicles tend to drive slightly more than their electric vehicle counterparts. For a comparison against conventional gasoline vehicles, we employed the California Household Travel Survey and for ordinary electric vehicles we employed the Plug-in Hybrid & Electric Vehicle (PH&EV) multi-year panel survey of over 14,000 respondents to derive a generalized profile of electric vehicle travel patterns. While the difference between ICVs and PHEVs is relatively small, both outpace short-range and long-range BEVs. However, we find EV TNC travel behavior is significantly higher than typical vehicles in California by at least a factor of two. We observe a drastically different distribution of mileage traveled by everyday vehicles (whether gasoline or electric) and those within the TNC fleet.

Two types of TNC vehicles are represented in Figure 1. The “TNC (single service)” distribution is derived from over 400,000 trips provided by BEVs for one TNC service. It is highly likely that this distribution is an underrepresentation of the total daily miles traveled because most vehicles drive for more than one TNC service. The “TNC (full-time)” can alternatively be considered an upper-bound of TNC travel: the distribution is constructed from a set of over 1,000 vehicles that

[4] https://www.nrel.gov/transportation/secure-transportation-data/tsdc-california-travel-survey.html

are known to be driving full-time (as their primary occupation) and contain the comprehensive travel for both Uber and Lyft services.

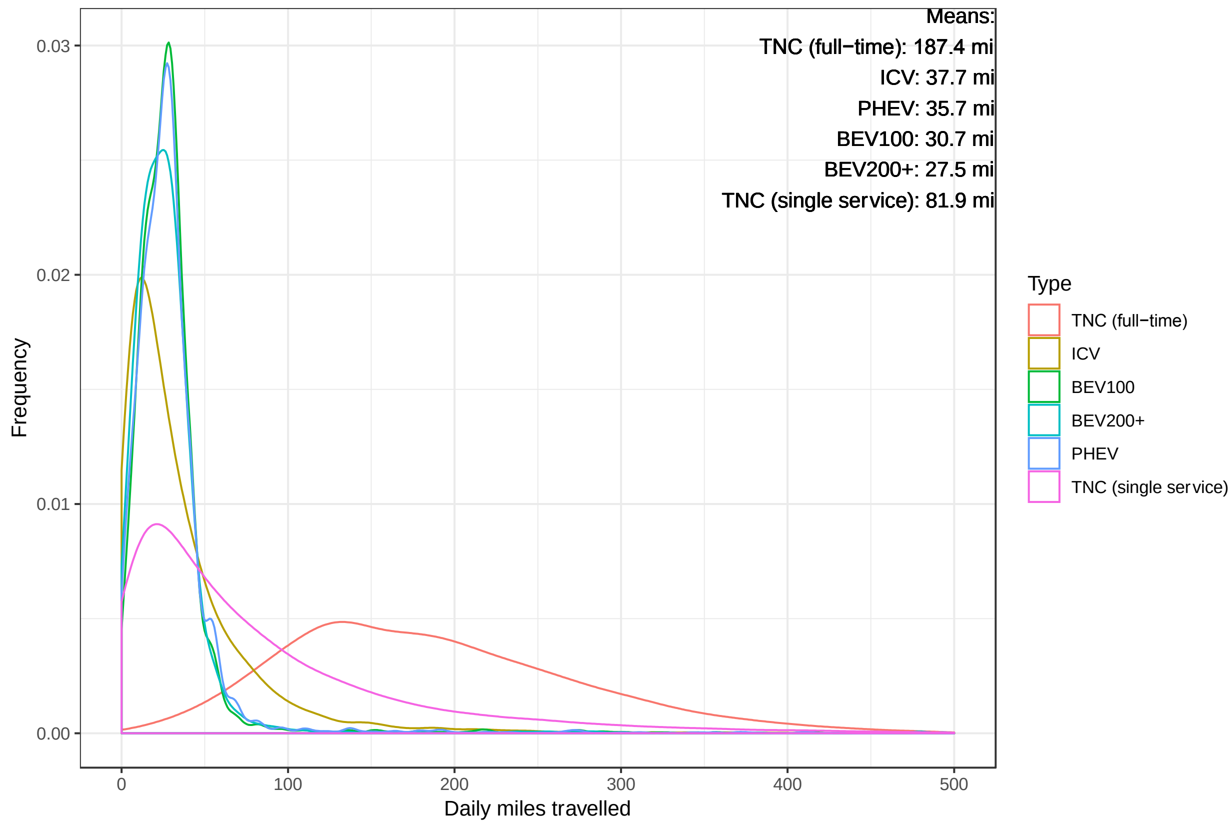

Figure 1. A comparison of average daily travel behavior in California. Comparison by gasoline vehicles (California Household Transportation Survey), plug-in hybrids, short and long-range battery electric vehicles (UC Davis Plug-in Hybrid & Electric Vehicle center survey [n=14,500]) compared to TNC electric vehicles. The "TNC (single service)" are compiled from a set of over 400,000 BEV trips from a single TNC, this distribution is likely an underestimate of the daily distance because the BEVs are likely driving for more than one service. The "TNC (full time)" consist of a subset of over 1,000 BEVs that are known to be full-time drivers and contain trips for both Uber and Lyft services.

