Investigating the use of electric vehicles in new mobility services

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ABSTRACT: The coupling of electric vehicles and new mobility services has the potential to increase the benefits of electrification due to the increased miles traveled and higher passenger occupancy on average of new mobility fleets. We examine electric vehicle use in new mobility service fleets through the Maven rental program launched by Lyft in 2017. The project leverages novel datasets from Lyft and EVGo to conduct analysis on the charging patterns and usage patterns of electric vehicles within the new mobility fleets. These insights allow us to quantify the emissions benefits as well as the capability of vehicles to perform their services, as well as the effects of the service on other electric vehicle charging behavior.

KEY WORDS: new mobility services, electric vehicles, Lyft, DC fast charging, Maven

1. INTRODUCTION

Transportation network companies (TNCs) are a relatively new transportation service provider and include rapidly growing companies such as Uber and Lyft. The general business model of these companies is to leverage existing vehicle owners to provide rides through a peer-to-peer "sharing economy". The drivers for TNCs earn money by providing rides for users who pay for the service, a portion of which goes to the parent companies. The growth of these companies has been tremendous: Uber and Lyft have provided a combined 5.5 billion rides with over 50 million users of the services, a remarkable growth especially considering the services have been around for less than a decade. As these services continue to expand, there are several unique opportunities for disruptive changes in the transportation sector.

One possible transition that TNCs may help to enable is a cleaner vehicle fleet through the electrification of their vehicles. The benefits of the emissions reduction from plug-in electric vehicles (PEVs) is compounded by the fact that the vehicles driven for these services are driven significantly more. Additionally, electric vehicles can be particularly compelling for drivers of TNCs due to the lower use-phase costs of the vehicles but may face other difficulties in the form of higher upfront costs to purchase and possible range imitations. However, there are also alternatives to the traditional driver-owned service model, including programs that allow participants in ride-hailing service economies to use a fleet or car-share vehicle rather than their own (this is common if the driver cannot afford their own vehicle). 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. After the Chevrolet Bolt was released in late 2016, Maven announced a partnership with Lyft called "Express Drive" that provided a fleet of Chevrolet Bolts for use in a limited number of cities across the country that began in early 2017. Later in 2017 Maven expanded the program to include a program called "Maven Gig" which provides a weekly car rental service for those driving in the shared platform services.

In this study, we examine empirical data on the use of Chevrolet Bolts associated with Maven within Uber and Lyft fleets, employing data from eVgo (an electric vehicle charging network provider). Since the travel intensity of vehicles used in the TNC fleets is so high, the relative benefits of the cleaner vehicles are significantly higher, and our work attempts to quantify this. However, the higher travel intensity also requires much more charging, the implications of which we also attempt to identify in this study. The remainder of the paper is structured as follows: a brief review of existing studies on the topic in Section 2, an overview of the data used for the research in Section 3, a description of the methods in Section 4, and the results followed by a discussion and conclusion in Sections 5 and 6 respectively.

2. LITERATURE REVIEW

The benefits of electrifying new mobility services has been discussed in the literature—in theory, but there are no examples of empirical work examining the real world impacts. As early as 2011, Kley et al. identified electric vehicles in the context of products that could be leveraged in different types of mobility services such as "car sharing", "fleet concepts", or "transport service" (despite the relative dearth of these services at the time).

The authors identify critical issues of charging infrastructure and electric drivetrain technological restrictions on the value proposition, value chain configuration, and revenue model of the new technology vehicles within the new service ecosystem (Kley, Lerch, & Dallinger, 2011). This study laid the groundwork for important considerations of two rapidly growing fields and difficulties in integrating the two together in a successful business operation. In 2012, the Polytechnic University of Milan in the city of Milan, Italy launched "Green Move", an electric vehicle sharing system, the details and design of which were documented in a peer-reviewed article (Lue, Colorni, Nocerino, & Paruscio, 2012). The ambitious project featured a peer-to-peer approach using an integrated device that bridged the user, vehicle, and a control center with keyless mobility (using smartphones). Unfortunately, the project was not a commercial service and limited in size to only four electric vehicles. It ended in 2013, but was one of the earliest conceptions of electric vehicles being used within new mobility services.

