Impact of COVID-19 on Mobility and Electric Vehicle Charging Load

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Abstract—The COVID-19 pandemic significantly disrupted mobility and electricity consumption in 2020. The changes seen reflect responses to new COVID-19 cases, local health guidelines, and seasonality, making the impact regionally unique. This paper presents a data-driven case study of electric vehicle (EV) charging and mobility in the wake of COVID-19 in Utah. The study shows that the number of EV charging sessions and total energy consumed per day dropped by 40% immediately after the arrival of the first COVID-19 case in Utah. By contrast, the energy consumed per charging session fell by just 8% over the same period and the distribution of session start and end times remained very consistent throughout the year. While EV mobility dropped more dramatically than total vehicle mobility during the first wave of COVID-19 cases, and returned more slowly, both returned to stable levels near their mean values by December 2020, despite a dramatic increase in new infections.

Index Terms—COVID-19, electric vehicles, mobility.

I. INTRODUCTION

More than one year after the first reported case of COVID-19 in the United States (U.S.) on January 20th, 2020, mobility remains depressed as people seek to avoid COVID-19 transmission. In April 2020, the lowest point in mobility trends, visits to retail and recreation, transit stations, and workplaces were 40%, 50%, and 50% below baselines, respectively [1]. Mobility and COVID-19 transmission are positively correlated across the country, but changes in infections lag those in mobility by up to three weeks [2]. This lag challenges effective policy development to curb COVID-19 transmission. In response to COVID-19 precautions and stay-at-home recommendations from health experts, corporations and their employees have embraced work-from-home opportunities. Seventy-seven percent of employees worked from home regularly during 2020 as compared to just 9% prior to the COVID-19 outbreak [3]. As more employees work from home fewer get into vehicles for their daily work commutes, comprising 28% of the annual vehicle miles traveled in the U.S. [4].

The COVID-19 pandemic has firmly evidenced the connection between mobility, economic activity, and electricity consumption [5]. A mobility-aware model for load forecasting demonstrated significantly improved accuracy over traditional, historic models whose performance was degraded by the unique circumstances of COVID-19 [6]. At its height, the pandemic depressed total energy demand in the U.S. to a 16 year low and disrupted historic load profiles [6], [7]. EV utilization connects COVID-19 cases, mobility, and electricity consumption. Despite mobility reductions and economic contractions, EV sales grew by 40% globally in 2020 [8].

The overall decline in mobility offers an opportunity to explore how these changes manifested in EV driving, and energy consumption, in comparison to aggregate mobility measures. EV driving patterns differ from internal combustion vehicle (ICV) patterns due to their reduced range capacity, charging station sparsity, recharge time, and driver demographics [9]. Ultimately, EV adoption represents a rare opportunity for increased electricity sales for utilities and decreased air pollution for local governments. Further energizing the effort to understand EV utilization in the time of COVID-19 and beyond is the positive correlation between public EV charging infrastructure and adoption [9].

To the authors’ knowledge, this work presents the first data-driven case study of EV mobility and electricity consumption in the time of COVID-19. The analysis presented relies upon national mobility trends with a focus on available traffic volume and EV charging data in the state of Utah. Section II reviews the available data, scope of analysis, and sets the context for the results presented in Section III. High-level implications of these findings are presented in Section IV.

II. DATA AND METHODOLOGY

This paper identified four sources of data, in addition to COVID-19 case numbers [10], for this data-driven analysis of EV mobility and demand patterns. Mobility data lays the groundwork for vehicle travel in the U.S. and Utah. Traffic volume data offers highway specific transit profiles. When observed in discrete temporal contexts, Utah EV charging data can be used to study changes in EV driving after COVID-19. Finally, a 2020 event timeline, overlayed onto the data above, offers holiday and key event background on observed trends.

A. Mobility Data

This work employs Google COVID-19 Community Mobility Reports (CMRs) to inform mobility analysis [1]. The study of mobility is incorporated to understand the dominant trends that existed in the presence of seasonal changes, holidays, and days of the week. This high-level depiction of mobility allows for separation and observation of COVID-19 impacts on human mobility. The CMRs are taken from anonymized Google location data and track changes in destination mobility. Google has categorized all destinations as one of retail and...
recreation, grocery and pharmacy, parks, transit stations, workplaces, or residential. Formally, the five weeks of January, an approximate “pre-COVID” period in the U.S., are used as a baseline for mobility comparison. Note, CMR data does not offer multi-year comparison data or feature correction to allow for controlled comparison of mobility throughout the COVID-19 pandemic. Baselining is limited to the five week period spanning from January 3 to February 6, 2020. Percent mobility changes are measured in comparison to this period for the corresponding day of the week.