One of the primary concerns of BEV use in TNC services is that the limited range of the electric vehicle will prevent the vehicles from being used in the same manner as gasoline vehicles. In addition, traveling to charging stations and the length of time required to charge BEVs being used for ride-hailing may also detract from drivers' ability to provide the same length of service as a gasoline vehicle. Surprisingly, we find that electric vehicles actually provide the same level of service in terms of number of rides and distances of trips every day. The distributions of daily distances in Figure 2 are compared using a Kolmogorov-Smirnoff test and are revealed to be statistically identical. Though we are confident in similarity of service by amount, we do not rule out possible differences in where the services are provided. For example, rather following the spatial distribution of service provided by gasoline vehicles, it is possible that BEV services are clustered around accessible charging stations.

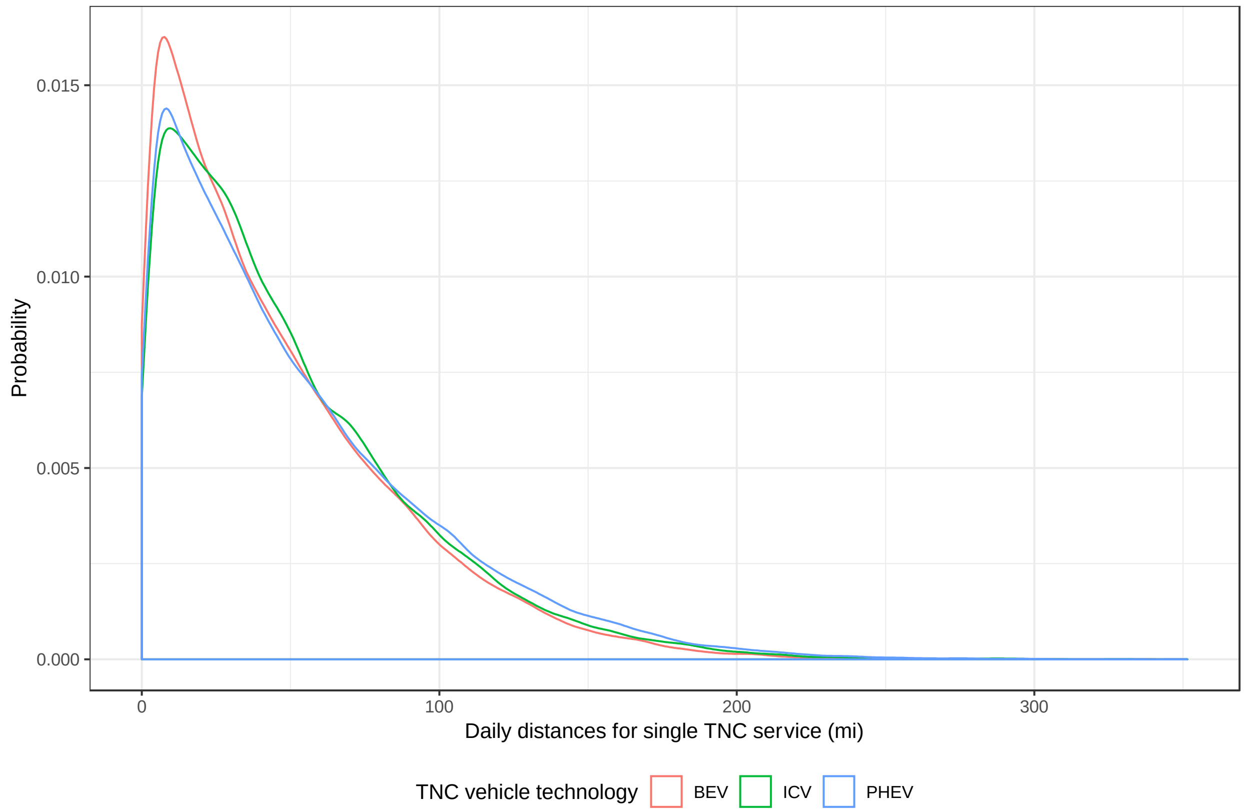

Figure 2. Comparison of daily distribution of travel behavior. Values by Lyft ICVs (n=928 vehicles and 395,212 trips), PHEVs (n=1,664 vehicles and 600,193 trips), and BEVs (n=1,736 vehicles and 427,624 trips). A Kolmogorov-Smirnov test provides statistical evidence that the distributions are the same.

