Evaluating Electric Vehicle Public Charging Utilization in the United States using the EV WATTS Dataset

Preprint

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2 National Renewable Energy Laboratory

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Evaluating Electric Vehicle Public Charging Utilization in the United States using the EV WATTS dataset

Ewan Pritchard[1], Brennan Borlaug[2], Fan Yang[2], Jeff Gonder[2]

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Executive Summary

The utilization of electric vehicle (EV) charging in the United States is a rapidly evolving puzzle further complicated by changes in travel habits brought on by the global COVID-19 pandemic. The EV WATTS dataset is the largest publicly available dataset on the utilization of EV charging in the United States and provides key insights into the changing patterns of public vehicle charging and vehicle use as EV range increases, commute patterns evolve, and more infrastructure becomes available.

1 Introduction

At the time of writing, there are 50,780 publicly accessible charging locations within the United States with 129,856 ports [1]. These include 100,765 level 2 (L2) ports, which use 240/208Volt alternating current (AC) electricity and deliver 7.2 to 19.2 kilowatts (kW) of power (around 25-75 miles of range added per hour), and 29,091 direct current fast charging (DCFC) ports that convert three-phase AC electricity to DC delivering up to 350 kW of power, though most ports today provide 150 kW (around 250 miles of range added in 30 minutes) or less [2]. As part of the Bipartisan Infrastructure Law enacted in 2021, the United States will invest $7.5 billion to meet the Biden Administration's goal of establishing a national network of 500,000 EV chargers by 2030 [3]. Like existing electric vehicle service equipment (EVSE), many of these new stations will be installed, operated, and/or maintained by private entities using a variety of business models [4]. A clear understanding of the terminology, use cases, times, and locations where charging is beneficial is critical to the success of this rollout.

2 The EV WATTS Dataset

The EV WATTS dataset is a US Department of Energy (DOE) supported collection of onboard EV telematics (vehicle) data and EVSE data from the United States. It spans from October 2019 to the present and informs future research, development, and deployment of these technologies. The dataset is collected and anonymized by Energetics [5] and made available for researchers at the national labs for detailed analysis. A further anonymized dataset is available for public use via download or through interactive dashboards at the EV WATTS website (evwatts.org).

Where do you answ this?

This paper adopts the terminology outlined in the Open Charge Point Interface (OCPI) protocol as shown in Figure 1: Image describing the OCPI protocol, which classifies a charging station as a site with one or more

EVSE ports (and potentially multiple pedestals) at the same location. The port count is defined by the sum of ports at each EVSE that can be simultaneously activated.

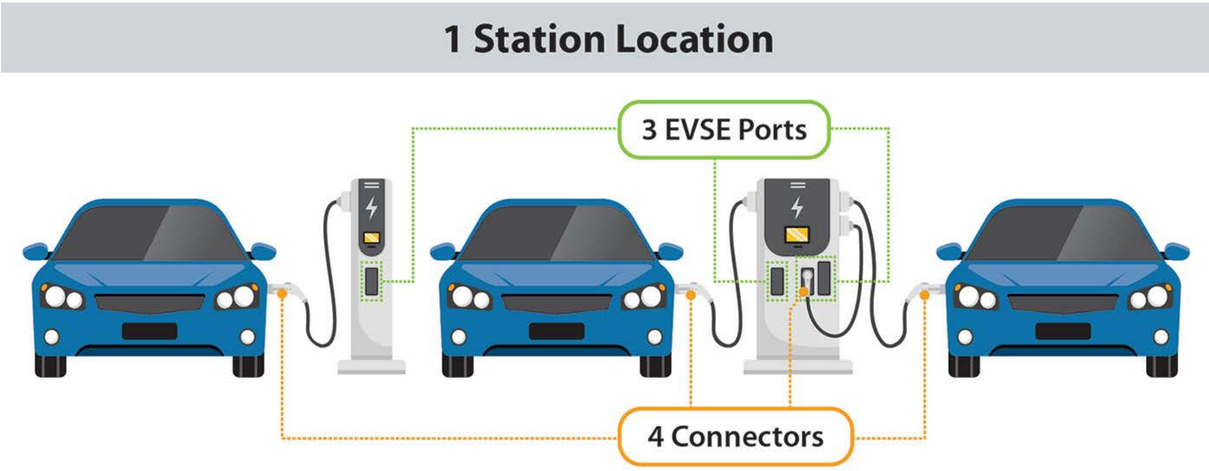

Figure 1: Image describing the OCPI protocol courtesy of US DOE AFDC

At the time of writing, the EV WATTS dataset contains data from over 50,000 charging ports and over 13 million charging sessions from all states and territories of the US and should serve as a significant wealth of insight and knowledge in the electric vehicle marketplace for the foreseeable future as the public research community begins to investigate the dataset.

3 Results and Discussion

3.1 Data subset

The EV WATTS dataset contains data from both public and private EVSE. For this study, we will focus only on public EVSE, additionally, we have filtered out stations with venue types (Null), Fleet, Mobility-Hub, Single Family, or Multi-Family. The dataset also contains a lot of information regarding charging errors where sessions transmit little to no power, have zero or overly short session length, or overlap each other among other erroneous cases. Such sessions are issued "error flags", thus allowing a user to easily filter them out of a dataset. These error flags were filtered from the dataset for this study. The resulting dataset contains 6,842 Stations with 13,926 EVSE (21,622 ports) across the seven remaining venue types and nine regions with distributions as shown in figures 2 and 3 respectively.