B. Utah Traffic Volume Data

Highway sensors around Utah record passing vehicles by anonymously sensing on-board electronic signals such as Bluetooth and Wi-Fi [11]. A vehicle picked up by two sensors is called a “match.” Matches do not provide a precise measure of traffic volume, but inform average speed and relative changes in vehicle movement. A primary highway in the Salt Lake City metro area is selected as representative of metro-area traffic throughout the state. The 2020 dataset for this stretch of highway includes over 1.3 million vehicle matches. Focus on the Salt Lake City metro area follows from the increased risk of COVID-19 transmission in urban areas, social distancing and health guidelines non-withstanding, and the fact that 31% of the state of Utah lives in Salt Lake County.

C. Utah EV Charging Data

Session level EV charging data, charger identity, charger location, session start time, session end time, and energy, is taken from networked EV charging stations around the state comprising more than 32,000 charging sessions, 2,800 EV drivers, and 366 MWh of energy over the 2020 analysis period. Session level data informs EV charging patterns before, during, and since the onset of COVID-19 infections. This work analyzes local and long distance driving modes by grouping chargers by installation location. Public chargers are those located at commercial businesses, public parks, and municipal buildings along surface streets in cities and suburbs. The public charger dataset includes 19,500 sessions across 20 level 2 (L2) chargers. Highway chargers are located at gas stations along major highways in support of long distance EV trips. Th highway charger dataset includes 800 DC fast and 400 L2 charging sessions across a total population of eight DC fast and eight L2 chargers.

D. Utah COVID-19 Event Data

The trends depicted by mobility, traffic, and EV charging data are set in time by key events, such as case spikes and health guidelines, during COVID-19 in Utah. The occurrence of these events is taken from the Utah COVID-19 response team’s timeline [12]. These events are overlayed on top of mobility trends to better understand how the public at large responded to COVID-19 with special focus on how those responses manifested among ICV and EV drivers. On February 28th, the first COVID-19 patient arrived in Utah. In response, the state government issued the “Stay Safe, Stay Home” order on March 27th. On April 17th, the state announced its plan for re-opening. The 49 days between the arrival of the first case and announcement of re-opening correspond with the greatest change in mobility and define a key time span for analysis.

III. Analysis and Discussion

Rolling averages offer a means to distinguish the COVID-19 influence on mobility from normal daily patterns. Changes in COVID-19 cases and consequent health guidelines have long-term, greater than three weeks [2], impacts on mobility in aggregate. This study considers day-to-day oscillations in mobility, or more precisely changes in mobility by type of location visited, as signal noise that is short in period and counter-indicative of long-term COVID-19 caused trends. Daily workplace visitation, as measured by changes in mobility, depicted in Fig. 1, illustrates the difference in short and long term mobility trends. Here, the regular oscillations of transit patterns are present in the daily values. The daily data presented in Fig. 1 depict normal, weekly oscillations. The percent change in daily workplace mobility first dropped due to the President’s Day holiday weekend and then rebounded to zero percent immediately afterward, indicating a continuation of regular pre-COVID mobility patterns, as compared to the baseline period in January. After the first COVID-19 case, however, long-term workplace mobility dropped significantly and remained depressed as COVID-19 cases rose. Regular, positive weekend spikes in workplace mobility represent a regression towards baseline mobility, the zero mean value, as fewer workplace commutes typically occur on weekends. A large decrease in daily workplace mobility occurred on the Memorial Day holiday followed by a short-term doubling in the number of new daily COVID-19 cases [10]. The close occurrence of the holiday weekend and increase in COVID-19 is an example that fits into the literature establishing a correlation between mobility and COVID-19 transmission [2]. Rolling averages offer a means to filter out short-term oscillations in mobility, expose long-term changes, and extract COVID-19 impacts from this data.