EVs serving TNCs account for a relatively small fraction of California's EV fleet, but a disproportionately high demand for publicly accessible chargers. The growth and utilization of electric vehicles—particularly Chevrolet Bolts, in TNC services has been explosive, especially since the introduction of the model in early 2017 the vehicles have continually grown in energy demand as seen in Figure 3. Since 2014, we track approximately 105,000 unique vehicles charging at DC fast charging stations (representing a little less than half of the total number of full electric vehicles in California) while the current number of trackable TNC operating vehicles stations numbers at just over 1,000 unique vehicles at the end of May 2018. While these TNC vehicles represent less than 0.5% of the electric vehicles in California, the charging demand from this service is 30% of the total energy demand for the remaining electric vehicles (in other words, the tracked TNC vehicles have *sixty* times the energy demand of other electric vehicles).

Figure 3. Weekly charging demand of EVs serving TNCs from August 2016 through October 2018 in San Diego, Los Angeles, and San Francisco. The "Combined" line is an underestimate of total charging: plug-in hybrid electric vehicle charging demand is not included, nor does this include all ride-hailing services (combined ends early as the TNC data is only available through April 2018). The "DC Fast (known)" also represents known full-time drivers of TNC services. By October 2018, the charging demand for DC fast represents nearly 35% of non-Tesla fast charging demand. The plot includes data from 1,240 charging locations in California (out of a total of 1,413 locations statewide), including locations owned and operated by several different charging network providers. There is currently no explanation for the dips in demand, which are observed in the data.

From the beginning of 2017, the charging demand grew by approximately 10-fold in size over a span of 9 months followed by another 5-fold growth over the next 6 months. The continuous rapid growth speaks to a critical challenge for both the TNC services and charging service providers to enable electrification. It should also be noted that the location of the chargers corresponds relatively closely with the dense urban areas with high demand for ride-hailing services, but not all stations are necessarily being employed for charging TNC service vehicles. Careful consideration should be made for the location-based demand of the ride-hailing services and finding corresponding charging locations in order to minimize deadheading (movement of service vehicles in non-revenue mode) related to charging the vehicles.

In Figure 4, we display the amount of energy charging requirements for TNC vehicles compared to "regular" electric vehicles in California. We observe a very different distribution of charging patterns between the two types of vehicles. The charging demand from TNC vehicles is relatively uniform from 0 kWh up to 40 kWh. While the average charging event for these vehicles is around 20 kWh (approximately 60–70 miles in range), these vehicles are visiting charging stations on average 2.5 times a day while other unique electric vehicles visit DC fast charging stations on average once every 2 weeks. This means that despite the range "limitation" of electric vehicles, we observe that these TNC service vehicles are regularly traveling to and exceeding this mileage on a daily basis. This stands in comparison to ordinary electric vehicles that are charging on average 11 kWh during a fast-charging session. There is a unique spike in the ordinary vehicle distributions that is the result of certain restrictions on the length of charging to 30 minutes.