Filter out Flags

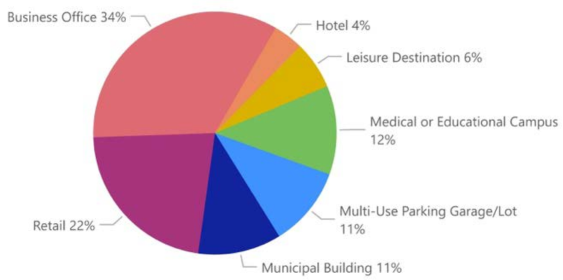

Figure 2: Dataset Venue Distribution

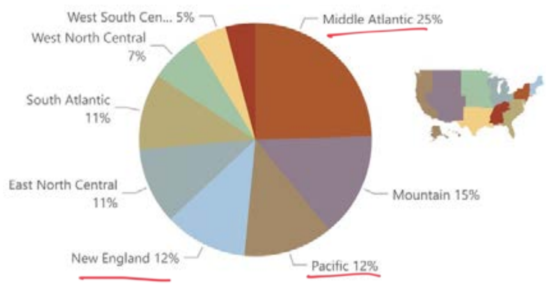

Figure 3: National Distribution of Dataset

The resulting public charging dataset contains 4,295 DCFC EVSE (2,596 stations, 4,277 ports, 2.10 million sessions) and 9,649 Level 2 EVSE (4,380 Stations, 17,332 ports, 4.39 million sessions).

3.2 Utilization

Utilization is a common measure of performance for a charging network. Higher utilization is often presented as a measure of appropriately placed charging infrastructure. However, this can be a deceptive measure of how beneficial a particular charging location may be. Currently, the EV charging network is still in its infancy. As a result, crucial charging stations that are currently poorly utilized may be overlooked by using utilization as a sole metric of performance. These remote stations can provide a critical bridge from one locale to another or may significantly increase the operational radius of various EVs. There is also an argument that utilization may not be the most appropriate measure if the goal of the infrastructure is providing "critical" infrastructure and a more positive electric vehicle ownership experience. In this case, utilization can be seen as a supply-centric measure. A more demand-centric countermeasure is EVSE availability. Many charger networks are now presenting online access to real-time feedback from stations, which provides a window into availability to consumers.

There is a multitude of possible calculations for utilization that can be considered, and a reader should be aware of the specific utilization measure being used and the focus of the metric. Some of the possible measures of utilization are as follows:

Availability is a key demand side metric

- Session count utilization
- Charger occupation-based utilization
- Active charging-based utilization
- Infrastructure maximization-based utilization
- Maximum site-based utilization

Session count utilization can provide a quick snapshot into trends and is significantly less resource intensive for calculation using large datasets like the EV WATTS dataset. In this case, the count of sessions that begin at a particular time is counted within a timeframe as described in (1) where U_{sc} is the utilization of n EVSE over t time and *sess* is the count of sessions at each EVSE.

$$U_{sc} = \frac{1}{n} \cdot \frac{1}{t} \cdot \sum_{i=1}^{n} sess_{i,t} \tag{1}$$

Occupancy time

Charger occupation-based utilization for a single EVSE is a measure of the percentage of time within a specified period that a vehicle is connected to the unit relative to the maximum possible connection time as shown in (2). Here n is the number of ports in the dataset, *occ* is the actual occupancy, and *max* is the maximum occupancy possible. Occupancy and the maximum can be measured in seconds, hours, days, etc. The maximum is specific to each EVSE and should not include periods where the unit is not in service.

vs

$$U_{occ} = \frac{1}{n} \sum_{i=1}^{n} \frac{occ_i}{max_i} \tag{2}$$

Charging time

Active charging-based utilization uses a similar calculation (3) as occupation-based utilization but uses the period a charger was providing energy (*ch*). Charge idling (when an EV is plugged into a station but is already fully charged) is not considered in utilization. As with all utilization measures, only chargers in service at the time are considered in this measure.

$$U_{cha} = \frac{1}{n} \sum_{i=1}^{n} \frac{ch_i}{max_i} \tag{3}$$

Power capacity utilization

Infrastructure maximization-based utilization supports the goal of maximizing the investment in assets based on installed power. As such, a 350kW charger charging a vehicle at a constant 100kW has only 29% utilization. This method of utilization can be very valuable for evaluating how right-sized equipment is for a particular location. This metric is also useful for understanding the profitability of a station that charges by the kWh. Where n is the number of ports in the dataset, cap_i is the maximum capacity of the station (usually in kW), t is the time duration and $e_{st.i}$ is the amount of energy transferred from station i over t time, we can write this calculation as (4)

$$U_{power} = \frac{1}{n} \sum_{i=1}^{n} \frac{e_{st,i}}{cap_i} \tag{4}$$

$\frac{\text{Actual Energy Delivered}}{\text{Total Energy Delivered}}$

Particular attention should be paid to the number of ports (n) used to normalize each calculation as well as the time segment in question. In this case, the number of ports is varying over time as ports go on and offline

Charger productivity metric : $\frac{\$}{KWH} \times \frac{KWH\_Delivered}{\$/KWH \times KWH_{available}}$

due to maintenance or other issues. As described previously, periods where a port was unavailable for use by a consumer are not considered in these calculations as much as is practical. The different utilization measures exist depending on the nature of the audience such as consumer, utility, charge network operator, government agency, etc. In the case of an electric utility, Borlaug et. al. [6] pose that an Infrastructure maximization-based utilization is appropriate for utilities and station operators and are used here for comparison.

