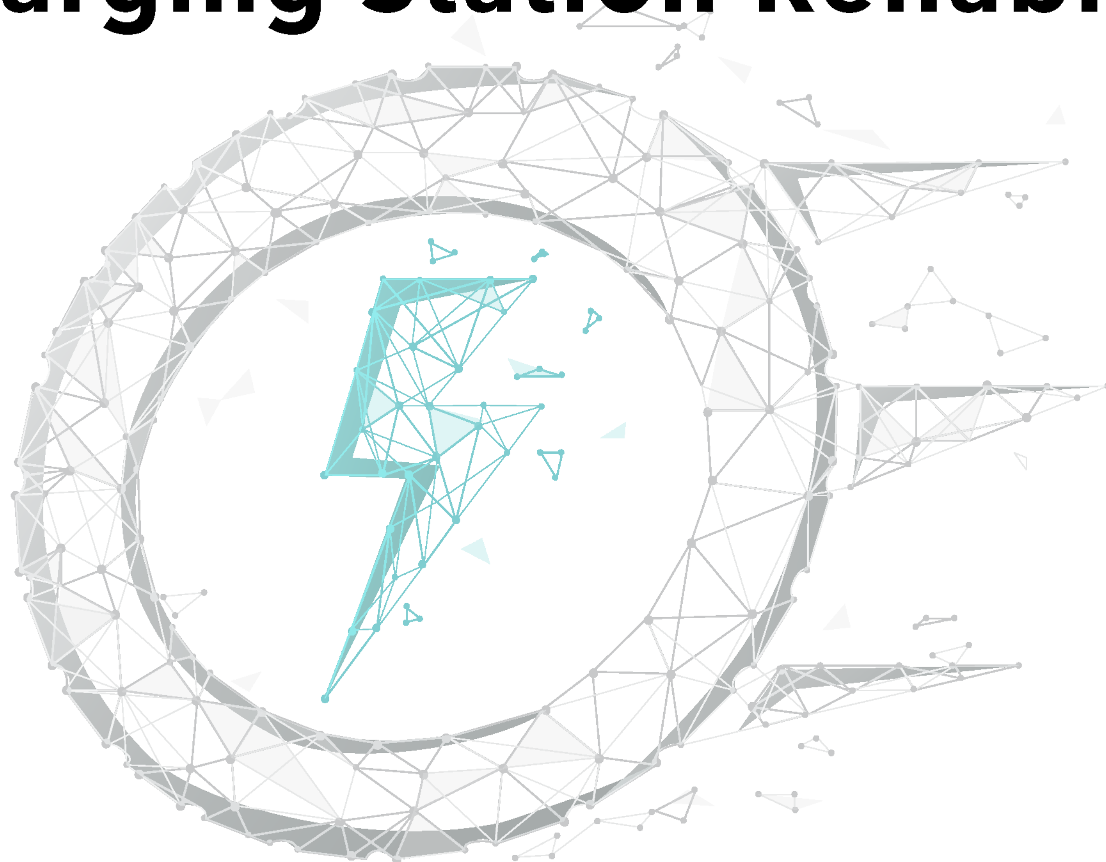
MARCH 2024



EV WATTS WHITEPAPER SERIES

Electric Vehicle Charging Station Reliability



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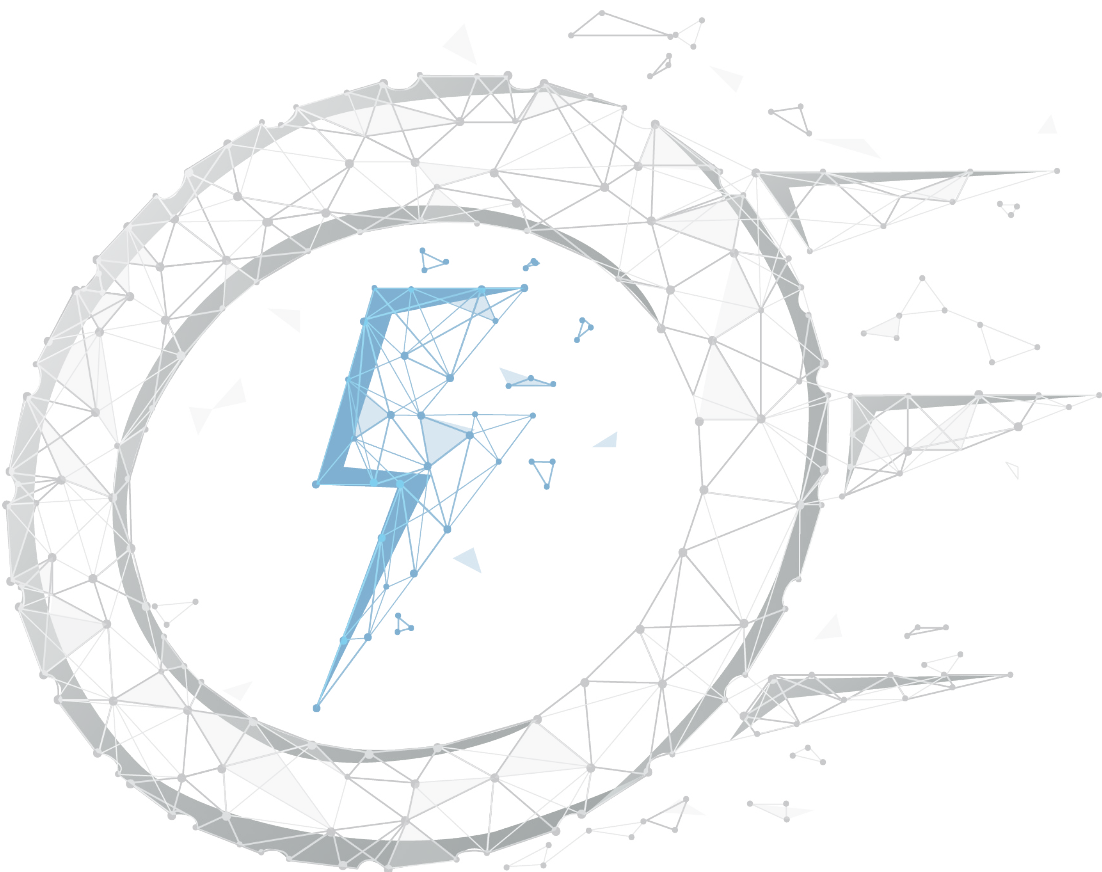

Acknowledgment

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Vehicle Technology Program, Award Number DE-EE0008890.

energetics
Clean Energy Consulting

Electric Vehicle Charging Station Reliability

Introduction

As electric vehicles (EVs) grow in popularity, ensuring a universally reliable and accessible public charging experience becomes an increasingly important component of fulfilling demand and increasing ownership satisfaction. Unfortunately, the nascent and unpredictable nature of public EV charging is a challenge for drivers that use public chargers, with greater impacts on drivers with limited or no access to workplace and/or home charging. This study leverages charging session data to quantify the experience of EV drivers using error codes and power transfer data reported by charging station equipment to quantify the most common issues preventing drivers from charging or from receiving expected charge levels.

> *"The declining customer satisfaction scores for public charging should be concerning to automakers and, more broadly, to public charging stakeholders"*
> - Brent Gruber, executive director of the EV practice at J.D. Power[i]

According to the *J.D. Power 2023 U.S. Electric Vehicle Experience (EVX) Public Charging Study℠*, between 2022 and 2023, customer satisfaction with public alternating current (AC) Level 2 charging declined by approximately 1.6% and has dropped annually since the study began in 2021. Satisfaction with direct current (DC) fast chargers declined even further, dropping 20 points to 654, on the study's 1,000-point scale.[i] Common issues identified by researchers and in mainstream media include problems accessing charging stations (e.g., lack of charging stations where they're needed, damaged connectors or cables, vehicles blocking access to chargers when not charging), hardware malfunctions (e.g., broken or worn cables and connectors, faults in internal charger electronics), and software problems (e.g., inability to authorize payment methods, communication problems between vehicle/charger/server).