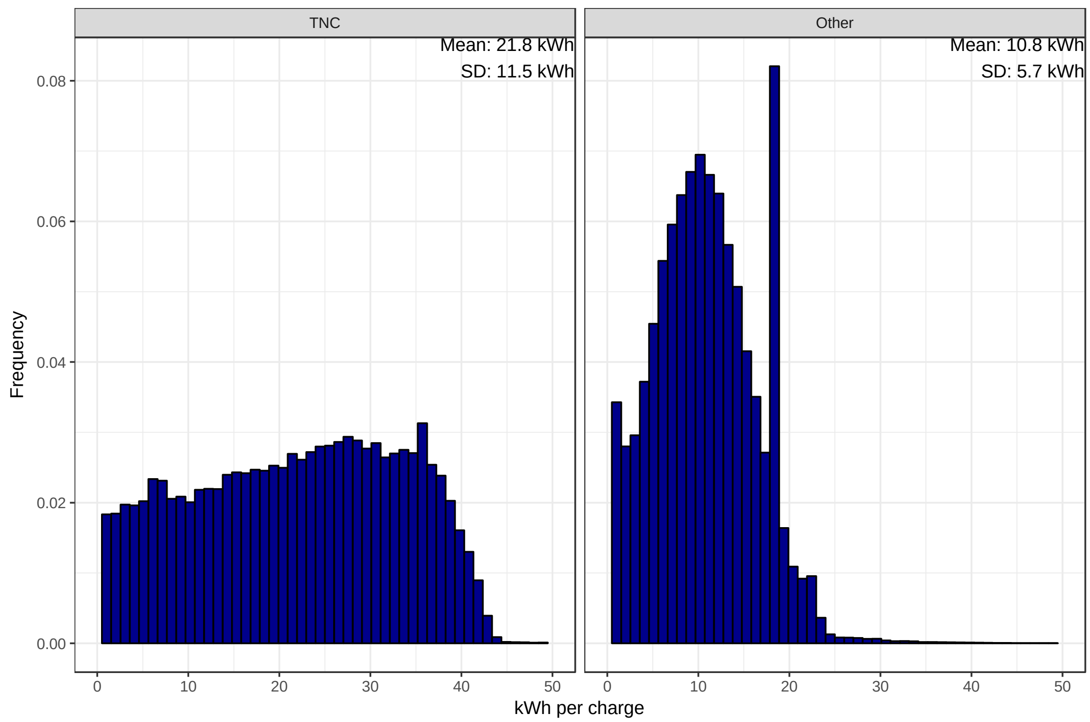

Figure 4. Distribution illustrating the amounts of energy used per charging event for TNC and non-TNC ("Other") EVs in California. The distribution is much more uniform for TNC EVs than for non-TNC EVs and exhibits a higher average as well: TNC EVs use an average of 21.8 kWh per charge while non-TNC EVs use only 10.8 kWh per charge. The spike in the "Other" vehicles can be attributed to restrictions limiting cars to 30 minutes of charging.

The charging patterns of TNC vehicles are also noticeably different from the DC fast charging patterns of other electric vehicles. Since the DC fast chargers are all public infrastructure (as opposed to being available at home locations), we observe negligible charging events for regular EVs occurring between the hours of around 3:00 a.m. to 8:00 a.m. However, for the TNC EVs, we still observe a relatively high proportion of charging events happening over this same time-period. TNC vehicles also have a dip in charging between the hours of 6:00 p.m. to 8:00 p.m., likely due to increased demand for ride-hailing services at that time whereas this time period is actually the highest peak for observed charging behavior among regular EVs. Interestingly enough, there is a slight difference in the distributions by region. In particular, San Diego has two peaks during these hours for TNC vehicles (at 5:00 a.m. and 8:00 a.m.) which are not observed in the other regions. Additionally, for ordinary electric vehicles in San Diego there are a continued upwards trend in charging starting at 7:00 a.m. through 3:00 p.m. while there is a noticeable flattening in both Los Angeles and San Francisco after 10:00 a.m. Upon closer inspection, we do find that some of these abnormalities are due to a relatively small volume of vehicles having a distinct impact on the load shape. While the number of events is still high (in the thousands), the charging pattern observed in San Diego can be attributed to a handful of vehicles. In the latter months, once more vehicles are observed in the charging dataset, the load shape pattern is much more similar to Los Angeles and San Francisco.