3.3 Public EVSE Utilization Over Time

Borlaug, et. al. have shown a regression of the public data with key details of the factors affecting utilization [6]. Figures 4 and 5 illustrate three of the average daily public charging station utilization methods over the October 2019 through December 2022 timeframe by venue type for L2 and DCFC stations, respectively. These figures present a five-day rolling average of values. A key observation from these figures, is the effect of COVID-19, especially in the utilization of DCFC in Figure 5 along with the variation in behavior change and rate of recovery to pre-COVID levels by venue type. It can also be seen that the pandemic disproportionately affected DCFC and more strongly in office, multi-use parking, and municipal buildings.

The three methods of utilization highlight the strengths of each, where a steady increase in the average daily energy in kWh/port can be seen across all sectors while connection time remains relatively flat indicating a move to higher capacity vehicles, charging rates and charging levels. Level 2 daily sessions remain relatively flat while DCFC sessions are steadily increasing over time. The highest connection time is L2 multi-use parking. The highest number of sessions per day is DCFC at municipal buildings. DCFC on average has approximately twice the energy use per day. The highest energy use per day is mixed among business office, multi-use parking, municipal buildings, and retail and will be discussed in further detail in the subsequent section regarding daily use.

DCFC have 2x Power use
daily vs L2

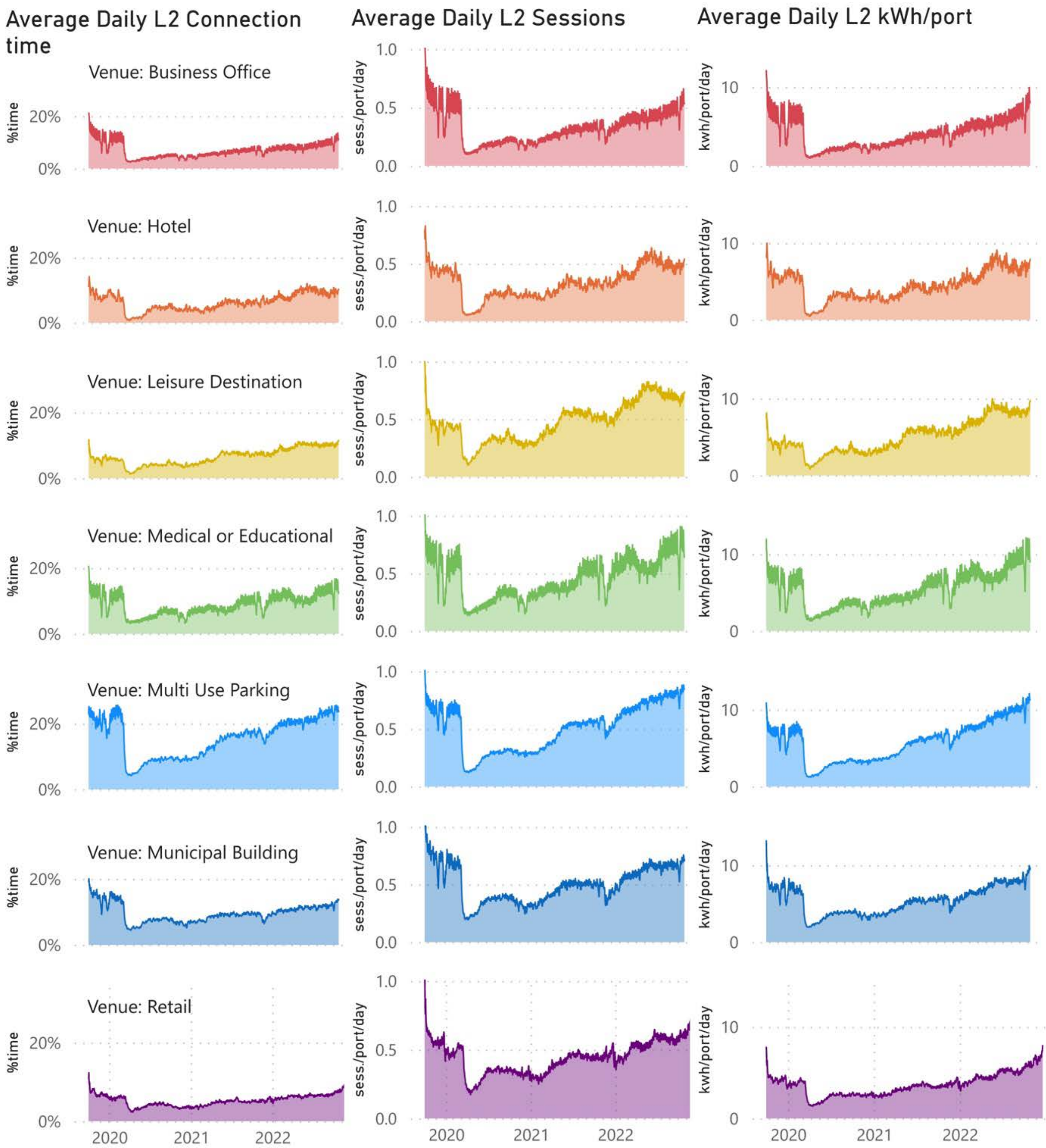

Figure 4: A comparison of three utilization measures for public Level 2 charging station utilization by venue type from October 2019 through December 2022.