Energetics leads EV WATTS (Electric Vehicle Widescale Analysis for Tomorrow's Transportation Solutions), a multi-sector project that facilitates the nation's move toward sustainable transportation. The project is collecting real-world use data from plug-in EVs and charging stations to address a growing need for practical information about vehicle electrification. The team analyzes these data to improve our understanding of driving and charging patterns. EV WATTS is helping to demonstrate how the latest advancements in EVs and charging station technology address barriers, improve the business case for electrification, and determine what behavioral changes electrification may require.

The project uses charging station data and vehicle usage data to build one of the largest datasets of its kind. The data collected for EV WATTS is aggregated and anonymized so that it can serve as a resource to researchers, policymakers, and other stakeholders. Using the data, the team has created interactive dashboards that display statistics and findings from EVs and charging stations. The dashboards allow users to explore this anonymized dataset, looking at energy demand, use patterns, charging details, and more. The most recent EV WATTS dashboards are available at EVWATTS.org.

EV WATTS is sponsored by the U.S. Department of Energy (DOE). Input and other assistance is provided by DOE national laboratories, Clean Cities Coalitions, fleets, state and local governments, vehicle manufacturers, utilities, EV drivers, and charging station providers.

EV WATTS

The analysis performed in this study seeks to identify trends and explain commonalities using a sample of >13 million charging sessions recorded in the EV WATTS database. The charging sessions took place across various geographic regions, site types, and charger power levels. The results of this study allow policymakers and infrastructure professionals to better identify and understand drivers' primary pain points and examine how the charging network can be made more resilient and reliable.