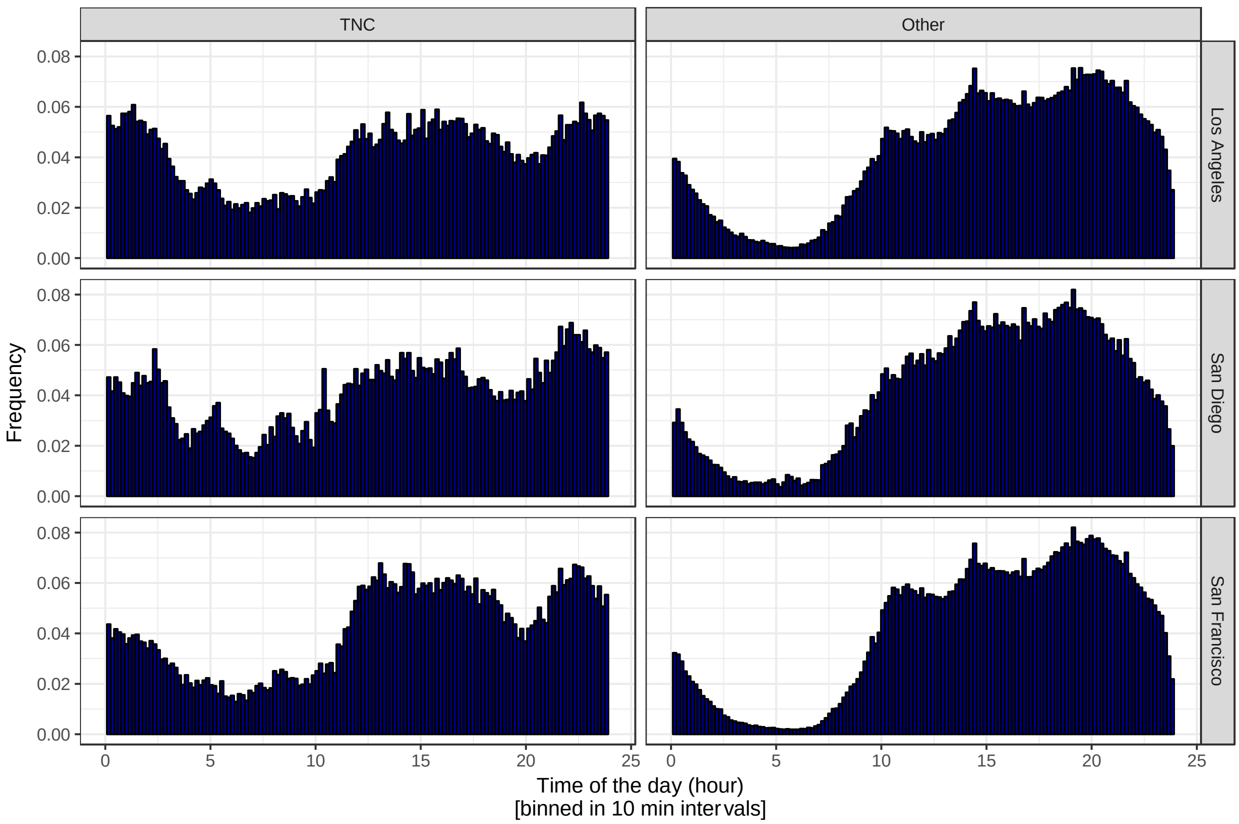

Figure 5. A histogram of time of day that charging occurs for TNC vehicles and for other electric vehicles in San Diego, Los Angeles, and San Francisco. In comparison to regular electric vehicles, there is a significantly higher frequency of charging events occurring between midnight and 8:00 a.m. In particular, there appear to be two peaks in San Diego for TNC EV drivers, one at 5:00 a.m. and one at 8:00 a.m. Additionally, there is a dip in charging for TNC drivers at around 6:00 p.m. to 8:00 p.m., likely due to higher demand for ride-sharing services at the time, which is contrary to regular EVs where this time period is the highest for charging events.

The overview from the charging event data provides a number of interesting insights into the differences between electric vehicles providing services for ride-hailing programs (such as the Chevrolet Bolts) and regular electric vehicles. The travel intensity of TNC EVs is striking and points to a need for greater charging infrastructure to help manage the energy demand from these vehicles.

Emissions Implications of EVs Driving for Uber and Lyft

We can calculate the associated emissions for each charging event based on the amount of energy demand and the time of the event. The upstream emissions resulting from plugging in an electric vehicle depends on the time of charging because different power plants are responding to increase in charging demand at different times of the day. We calculate the average marginal emissions in California on an hourly basis from the California Independent System Operator Greenhouse Gas Emission Tracking Reports[5] that allow us to understand how clean/dirty the electric grid is at different times of the day. Due to the high availability of solar power, the emissions during the day are lower than the nighttime emissions, though California as a whole has a relatively cleaner grid compared to the remainder of the United States.

In Figure 6, we provide a complete display of the emissions associated with every charging event for TNC PEVs from January 2017 through May 2018. The vertical variation is a result of differences in grid emissions at different times of the day. There are two distinct bands for the points that are a result of the relatively different emission rates of the electric grid at daytime and night time. The horizontal variation is a result of longer EV travel distances from the electric vehicles that lead to larger energy demand.

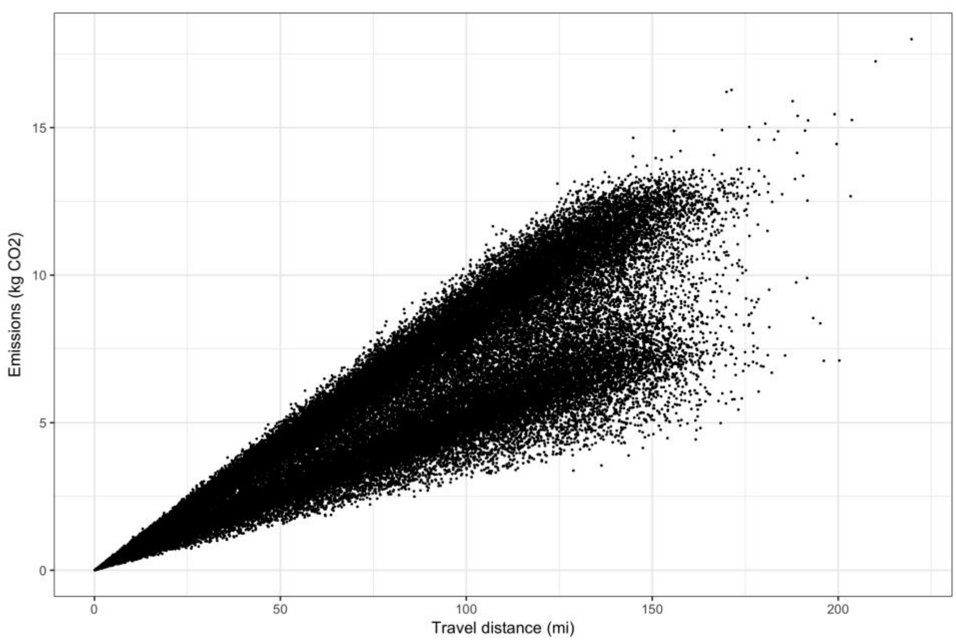

Figure 6. The emissions associated with every observable TNC charging event from January 2017 through May 2018. The emissions are a function of the average hourly marginal emissions in California at the time associated with the charging event as well as the total charging amount. There are two relatively distinct bands resulting from the bimodal daytime and nighttime emissions factors in California.