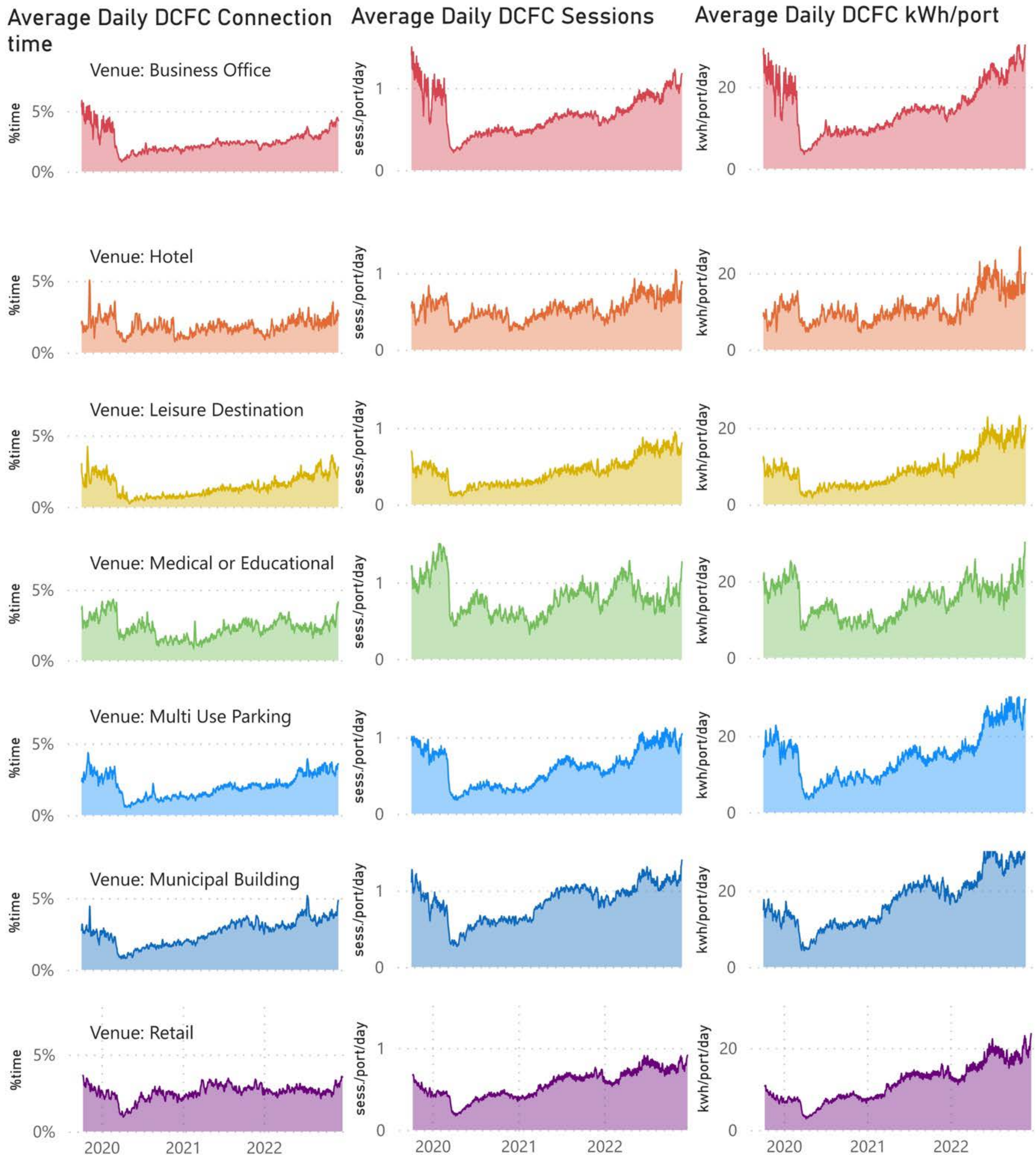

Figure 5: A comparison of three utilization measures for public DCFC charging station utilization by venue type from October 2019 through December 2022.

3.4 Daily Public EVSE Utilization

As was demonstrated in the previous section on use utilization over time, the utilization of EVSE has been steadily increasing since the pandemic. Daily utilization patterns vary widely by venue type, charging level, and weekdays versus weekends. A deep understanding of daily utilization patterns can provide utilities, charging system operators, and local governments with key knowledge to implement a custom mix of EVSE to influence charging behavior towards specific goals such as reduced overall emissions or grid congestion relief. The resulting Level 2 and DCFC daily utilization curves presented in figures 6 and 7 respectively provide this insight. Each of the curves have the characteristic "n" shape (lower usage overnight) which aligns with public charging in general. Private stations typically follow an inverse "u" shaped curve (higher night-time charging use) but are not included in this analysis. Private stations typically include single-family homes, multi-unit dwellings, and fleet operations.