As both car-sharing and ride-hailing services increased in popularity and size, there was a corresponding increase in research on the topic. Though the focus of a 2014 study by Barth and Shaheen was on providing a comprehensive overview of these new mobility services, the authors did identify the potential of hybrid and electric vehicles being used in these services to provide a large benefit. In particular, they point out that the California Air Resources Board (CARB) has an intrinsic interest to link the 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) resulting from ride-sharing if it were used to replace personal vehicles in Changsha, China. Using big data analytics and machine learning algorithms, they identify potential for ride-sharing to reduce travel intensity by up to 24% resulting in reductions of 4 tons of CO_2 daily (Jalali, Koohi-Fayegh, El-Khatib, Hoornweg, & Li, 2017). This is the only study in current literature that quantifies the synergistic emission outcomes from electrifying ride-sharing vehicles but is strictly a modeled result and may not represent reality if electric ride-share were introduced into Changsha.

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. Regina and Mishra provide an overview of the landscape of shared mobility landscape as well as some of the associated impacts of the services (Clewlow & Mishra, 2017). Cassetta et al. demonstrates an upward trajectory in both new mobility services (both ride-hailing and car-sharing modes) simultaneously with electric mobility, though the integration of the two is no considered (Cassetta, Marra, Pozzi, & Antonelli, 2017). Jittrapirom et al. reveal a potentially interesting demand-based incentive for electric vehicles via preferential modes based on cost, time, and CO_2 footprint (specifically from the WienMobil Lab in Vienna, Austria) which would naturally favor electric vehicles due to their relative cleanliness (Jittrapirom, et al., 2017). More directly, Sarasini identifies new mobility services as a key business model that can be linked to electric vehicles to help implement climate policies that seek to promote low-carbon technologies. Additionally, the authors point out that operators of the mobility services are likely to be more prone to pursue vehicles under a total-cost-of-use perspective and thus are more amenable to electric vehicles that have lower marginal costs than conventional vehicles (Sarasini & Linder, 2018). Lastly, Sprei discusses the potential of combining the two disruptions (electrification and shared mobility) alongside automation. Specifically, she points to the need of regulation to maintain the correct trajectory and ensure that the proper outcomes are met given these large revolutions in the transportation sector (Sprei, 2018).

It is clear from the existing literature that there is a gap in empirical evidence that measures the impact of combining shared mobility services with vehicle electrification. The work presented in this study is the first to provide real-world insight into the implications of electric vehicle use in services such as Uber and Lyft. These insights include an overview of the travel intensity and energy demand from PEVs being used in these services within California. We also measure the comparative emissions savings from electric vehicle use as well as the associated charging infrastructure implications from higher intensity usage.

3. DATA

We employ a high resolution dataset of 3 million separate charging events within the eVgo charging network spanning April 2014 through May 2018. The charging stations under eVgo are primarily DC fast chargers (operating at approximately 50 kW of power output) and are not necessarily representative of typical charging behavior (timing and rate) by PEV owners. Each charging event contains information on the following attributes:

- Session start and end times
- Location ID, charger ID, site address, host information
- Connector type
- Unique ID for customer (based on key fob ID), customer address
- Product (membership type with eVgo)
- Energy transferred and time at charger

Using the site address, we are able to obtain exact longitude and latitude information for each of the site locations by geocoding through Google Maps API. This provides a spatial observation of charging demand across the three cities of interest (San Diego, Los Angeles, and San Francisco).

This study focuses specifically on the "Maven" product membership which identifies users of Chevrolet Bolts in the Maven service for ride-hailing purposes. It is important to note that the current membership allows for free DC fast charging, which may induce different behavior (both in the decision to use the vehicle and how it is operated by the renter).