[5] http://www.caiso.com/TodaysOutlook/Pages/Emissions.aspx

How much emissions have been saved from the use of EVs in ride-hailing services? If we assume that the EVs were all instead relatively fuel-efficient gasoline vehicles (35 MPG), we can calculate the difference in emissions across all miles traveled as captured by the charging infrastructure (left panel, Figure 7). The daily emission savings averages at 38.7 kg of CO_2 for electrifying the ride-hailing service. Across all ~1,000 BEVs from the beginning of 2017 through May 2018, this has resulted in a total savings of 1,142 tons of CO_2, the equivalent of removing approximately 260 gasoline vehicles off the road (note that this is true unless the electric vehicles themselves change the demand for ride-hailing services). When we compare these savings against replacing average gasoline vehicles (not in ride-hailing services) with electric vehicles, the emissions reductions are nearly three times lower (right panel, Figure 7).

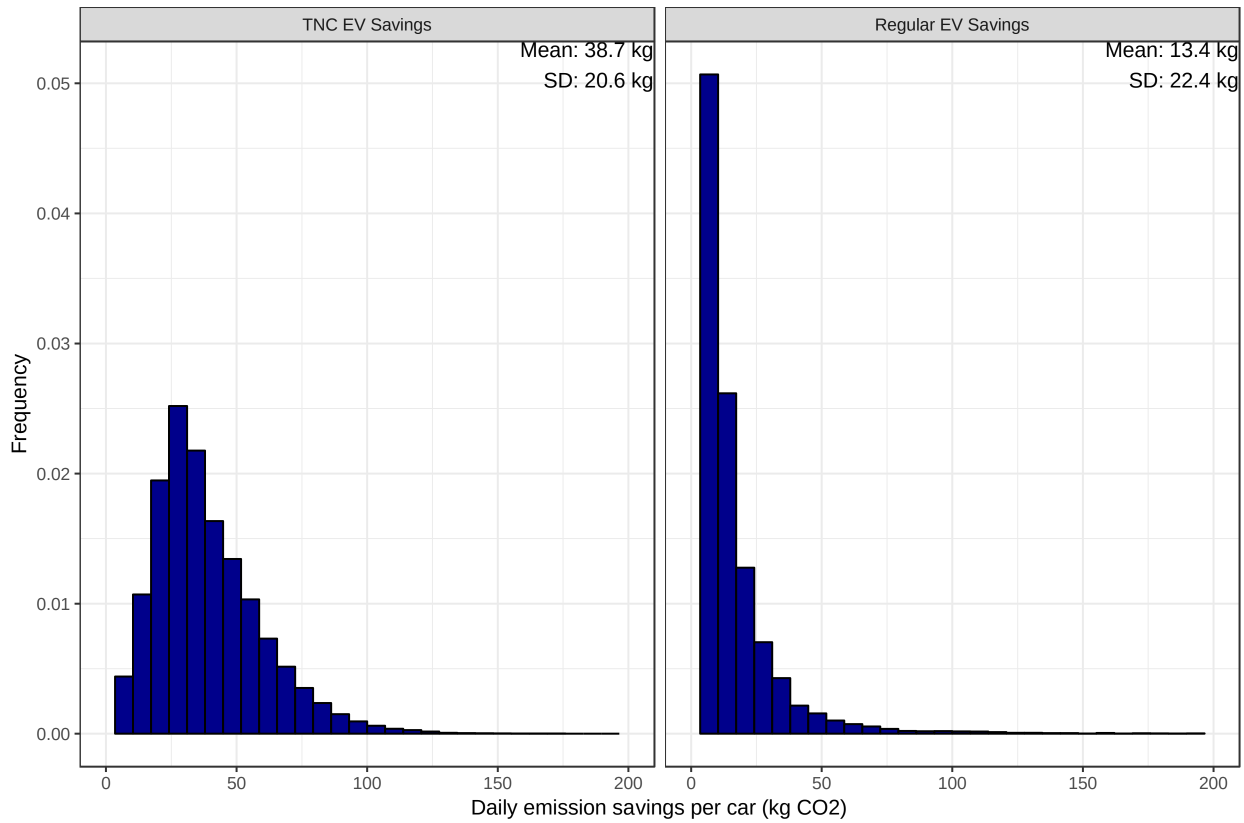

Figure 7. A histogram of the comparative emission savings. The left histogram is for switching a ride-hailing vehicle from a gasoline vehicle (29.4 MPG average in ride-hailing fleet) to an electric vehicle (28 kWh/100 mi average in ride-hailing fleet). The right histogram is for switching an average gasoline vehicle in California (assuming 27 MPG) to a comparable electric vehicle in the TNC fleet. We find the emissions savings to be nearly three times higher for electrifying ride-share versus electrifying the average California driver.