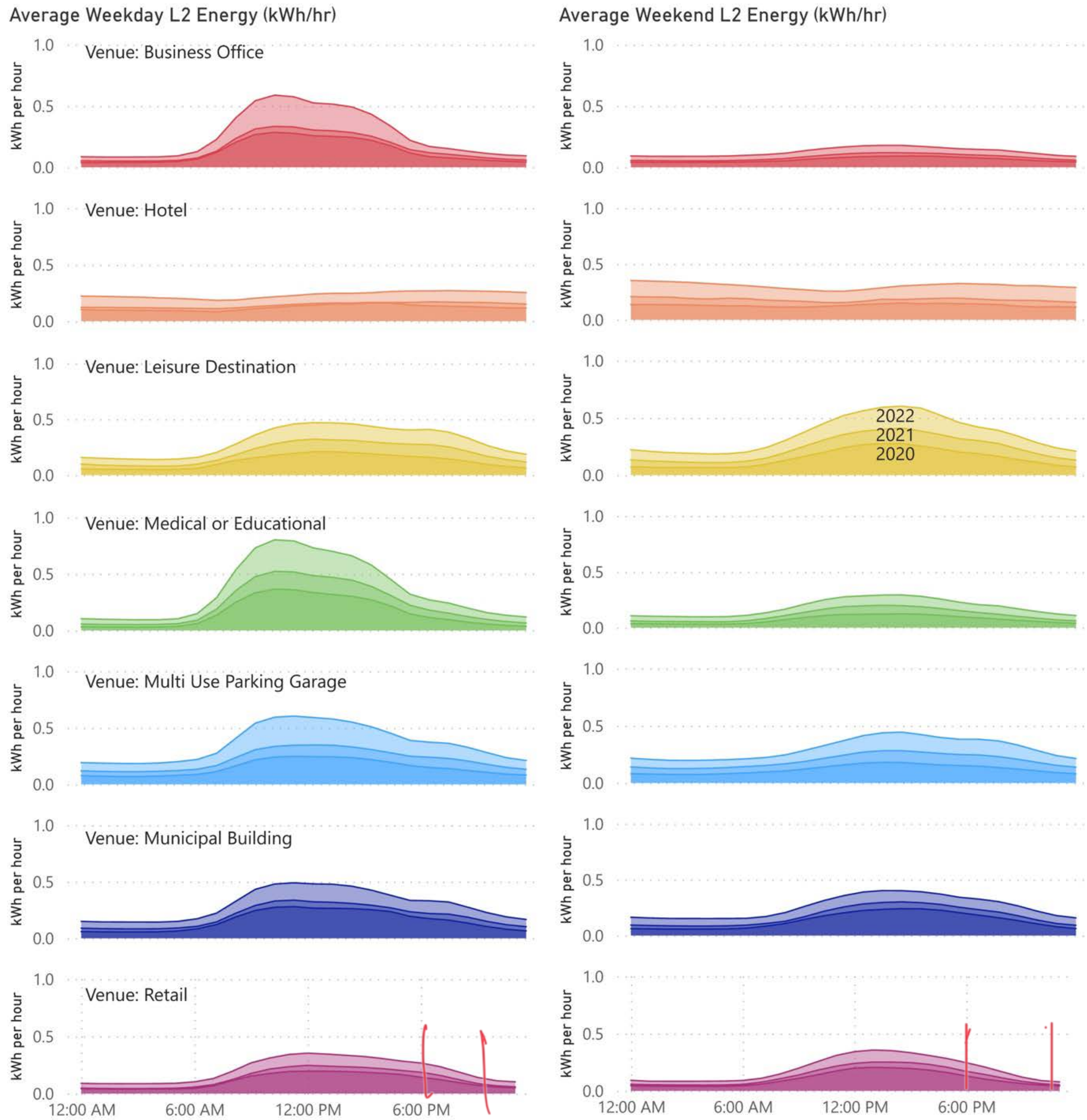

Figure 6: Daily Level 2 Utilization

Several of resulting the use profiles demonstrate a smooth daily curve which very closely follows the observed duck curve seen in solar array production. A utility with high solar penetration and looking to match this curve with demand may consider focusing on the venue types shown. Venue types that have a high daily operating curve are business offices and medical or educational campuses. It is also a significant observation that L2 charging profiles change more significantly between weekday and weekend. Figure 7 shows that DCFC charging provides a more continuous profile on weekend as well as on weekdays. A counterintuitive observation is that public DCFC at business offices has been growing significantly and shows higher energy use on weekends than on weekdays.