A. Mobility

Changes in mobility by destination classification is presented in Fig. 2 according to Google CMR data. The 30-day rolling average captures both long-term COVID-19 changes in mobility as well as seasonal changes. A significant increase in park visitation in the Salt Lake City area occurred in the spring and summer. Throughout the western U.S., increased park visitation during the spread of COVID-19 was driven...
by the change in season [13]. Recall that the baseline for mobility is January 2020 and CMRs do not offer year-over-year analysis, so it is expected for park visitation to greatly increase in the summer as compared to a winter baseline.

Observing the short term oscillations and seasonal change clarifies the connections between mobility, COVID-19 transmission, government policies, and the public’s response. A decrease in visitation to public locations beginning in March, reaching their lowest levels in April, are reflective of the first wave of COVID-19 cases. The sustained increase in visitation to residential locations during this first wave suggests people shifted recreational trips from public locations to private residences they considered safe. Workplace mobility remained far below baseline levels as employers adopted work-from-home policies [3], which illustrates the subtle weekly periodicity of the dominant Monday to Friday work week. Only grocery and pharmacy mobility returned to near baseline levels indicating the regular need for food and medicine for a population regardless of the season, holiday or COVID-19 events. Although still depressed, mobility trends in Salt Lake City area stabilized and disconnected from the trajectory of new COVID-19 case numbers since a marked decrease during the first wave of cases in April 2020.

B. EV Charging Preferences

The magnitude and timing of EV charging demand are important to utility load planning [14], [15]. This work offers a unique insight into how EV charging demand profiles changed during the pandemic. COVID-19 infection trends are classified into several discrete 49 day periods according to their relation to the 49 days between the state’s first case on February 28th and the state’s announcement on April 17th of an economic recovery plan for reopening, “1st wave” period [12]. Within the “1st wave” period, the state issued a “Stay Safe, Stay Home” directive on March 27th in response to the growing number of new COVID-19 cases. The 49 days immediately after the announcement of the reopening plan represent the “1st fade” analysis period. After April 17th, the period since the directive, Salt Lake City experienced additional waves of new COVID-19 cases.

The “1st wave” period correlated with the biggest change in EV charger utilization. Average daily energy demand from all EV chargers in Salt Lake City dropped from approximately 1200 to 700 kWh per day in the weeks immediately before and after COVID-19 in Utah, as shown in Table I. The number of sessions per day and total EV charging energy dropped by 35% and 40% respectively, but charging energy per session dropped by just 8%. This discrepancy indicates that despite a large change in charger utilization in the aggregate, individual charging session preferences remained consistent. Similarly, a modest decrease in active charging duration of 12% occurred. The drop in active charging duration and session energy may suggest that EV drivers took shorter trips during the “Stay Safe, Stay Home” period and thus had lower EV range demands, but EV trip specific data is not available to make that claim explicitly. The “1st fade” period exhibits a slight rebound in session level energy, but otherwise characterizes a decrease in total public EV charger utilization. At the end of 2020, going into 2021, per session dropped by just 8%. This discrepancy indicates that despite a large change in charger utilization in the aggregate, individual charging session preferences remained consistent.

Beyond the “1st fade”, this study classifies additional 49 day periods, “2nd wave,” “2nd fade,” “3rd wave,” “4th wave,” and “5th wave” spanning the dates described in Fig. 3, to explore the longer term recovery of EV charging after the initial onset of COVID-19 transmission and statewide response in 2020. These subsequent periods continued the modest rebound in
total EV charger utilization after the “Stay Safe, Stay Home” directive in the “1st wave”. This trend is depicted in the total energy and number of sessions plotted per period in Fig. 3. The lowest period of EV charger utilization correlated with the period of lowest mobility shown in Fig. 2. Over these periods, average energy consumption per session ranged between 9.89 in the “2nd Wave” and 12.67 kWh in the “5th Wave”.

The consistency of per session energy consumption is further underscored by the comparison histogram in Fig. 4.

Charging preferences can be further expressed according to session start and end times as in Fig. 5. Public charging session start time typically follows a bi-modal distribution which corresponds with EV commuters arrival to work and return from lunch [9]. The broad adoption of remote work and school practices immediately after the introduction of COVID-19 did not change the dominant EV charging session time behaviors, but made them less prominent. The total number of EV charging sessions in Salt Lake City dropped significantly after the arrival of COVID-19, but the profile shape remained consistent through the “4th wave” period. By the end of 2020, “5th wave”, the prominence of arrival to work charging sessions had been eliminated and late night charging sessions increased suggesting a persistence of remote working and a return to public, night time recreation.