4. METHODS

4.1. Counterfactual emissions calculations

We calculate the emissions associated with each of the charging events from the eVgo data, which enables us to understand the contribution of electrifying ride-hailing services to reducing emissions. The emissions are calculated as follows:

$$emissions_i^{\mathrm{Maven}} = kWh_i \cdot gridEmissions_t \quad (1)$$

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) using historical hourly load data and corresponding hourly emissions data from 2014 through 2018. This provides the average hourly emissions for the grid across the full span of data. Emissions rate range between 270 g CO2 to 350 g CO2 per kWh during nighttime hours and drops to 150 g CO2 to 200 g CO2 per kWh during daytime hours. The kWh parameter is obtained directly from the data.

We can also estimate the counterfactual emission savings from electrifying the ride-hailing vehicles. Because drivers can actually rent gasoline vehicles through the Maven 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 Chevrolet Bolts. However, it is important to note that some of the travel behavior would differ because gasoline vehicles would not have to travel to charge their vehicles (though they would need to drive to gas stations). The emission savings from these vehicles can be calculated by taking the difference between the emissions calculated above in Eq. (1) with the corresponding gasoline vehicle emissions, all together represented as:

$$em.savings_i^{\mathrm{Maven}} = kWh_i \left(\frac{8887\mathrm{g\ CO_2}/\mathrm{gal\ gas}}{efficiency^{\mathrm{PEV}} \cdot MPG} - gridEmissions_t \right) \quad (2)$$

The Chevrolet Bolts in our analysis are assumed to have an efficiency of 28 kWh per 100 miles. The substitute ride-hailing gasoline vehicle is assumed to have an efficiency of 35 miles per gallon for the MPG parameter (we assume that ride-hailing vehicles are generally more fuel efficient than average).

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 PEV adoption policy. The process to calculate the emissions can be seen below in Eq. (3)-(5).

$$emissions_j^{\mathrm{ord.gas}} = \frac{VMT_j}{MPG} \cdot \frac{8887\mathrm{g\ CO_2}}{\mathrm{gal\ gas}} \quad (3)$$

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

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

The set j describes the index for individual observations of travel behavior from a separate dataset: the California Household Transportation Survey. We focus primarily on estimating emissions savings as a bounding exercise, particularly related to the emission savings from the Maven electrification program, and therefore estimate an optimistic scenario for the emission savings from switching a regular (non-ride hailing service) vehicle to an electric vehicle (em.savingsord). Therefore the MPG parameter is assumed to be 27 MPG (approximately the average in California) and the gridEmissions parameter is assumed to be 186 g CO2/kWh, the lowest average emissions rate.

5. RESULTS

The results are divided into three primary subsections: in Section 5.1 we provide an overview and insights into key data figures derived from the eVgo dataset, in Section 5.2 we employ the data to explore charger utilization and congestion issues related to Maven usage, and lastly in Section 5.3 we quantify the to-date emissions impacts of electrifying the ride-sharing through the Maven service.

5.1. Exploring the growth of EV usage in TNCs

The growth and utilization of Chevrolet Bolts from Maven has been explosive, since their introduction in February 2017 the vehicles have continually grown in energy demand as seen in Figure 1 below. Since April of 2014, there have been 97,001 unique vehicles charging at eVgo stations (representing a little less than half of the total number of electric vehicles in California) while the current number of Chevy Bolts operating and charging at eVgo stations numbers at 1,047 at the end of May 2018. However, while the Chevy Bolts in Maven represent less than 1.1% 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, Maven vehicles have thirty times the energy demand of other electric vehicles).