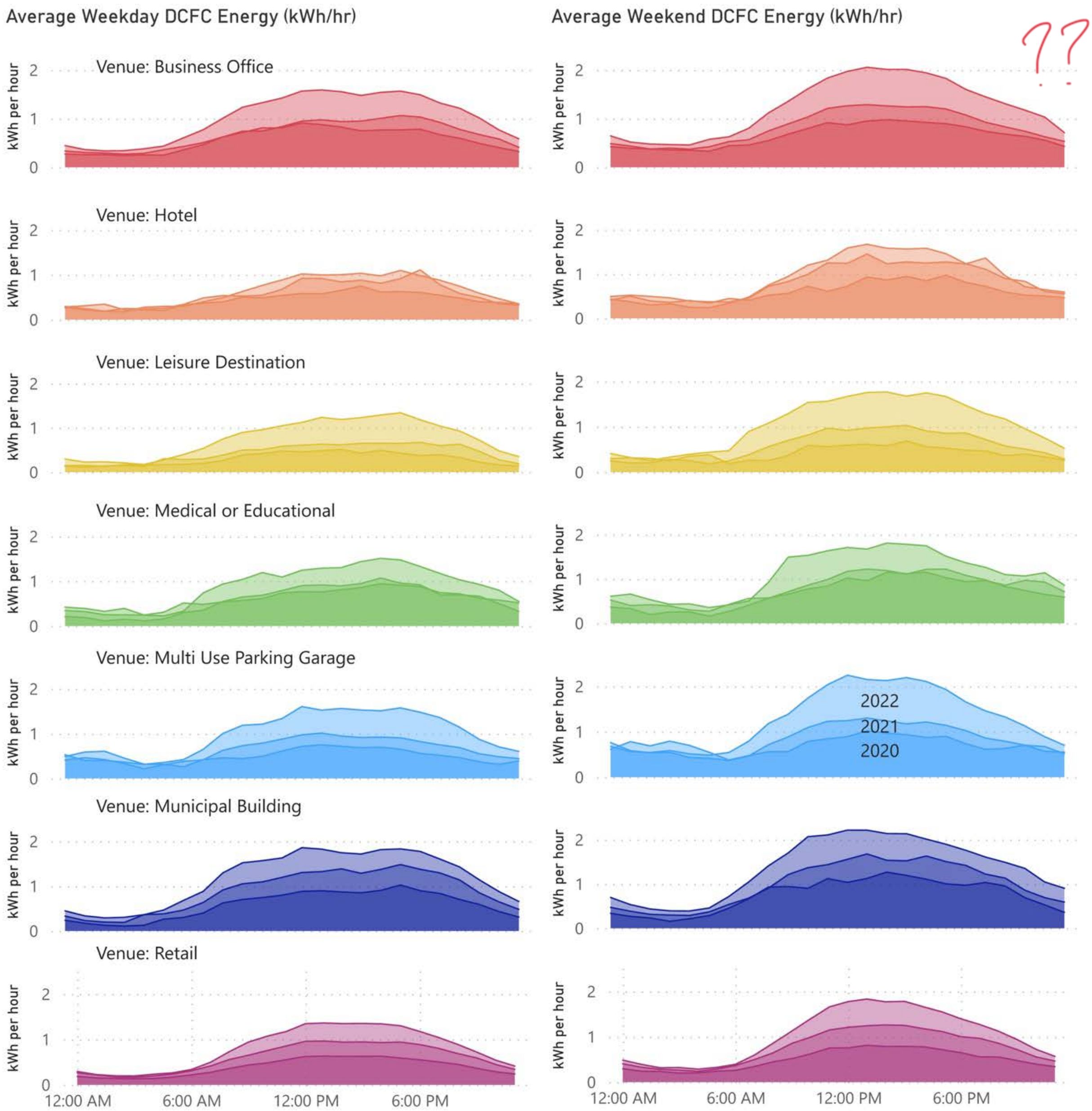

Figure 7: Daily DCFC Utilization

As discussed earlier with utilization over time, the EV charging industry is still recovering from the pandemic, and venues experience different rates of recovery or growth. In figures 6 and 7, we have presented three overlayed annual curves with each becoming lighter for each year. In each case, there has been growth year over year; however, certain venues and charging levels have grown faster than others. Overall DCFC use has been increasing for the public charging sector much faster than Level 2. DCFC at multi-use garages and business offices has seen the fastest growth in usage year over year from 2020 to 2022 with the most significant growth during the middle of the day. The specific data from 2022 hourly occupancy is provided in tables 1-4. The total at the bottom of each table is the sum of the hourly usages and shows the daily average of energy per port (kWh/port/day) in 2022 only. The 2022 data was used as it represents the most current information in a very dynamic field. Table 1 shows that for L2 charging, Medical and Educational campuses provide the greatest peak during the day, yet multi-use parking provides a greater daily average use and is spread more evenly throughout the day. Table 2 shows that Leisure Destinations provide both the highest total and greatest peak for L2 energy on weekends. Public Parking and Municipal are the next highest among L2 on weekends.

Table 1: Average 2022 Level 2 Weekday Port Utilization by Venue

Hour	Business Office	Hotel	Leisure Destination	Medical or Educational Campus	Multi-use Parking Garage/Lot	Municipal Building	Retail
12:00 AM	0.09	0.22	0.16	0.10	0.19	0.15	0.09
1:00 AM	0.08	0.22	0.15	0.10	0.19	0.14	0.09
2:00 AM	0.08	0.22	0.15	0.10	0.18	0.14	0.09
3:00 AM	0.08	0.21	0.14	0.09	0.18	0.14	0.09
4:00 AM	0.08	0.21	0.14	0.09	0.19	0.14	0.09
5:00 AM	0.09	0.20	0.14	0.10	0.20	0.15	0.09
6:00 AM	0.13	0.19	0.16	0.15	0.22	0.17	0.10
7:00 AM	0.23	0.18	0.20	0.29	0.27	0.22	0.13
8:00 AM	[illegible]	0.19	0.28	0.54	[illegible]	0.33	0.19
9:00 AM	0.54	0.20	0.36	0.73	0.54	0.43	0.27
10:00 AM	0.59	0.22	0.42	0.80	0.59	0.48	0.31
11:00 AM	0.57	0.23	0.46	0.79	0.60	0.49	0.34
12:00 PM	0.52	0.24	0.47	0.73	0.59	0.48	0.35
1:00 PM	0.51	0.25	0.47	0.70	0.58	0.48	0.34
2:00 PM	0.49	0.25	0.46	0.66	0.55	0.46	0.33
3:00 PM	0.43	0.25	0.44	0.58	0.51	0.43	0.32
4:00 PM	0.33	0.26	0.41	0.45	0.45	0.38	0.31
5:00 PM	0.22	0.27	[illegible]	0.32	0.39	0.33	0.28
6:00 PM	0.17	0.27	[illegible]	0.27	0.37	0.33	0.27
7:00 PM	0.15	0.27	0.38	0.24	0.36	0.32	0.24
8:00 PM	0.13	0.27	0.33	0.20	0.33	0.27	0.19
9:00 PM	0.11	0.26	0.26	0.16	0.28	0.23	0.14
10:00 PM	0.10	0.26	0.22	0.13	0.23	0.19	0.11
11:00 PM	0.09	0.25	0.19	0.12	0.21	0.17	0.10
Total	**6.24**	**5.58**	**7.19**	**8.43**	**8.63**	**7.07**	**4.87**