C. EV Charger Utilization

Publicly available EV charger energy consumption, a surrogate for EV driving, offers a measure of EV driving trends in comparison to highway traffic volume data in the time of COVID-19. This study focuses on public and highway EV chargers to illustrate how mobility patterns changed during COVID-19 regarding local and long distance EV travel. Public chargers in the studied dataset are located along surface streets in cities and highway chargers are located along highways. The Utah traffic and EV charging data are standardized, zero mean and unit standard deviation, in Fig. 6 for side-by-side comparison. Typical highway traffic volume exhibits a seasonal profile which builds from spring into a summer peak and tapers down to its baseline in the fall when students return to school. The spread of COVID-19 and resulting statewide responses significantly altered this regular, seasonal profile.

Noticeably, there was a significant reduction in overall highway traffic and EV charging in response to the “1st wave” of COVID-19 cases prompting the state’s “Stay Safe, Stay Home” directive on March 27th. Highway traffic volumes demonstrate a near-immediate response to this March 27 directive. Public EV charger utilization presented the sharpest response to the “1st wave” of COVID-19 cases in Utah. This response may be attributed to the demographics and use cases surrounding public EV chargers. First, public EV chargers are concentrated in urban centers where COVID-19 infection has increased the fastest. Second, public EV chargers most support local EV commutes to work, errands, and recreation, all of which were discouraged or minimized for public health reasons. Finally, because EV drivers tend to come from high income households with high educational attainment they are most likely to have the option to work from home depressing work commute charging demand [3]. These factors help explain why public EV charger energy exhibited the clearest negative response to the arrival of COVID-19 and subsequent waves in cases. Highway EV charger utilization presented a more erratic trend during the “1st wave.” Highway EV chargers are sparsely distributed across the state where the spread of COVID-19 has varied from community to community. For example, while the November 15, 2020 counts for new COVID-19 cases in Salt Lake City were 800, there were just 28 new cases in neighboring Tooele county [10]. The varied exposure of different regions of the state to the pandemic resulted in spatial diversity accounting for the erratic utilization trend exhibited by highway chargers.
The State of Utah’s announcement of a plan to re-open the economy on April 17th, 2020, reversed these negative trajectories. Within 1 month, general highway traffic volume returned to its mean value while EV utilization trends lagged behind, indicating that EV drivers may have been more cautious towards COVID-19 risks. After Memorial Day weekend, Utah experienced its “2nd wave” of new COVID-19 cases prompting a small, temporary dip in summer traffic volume, a contraction in public EV charging, and a flattening in overall EV charger utilization. Conversely, highway EV charger utilization rose around the “2nd wave” and the July 4th holiday suggesting EV drivers took long distance summer trips away from city centers. The recovery of EV utilization measured across all EV chargers lagged behind that of public and highway chargers into October. This discrepancy may be attributable to the inclusion of workplace chargers, excluded by the public and highway trends, whose utilization is depressed during COVID-19. Beyond September, EV utilization trends stabilized around their mean values despite the continued rise in COVID-19 cases at the end of 2020.

IV. CONCLUSION

The analysis in this paper offers two key takeaways: First, public and highway chargers presented distinct utilization trends in the pandemic, reaffirming the need for case-specific EV charger load modeling and control. Second, public EV charger utilization was highly responsive to COVID-19 suggesting that EV drivers may be apt participants for future demand response programs that require response from such customers. For example, when COVID-19 cases rose, public EV charger utilization dropped more severely than traffic volumes and returned more slowly after case spikes subsided. During the pre-COVID peak, EV energy consumption comprised 1.2 MWh of daily load in Utah. Between the pre-COVID peak period and the height of mobility restrictions during the “1st fade” period, EV energy consumption dropped by 50.55% (30 MWh). In contrast, average session level energy and connected duration dropped by just 7.39% and 1.83% respectively over the same periods indicating that individual EV drivers have maintained consistent per-session charging behaviors despite reductions in aggregate demand. In short, when COVID-19 cases increased, EV drivers were more likely than other drivers to reduce their mobility in aggregate, but individual charging session statistics held consistent.

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