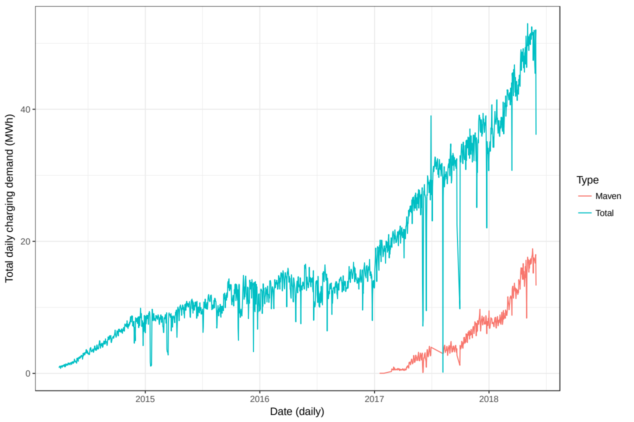
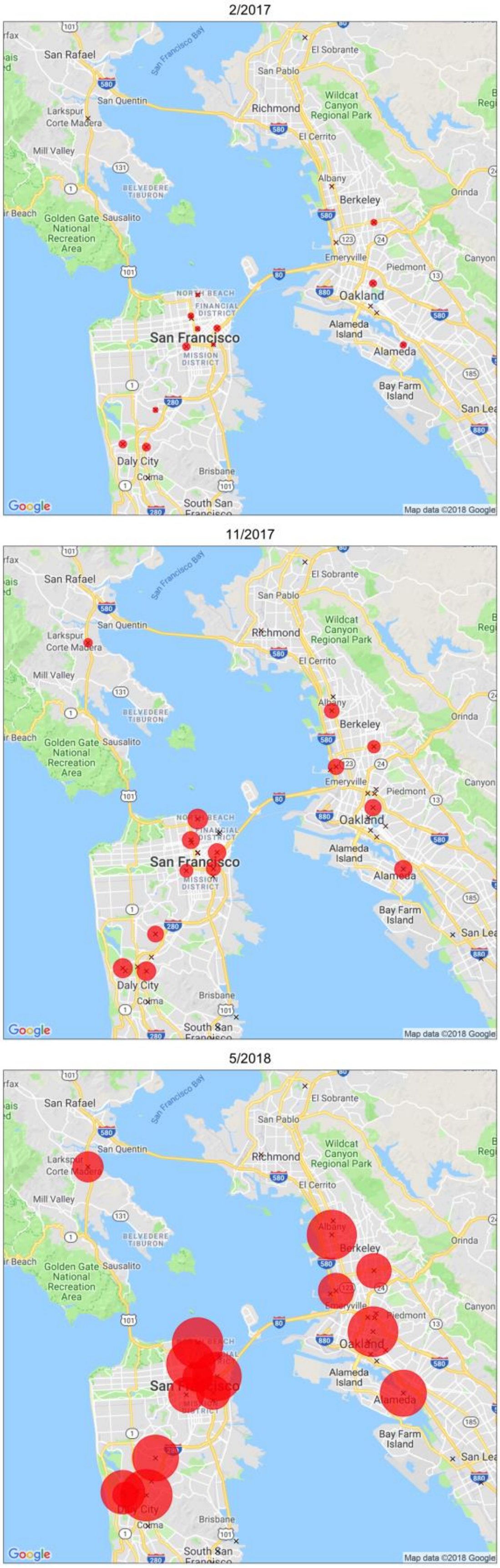


Figure 1: Total daily charging demand on eVgo network from April 2014 through May 2018 in San Diego, Los Angeles, and San Francisco. The total demand exceeded 50 MWh per day in April and May 2018 with the Maven membership product accounting for just under 20 MWh (averaging 31% of the total demand in May 2018.

In Figure 2, we show the relative growth of charging demand spatially by charging location. From the initial start month of February 2017, the charging demand grew by approximately 10 times in size over a span of 9 months followed by another growth of 5 times over the next 6 months. The continuous rapid growth speaks to a critical challenge for both the Maven (and other similar ride-hailing services) and charging service providers to enable electrification. In Section 5.2 we provide more in-depth analysis on understanding the implications of infrastructure congestion resulting from the Maven service. 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 that not all stations are being employed for charging Maven services. 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 3, we display the amount of energy charging requirements for Maven vehicles compared to "regular" electric vehicles in San Diego, Los Angeles, and San Francisco. We observe a very different distribution of charging patterns between the two types of vehicles. The charging demand from Maven 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), Maven vehicles are visiting charging stations on average 2.5 times a day while other unique electric vehicles visit charging stations on average once every 2 weeks. This means that despite the range "limitation" of a 238-mile battery on the Chevy Bolt, we observe that Maven 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 a specific eVgo membership type that restricts the length of charging to 30 minutes.