Table 2: Average 2022 Level 2 Weekend Port Utilization by Venue

Hour	Business Office	Hotel	Leisure Destination	Medical or Educational Campus	Multi-use Parking Garage/Lot	Municipal Building	Retail
12:00 AM	0.09	0.35	0.22	0.11	0.22	0.16	0.09
1:00 AM	0.09	0.35	0.21	0.10	0.21	0.16	0.08
2:00 AM	0.09	0.34	0.20	0.10	0.20	0.15	0.08
3:00 AM	0.09	0.33	0.19	0.10	0.20	0.15	0.08
4:00 AM	0.09	0.32	0.18	0.10	0.20	0.15	0.08
5:00 AM	0.09	0.32	0.19	0.10	0.20	0.15	0.09
6:00 AM	0.10	0.31	0.20	0.11	0.21	0.15	0.09
7:00 AM	0.10	0.29	0.24	0.13	0.22	0.17	0.11
8:00 AM	0.11	0.28	0.30	0.17	0.25	0.21	0.15
9:00 AM	0.14	0.27	0.38	0.21	0.29	0.26	0.20
10:00 AM	0.15	0.26	0.45	0.25	0.33	0.31	0.25
11:00 AM	0.16	0.26	0.52	0.28	0.37	0.36	0.31
12:00 PM	0.17	0.27	0.56	0.28	0.41	0.39	0.34
1:00 PM	0.18	0.29	0.59	0.29	0.44	0.40	0.36
2:00 PM	0.18	0.30	0.60	0.29	0.44	0.40	0.35
3:00 PM	0.17	0.31	0.58	0.28	0.42	0.39	0.33
4:00 PM	0.16	0.32	0.52	0.26	0.40	0.37	0.31
5:00 PM	0.15	0.32	0.46	0.23	0.38	0.34	0.28
6:00 PM	0.15	0.32	0.42	0.21	0.38	0.33	0.25
7:00 PM	0.14	0.32	0.39	0.20	0.37	0.30	0.21
8:00 PM	0.13	0.31	0.34	0.17	0.33	0.27	0.16
9:00 PM	0.11	0.30	0.28	0.14	0.28	0.22	0.12
10:00 PM	0.10	0.30	0.24	0.12	0.24	0.18	0.09
11:00 PM	0.09	0.29	0.21	0.11	0.21	0.16	0.08
Total	**3.02**	**7.32**	**8.49**	**4.33**	**7.20**	**6.15**	**4.50**

Tables 3 and 4 provide insight into the average daily distribution of DCFC charging. As shown in figure 7, all DCFC show larger daily swings than L2. The peak utilization for this charge level overall is on weekends with 31 kWh/port/day at multi-use garages. The highest weekday use is at municipal buildings with 28 kWh/port/day. Most venues show fairly similar usage profiles for weekend and weekday DCFC operations with higher use on weekends.

Table 3: Average 2022 DCFC Weekday Port Utilization by Venue

Hour	Business Office	Hotel	Leisure Destination	Medical or Educational Campus	Multi-use Parking Garage/Lot	Municipal Building	Retail
12:00 AM	0.26	0.17	0.13	0.26	0.28	0.24	0.15
1:00 AM	0.18	0.13	0.08	0.18	0.17	0.16	0.10
2:00 AM	0.15	0.10	0.08	0.12	0.14	0.12	0.08
3:00 AM	0.14	0.08	0.07	0.13	0.11	0.11	0.07
4:00 AM	0.17	0.13	0.05	0.08	0.11	0.13	0.09
5:00 AM	0.23	0.17	0.12	0.12	0.15	0.22	0.12
6:00 AM	0.39	0.20	0.22	0.21	0.27	0.42	0.19
7:00 AM	0.57	0.30	0.34	0.59	0.47	0.63	0.33
8:00 AM	0.81	0.42	0.56	0.79	0.80	1.04	0.55
9:00 AM	1.04	0.56	0.70	0.96	1.01	1.28	0.75
10:00 AM	1.14	0.68	0.78	1.08	1.09	1.36	0.88
11:00 AM	1.25	0.82	0.93	1.01	1.19	1.47	1.00
12:00 PM	1.39	0.96	1.01	1.15	1.42	1.70	1.16
1:00 PM	1.41	0.93	1.15	1.21	1.40	1.67	1.17
2:00 PM	1.37	0.94	1.08	1.29	1.44	1.60	1.17
3:00 PM	1.31	0.97	1.08	1.32	1.41	1.59	1.18
4:00 PM	1.35	0.95	1.10	1.41	1.39	1.69	1.18
5:00 PM	1.38	1.01	1.15	1.38	1.41	1.66	1.12
6:00 PM	1.30	0.88	1.04	1.22	1.29	1.59	0.99
7:00 PM	1.12	0.79	0.91	1.07	1.16	1.40	0.85
8:00 PM	0.98	0.67	0.79	0.91	0.97	1.18	0.68
9:00 PM	0.79	0.52	0.56	0.81	0.69	0.92	0.53
10:00 PM	0.57	0.40	0.34	0.59	0.50	0.67	0.36
11:00 PM	0.39	0.26	0.22	0.39	0.37	0.45	0.25
Total	**19.71**	**13.05**	**14.47**	**18.28**	**19.25**	**23.30**	**14.95**