Discussion and Policy Implications

EV use in TNC services has grown rapidly over the last year and a half and there is still tremendous potential for further expansion. Understanding the impacts of coupling EVs and TNCs is key: the ramifications of this new vehicle technology coupled with new mobility options, such as Lyft and Uber, is critical to transportation planning and policymaking. Our analysis indicates that TNC electrification could yield large benefits in the form of emissions reductions. But charging infrastructure will need to be upgraded and expanded in order to fully realize these benefits.

Because vehicles serving TNCs exhibit much greater average daily mileage than non-TNC (i.e., privately owned) vehicles, electrifying the former yields greater emissions reductions (on a per-vehicle basis) than electrifying the latter. We find that in California, using an EV in lieu of a gasoline-powered vehicle to provide full-time TNC service reduces CO_2 emissions by nearly 40 kg/car/day. This is nearly three times the emissions reductions achieved by replacing a privately-owned gasoline-powered vehicle with an EV. There is hence strong reason for policies promoting vehicle electrification to prioritize electrification of TNC fleets.

A common concern related to TNC electrification is that range limitations could prevent EVs from providing adequate TNC service. Our analysis indicates that range limitations are not an issue: there is no distinguishable difference between gas and electric cars driving for TNCs. The data show that in California, TNC EVs drive more than 190 miles per day on average (compared to an average of 20–30 miles per day for a typical non-TNC driver) and more than 300 miles a day in several instances. These figures are comparable to the mileage covered by gasoline-powered vehicles serving TNCs, and indicate that range concerns need not prevent TNC drivers from adopting EVs.

Although TNC EVs comprise a relatively small fraction of the overall EV fleet in California, they account for a disproportionately high share of public charging demand. The higher travel intensity of TNC EVs necessitates more frequent charging and/or more energy demanded per charging event. This means that TNCs need to rely more heavily on public charging stations. Deployment of additional public chargers will help support TNC electrification in new geographic areas and will ensure that TNC charging demand does not make it overly difficult for private vehicle owners to access public chargers.

As policymakers and planners consider options for improving charging infrastructure, it will be important to keep in mind temporal differences between TNC and non-TNC charging demand. Use of public chargers by non-TNC EVs is negligible during nighttime hours (when most drivers are at home), ramps up in the morning, and hits a peak between 6:00 p.m. and 8:00 p.m. By contrast, use of public chargers by TNC EVs is more evenly dispersed. Use of public chargers by TNC EVs is low but not negligible during nighttime hours, and moderately high from about 12:00 p.m. to midnight. Use dips between 6:00 p.m. and 8:00 p.m.—presumably because this time period coincides with the period of highest demand for TNC-provided rides.

Additional analysis reveals that when controlling for location and natural growth in charger usage, regular users have substantially reduced usage of the charging network on average 25% during the time period after the TNC PEV growth period. The associated change in charging behavior of other electric vehicles along with the extreme requirements for charging PEVs in TNCs is an important indication that infrastructure installation, use, and management will be critical aspects to the success of electrification of these services.

It is also important for policymakers to weigh the pros and cons of providing free or subsidized public charging. Continued availability of free chargers will do much to encourage TNCs and TNC drivers to go electric but may not be economically feasible at a large scale, especially given the outsize per-vehicle charging demand of TNC fleets. Further analysis is needed to determine the extent to which limiting free or subsidized charging would discourage EV adoption among TNCs.

This study is one of the first empirical studies of EVs in TNCs—and it certainly should not be the last. Much additional work needs to be done to characterize the relationship between vehicle electrification and ride-sharing/-hailing. We suggest prioritizing investigation into the following topics (though we note that this list is not comprehensive):

- Geospatial differences in travel patterns between EVs and gasoline-powered vehicles, especially with an eye towards optimal charger siting.
- Projections of growth in TNC electrification under different scenarios, and assessment of associated charging-infrastructure needs.
- Viable adoption and usage strategies, e.g., special incentives for EV TNCs.
- Policy support mechanisms to ensure beneficial outcomes for industry and society at large.

References

Ai, N., Zheng, J., & Chen, X. (2018). Electric vehicle park-charge-ride programs: A planning framework and case study in Chicago. *Transportation Research Part D: Transport and Environment, 59*, 433–450.

Barth, M., & Shaheen, S. A. (2014). Shared-Use Vehicle Systems: Framework for Classifying Carsharing, Station Cars, and Combined Approaches. *Transportation Research Record, 1791*, 105–112.

Becker, H., Ciari, F., & Axhausen, K. W. (2018). Measuring the car ownership impact of free-floating car-sharing - A case study in Basel, Switzerland. *Transportation Research Part D: Transport and Environment, 65*, 51–62.