However, while the Maven vehicles are typically charging exclusively on the eVgo network (due to their membership benefits allowing for free DC fast charging), the charging of other vehicles on eVgo's network may not be representative of their actual travel behavior (e.g. if there is a correlation between distance traveled and a PEV driver's decision to use fast charging). In Figure 4, we examine empirical travel patterns of other vehicles compared to the Maven fleet. 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. We observe a drastically different distribution of mileage traveled by everyday vehicles (whether gasoline or electric) and those within the Maven fleet. Ordinary vehicles average between 27 to 38 miles per day while the Maven Bolts are driving upwards of 189 miles per day on average. We find non-negligible instances of the Chevy Bolts driving between 400 and 500 miles per day, or twice the entire battery range of the vehicle. This is a relatively strong indication that, at least in the current ecosystem, the high-mileage Chevrolet Bolts are able to fulfill ride-hailing service needs—though further study must be conducted in order to determine whether or not the service provided by electric vehicles differs in any way from the service provided by conventional gasoline vehicles.



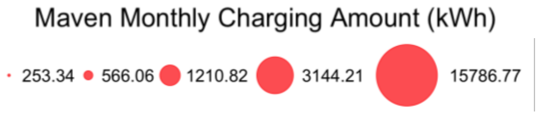


Figure 2: The total monthly demand of electricity from Maven vehicles in San Francisco from eVgo stations for a snapshot of three months: February 2017 (the introduction of the Maven product), November 2017, and May 2018. These stations have unusually high utilization rates as a result of the usage from the ride-hailing services relative to other stations.

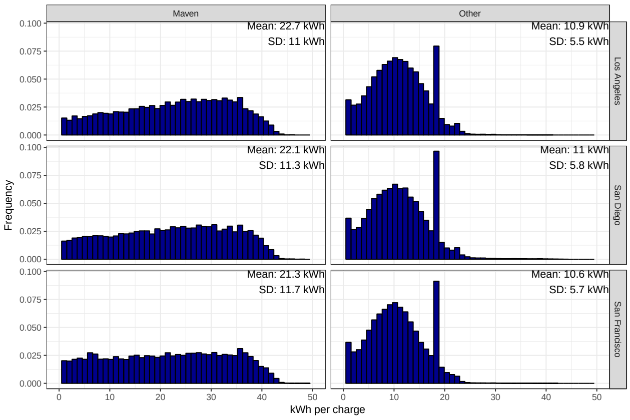


Figure 3: The amount of energy used per charging event for Maven vehicles and all other vehicles in San Diego, Los Angeles, and San Francisco. Maven vehicles have a significantly higher charge requirement with a relatively uniform distribution tailing off near 40 kWh (average of 22 kWh) while ordinary electric vehicles have a truncated normal distribution centered around 11 kWh. Note that the large peak in the "Other" vehicles is a result of specific eVgo membership policies that restrict users to 30 minutes of charging.

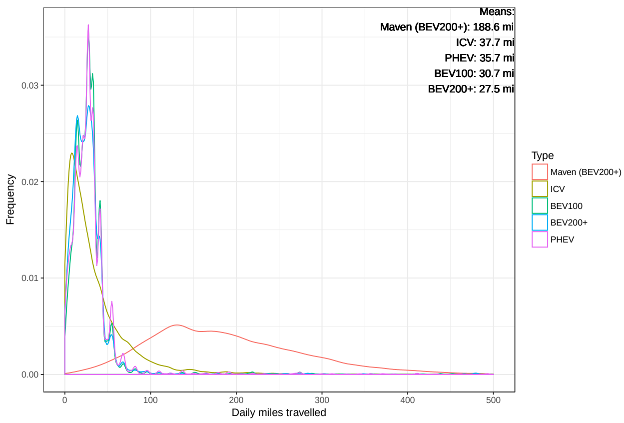


Figure 4: Distributions of travel intensity of Maven versus conventional internal combustion engine vehicles in California (from the California Household Travel Survey), and different electric vehicle technology types (PHEVs, 100 mile BEVs, and 200 mile BEVs; data derived from UC Davis Plug-in Hybrid & Electric Vehicle center survey [n=14,500]). The average daily

miles travelled for conventional vehicles and ordinary electric vehicles ranges from 27 to 38 miles per day while Maven drivers are traveling five to six times farther with nearly 190 miles averaged per day.