Table 4: Average 2022 DCFC Weekend Port Utilization by Venue

Hour	Business Office	Hotel	Leisure Destination	Medical or Educational Campus	Multi-use Parking Garage/Lot	Municipal Building	Retail
12:00 AM	0.33	0.25	0.17	0.34	0.29	0.35	0.20
1:00 AM	0.22	0.18	0.11	0.25	0.21	0.21	0.14
2:00 AM	0.17	0.12	0.06	0.17	0.18	0.14	0.10
3:00 AM	0.15	0.11	0.07	0.14	0.16	0.11	0.09
4:00 AM	0.14	0.10	0.07	0.13	0.15	0.11	0.08
5:00 AM	0.19	0.11	0.12	0.12	0.13	0.14	0.10
6:00 AM	0.30	0.18	0.20	0.20	0.23	0.32	0.15
7:00 AM	0.47	0.34	0.47	0.31	0.44	0.65	0.29
8:00 AM	0.73	0.56	0.70	0.63	0.77	0.96	0.51
9:00 AM	0.98	0.78	0.95	1.09	1.02	1.30	0.75
10:00 AM	1.24	1.03	1.19	1.32	1.38	1.67	0.99
11:00 AM	1.44	1.10	1.32	1.38	1.60	1.78	1.22
12:00 PM	1.57	1.33	1.45	1.40	1.81	1.87	1.32
1:00 PM	1.63	1.40	1.54	1.46	1.77	1.89	1.38
2:00 PM	1.61	1.40	1.56	1.58	1.79	1.81	1.34
3:00 PM	1.60	1.33	1.44	1.53	1.79	1.80	1.33
4:00 PM	1.54	1.34	1.47	1.50	1.70	1.75	1.24
5:00 PM	1.40	1.25	1.29	1.26	1.60	1.59	1.13
6:00 PM	1.24	1.09	1.13	1.12	1.32	1.46	0.97
7:00 PM	1.08	0.93	0.95	0.97	1.11	1.30	0.83
8:00 PM	0.95	0.77	0.87	0.84	0.96	1.11	0.69
9:00 PM	0.81	0.63	0.64	0.80	0.76	0.93	0.53
10:00 PM	0.65	0.42	0.42	0.76	0.53	0.67	0.38
11:00 PM	0.40	0.35	0.25	0.47	0.38	0.49	0.26
Total	**20.82**	**17.08**	**18.44**	**19.74**	**22.10**	**24.43**	**16.03**

4 Conclusions

The COVID-19 pandemic dramatically impacted the utilization of EVSE in the United States beginning with a precipitous drop in utilization in the first two weeks of March 2020. The drop in utilization was felt across all venue types and both L2 and DCFC charging stations; however, some venue types were more negatively impacted than others, and some were slower to recover from the drop. Overall, charging station utilization has recovered with DCFC becoming much more prevalent for public charging than before the pandemic.

Several distinct methods of evaluating utilization were discussed and evaluated along with the merits of each of the three. After presenting the EV WATTS dataset in three of the possible methods, the authors present detailed results from 2022 across multiple venue types using an energy utilization metric.

L2 charging profiles show a much greater weekday-to-weekend differential with higher use during weekdays. Business offices and Medical or educational campuses have the highest peak usage in L2 charging. DCFC shows higher use on weekends, but less variation between weekdays and weekends. DCFC public charging shows a greater peak daily concentration of use in the middle of the day versus L2 with a flatter distribution.

Overall port energy use in L2 ranges from 5.83 kWh/day for retail establishments on weekdays to 10.6 kWh/port/day for leisure destinations on weekends in 2022. Overall daily port energy use in DCFC ranges from 15.04 kWh/day for hotels on weekdays to 32.74 kWh/port/day for municipal buildings on weekends in 2022.

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Presenter Biography

Ewan Pritchard received his Ph.D in Mechanical Engineering from North Carolina State University and has worked extensively in the electric vehicle space for over 25 years. His primary area of focus has been in the electrification of school buses with a focus on overcoming the barriers to adoption through analysis and research. Ewan's doctoral thesis focused on developing a fluid energy model of the overrunning case of a torque converter in response to the development of a parallel post transmission plug-in hybrid school bus. The model explained the significant loss of energy found in the commercially available 2006-2008 International Truck and Bus plug-in hybrid school buses. Ewan currently works as a Subject Matter Expert for Energetics from his home office in Raleigh, NC.