Bergman, N., Schwanen, T., & Sovacool, B. K. (2017). Imagined people, behaviour and future mobility: Insights from visions of electric vehicles and car clubs in the United Kingdom. *Transport Policy, 59*, 165–173.

Bohnsack, R., Pinkse, J., & Kolk, A. (2014). Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles. *Research Policy, 43*(2), 284–300.

Brand, C., Cluzel, C., & Anable, J. (2017). Modeling the uptake of plug-in vehicles in a heterogeneous car market using a consumer segmentation approach. *Transportation Research Part A, 97*, 121–136.

Brendel, A. B., Lichtenberg, S., Brauer, B., Nastjuk, I., & Kolbe, L. M. (2018). Improving electric vehicle utilization in carsharing: A framework and simulation of an e-carsharing vehicle utilization management system. *Transportation Research Part D: Transport and Environment, 64*, 230–245.

Burghard, U., & Dutschke, E. (2019). Who wants shared mobility? Lessons from early adopters and mainstream drivers on electric carsharing in Germany. *Transportation Research Part D: Transport and Environment, 71*, 96–109.

Cassetta, E., Marra, A., Pozzi, C., & Antonelli, P. (2017). Emerging technological trajectories and new mobility solutions. A large-scale investigation on transport-related innovative start-ups and implications for policy. *Transportation Research Part A, 106*, 1–11.

Chan, C., Wong, Y., Bouscayrol, A., & Chen, K. (2009). Powering Sustainable Mobility: Roadmaps of Electric, Hybrid, and Fuel Cell Vehicles. *Proceedings of the IEEE, 97*(4), 603–607.

Clewlow, R. R., & Mishra, G. S. (2017). *Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States.* Davis: Institute of Transportation Studies.

Jacquillat, A., & Zoepf, S. (2018). Deployment and utilization of plug-in electric vehicles in round-trip carsharing systems. *International Journal of Sustainable Transportation, 12*(2), 75–91.

Jalali, R., Koohi-Fayegh, S., El-Khatib, K., Hoornweg, D., & Li, H. (2017). Investigating the Potential of Ridesharing to Reduce Vehicle Emissions. *Urban Planning, 2*(2), 26–40.

Jenn, A., Laberteaux, K., & Clewlow, R. (2018). New mobility service users' perceptions on electric vehicle adoption. *International Journal of Sustainable Transportation, 12*(7), 526–540.

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., Alonso-Gonzalez, M. J., & Narayan, J. (2017). Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges. *Urban Planning, 2*(2), 13–25.

Kley, F., Lerch, C., & Dallinger, D. (2011). New business models for electric cars - A holistic approach. *Energy Policy, 39*(6), 3392–3403.

Lue, A., Colorni, A., Nocerino, R., & Paruscio, V. (2012). Green Move: an innovative electric vehicle-sharing system. *Procedia: Social and Behavioral Sciences, 48*, 2978–2987.

Mounce, R., & Nelson, J. D. (2019). On the potential for one-electric vehicle car-sharing in future mobility systems. *Transportation Research Part A: Policy and Practice, 120*, 17–30.

Pavlenko, N., Slowik, P., & Lutsey, N. (2019). *When does electrifying mobility make economic sense.* San Francisco: The International Council on Clean Transportation.

Sarasini, S., & Linder, M. (2018). Integrating a business model perspective into transition theory: The example of new mobility services. *Environmental Innovation and Societal Transitions, 27*, 16–31.

Sprei, F. (2018). Disrupting mobility. *Energy Research & Social Science, 37*, 238–242.

Wang, L., Liu, Q., & Ma, W. (2019). Optimization of dynamic relocation operations for one-way electric carsharing systems. *Transportation Research Part C: Emerging Technologies, 101*, 55–69.

Weikl, S., & Bogenberger, K. (2015). A practice-ready relocation model for free-floating carsharing systems with electric vehicles - Mesoscopic approach and field trial results. *Transportation Research Part C: Emerging Technologies, 57*, 206–223.

Xu, M., Meng, Q., & Liu, Z. (2018). Electric vehicle fleet size and trip pricing for one-way carsharing services considering vehicle relocation and personnel assignment. *Transportation Research Part B: Methodological, 111*, 60–82.

Data Management

Products of Research

Data was obtained from several TNC sources (Uber and Lyft) in addition to several charging network service providers (Chargepoint, EVGo, Greenlots, Blink, etc.).

Data Format and Content

All of the data were provided in either comma separated value files or Excel (xlsx) format files. The content of the data were generally trip or travel information of ride-hail vehicles (for data from TNCs) and charging event data (for data from charging network service providers).

Data Access and Sharing

Data access is restricted as all the data used in this study was confidential.

Reuse and Redistribution

Data access is restricted as all the data used in this study was confidential.