The charging patterns of Maven vehicles is also noticeably different from the DC fast charging patterns of other electric vehicles. Since the eVgo chargers are all public infrastructure (as opposed to being available at home locations), we observe negligible charging events for regular PEVs occurring between the hours of around 3 am to 8 am. However, for the Maven Bolts, we still observe a relatively high proportion of charging events happening over this same time-period. Interestingly enough, there is a slight difference in the distributions by region. In particular, San Diego has two peaks during these hours for Maven vehicles (at 5 am and 8 am) which is not observed in the other regions. Additionally, for ordinary electric vehicles in San Diego there is a continued upwards trend in charging starting at 7 am through 3 pm while there is a noticeable flattening in both Los Angeles and San Francisco after 10 am. Maven vehicles also have a dip in charging between the hours of 6 pm to 8 pm, 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 PEVs.

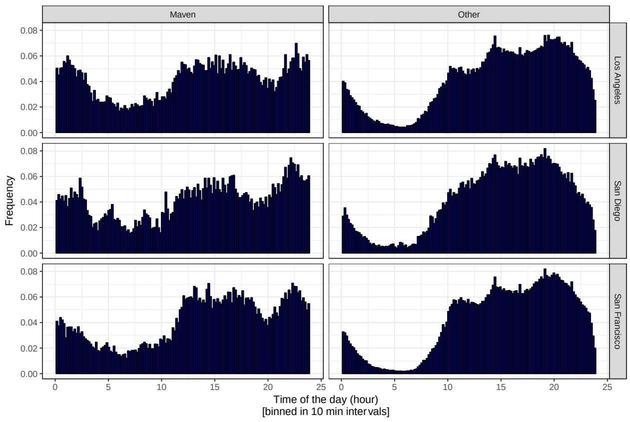


Figure 5: A histogram of time of day that charging occurs for Maven vehicles and for other electric vehicles in San Diego, Lose Angeles, and San Francisco. In comparison to regular electric vehicles, there is a significantly higher frequency of charging events occuring between midnight and 8 am. In particular, there appear to be two peaks in San Diego for Maven users, one at 5 am and one at 8 am. Additionally, there is a dip in charging for Maven users at around 6 to 8 pm, likely due to higher demand for ride-sharing services at the time, which is contrary to regular PEVs where this time period is the highest for charging events.

The overview from eVgo's 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 in Maven) and regular electric vehicles. The travel intensity for Maven vehicles is striking and points to a need for greater charging infrastructure to help manage the energy demand from these vehicles.

5.2. Infrastructure implications

The implications of electrifying ride-share has substantial impact on the development and use of charging infrastructure to support electric vehicles—both those used in the Maven program as well as providing service to ordinary PEVs. The data reveals heterogeneous impacts on charger use: for a qualitative example see Figure 6 and Figure 7 which show a pair of chargers at two different locations—one which is heavily influenced by Maven service charging usage (Figure 6) and one which is not (Figure 7).

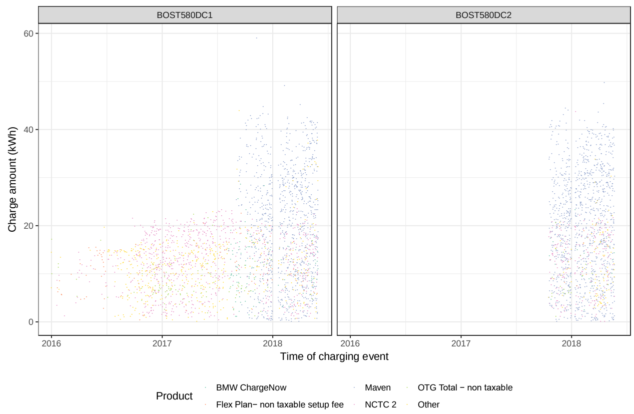


Figure 6: Two chargers at a location in Los Angeles, the introduction of the Maven service has led to a growth in the number of charging events, possibly associated with a decrease in the utilization by other users of the station

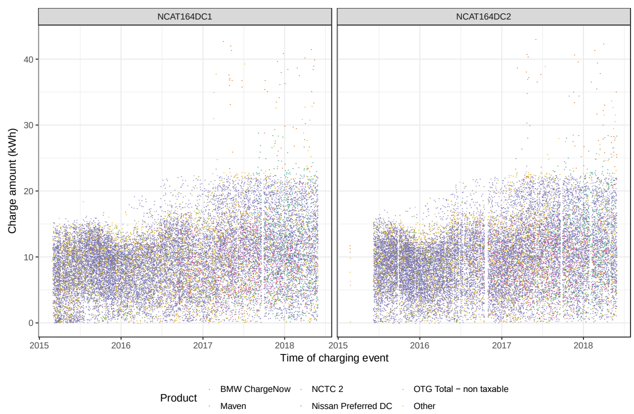


Figure 7: Two chargers at a location Fremont, the introduction of the Maven service has not led to a noticeable difference in the charging patterns of users visiting the station.

5.3. Emissions analysis

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 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 Maven vehicles from February 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 travel distances from the electric vehicles that lead to larger energy demand.

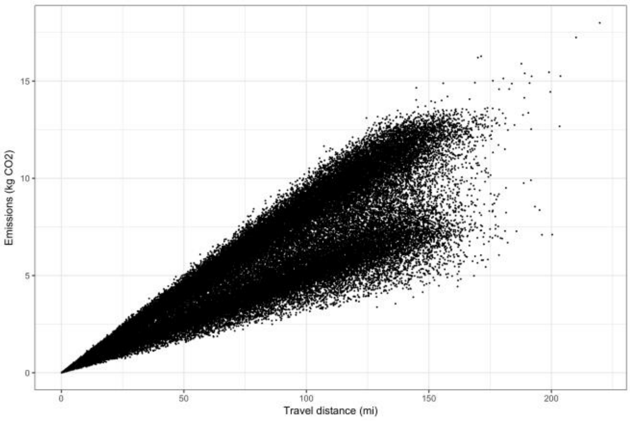


Figure 8: The emissions associated with every Maven charging event from February 2017 through May 2018. The emissions are a function of the average hourly marginal emissions in California at the time associated with the charging event as well as the total charging amount. There are two relatively distinct bands resulting from the bimodal daytime and nighttime emissions factors in California.

How much emissions have been saved from the Maven program introducing Chevrolet Bolts for ride-hailing services? If we assume that the Bolts 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 36.5 kg of CO2 for electrifying the ride-hailing service. Across all 1,047 Bolts from February 2017 through May 2018, this has resulted in a total savings of 1,142 tons of CO2, 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).

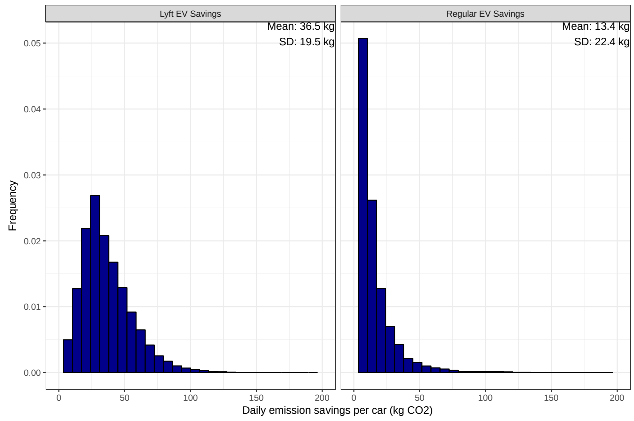


Figure 9: A histogram of the comparative emission savings for switching a ride-hailing vehicle from a gasoline vehicle (assuming 35 MPG) to a Chevrolet Bolt (based on Maven travel behavior) versus switching an average gasoline vehicle in California (assuming 27 MPG) to a Chevrolet Bolt (based on CHTS travel behavior). We find the emissions savings to be nearly three times higher for electrifying ride-share versus electrifying the average California driver.

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