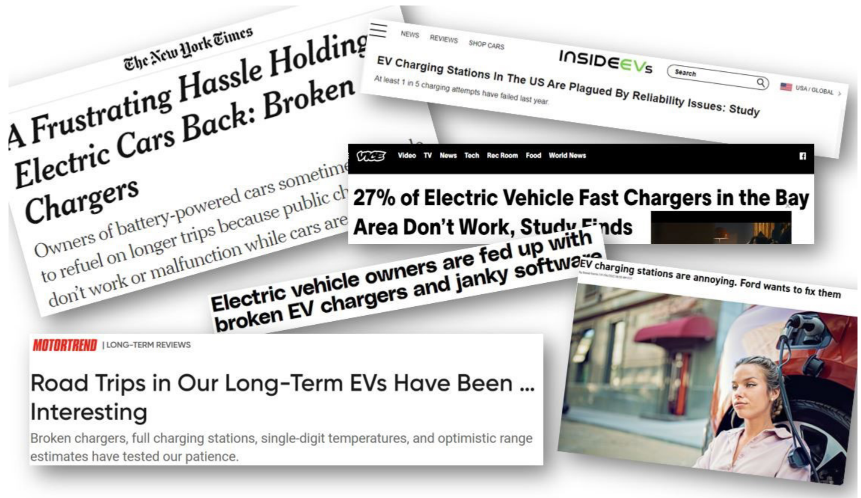

Figure 1: EV charging issues are commonly reported by mainstream media and industry publications

Data and Methodology

EV WATTS Data

A total of 13,192,532 individual sessions were examined—comprising 10,681,759 AC Level 2 and 2,510,773 DC fast charging sessions—using two methodologies, described below. The sessions cover 42 months of data (July 2019 through December 2022) and include all 48 contiguous states, Hawai'i, Washington, DC, and Puerto Rico. A "session," in this context, runs from the initial detection of a vehicle plugging into a charging station to the termination of that connection, regardless of the amount of energy dispensed by the station or the cause of the session's ending.

13.2M
Charging Sessions

42
Months

49
States
(plus Puerto Rico and Washington, DC)

Outside Sources

A combination of Open Charge Point Protocol (OCPP) documentation and interviews with network service providers informed the research team's understanding of which session ending codes qualified as "successful" or "unsuccessful" sessions. The EV WATTS sessions could then be sorted and aggregated based on their session ending codes.

Methodology

Assessment Based on Charging Session Termination Cause

There are 2,436,294 sessions in the sample data that report the conditions triggering the termination of each charging session in the "*ended_by*" field. The reported values were used to determine which sessions ended under "*normal*" circumstances (triggered by the user or charging station as part of an expected behavior) and which exhibited "*abnormal*" charging station behavior (causing an unsuccessful charging session). The research team used these codes to categorize charging sessions by their terminations (whether "normal" or "abnormal"). The team isolated commonly reported codes, estimated the overall success rate for initiated charging sessions, and determined general user experience bins (e.g., unable to charge, partial charge, successful charge).

The EV WATTS session data were aggregated by unique stop codes, based on an interpretation of raw values in the *ended_by* field, to determine the full spectrum of session termination conditions. "Normal" stop codes, shown in **Table 1**, include any sort of customer interaction or expected automatic cessation.

Table 1. "Normal" Charging Session Stop Codes

Stop Code	Definition
Plug-out at Vehicle or Station	Connector disconnected from vehicle
Customer	Customer ended session via app, station, etc.
Stop Button	Stop button pushed
Session Ended by Unlock	Session ended via unlock command at station or car
CPS Server	Cyber-physical server (CPS) terminated session per user request or other limit (e.g., kWh dispensed)
Time of Charge Reached	Allocated charging time expired

Meanwhile, "*abnormal*" stop codes, shown in **Table 2**, include any sessions ended because of electrical trips, external errors (e.g., loss of power, station resets), or other faults.

Table 2. "Abnormal" Charging Session Stop Codes

Stop Code	Definition
Timeout	Session ended by a failure of a component to respond
Plug Removed during Reboot	Vehicle unplugged during station reboot
Vehicle Triggered Emergency Stop	Vehicle required charger to end charging session
Station or Outlet Unreachable/Offline	Session stopped because of a lack of connectivity from the station
Electrical Fault or Failure	Issues (e.g., shorts, overcurrent events, loss of proximity pin) triggered a session stop
Physical Fault or Failure	Issues (e.g., overheating, ventilation faults, stuck relays) triggered a session stop
Unknown	Charging station reported unknown cause for session termination

This broad classification of stop codes allows for a high-level examination of "normal" versus "abnormal" session terminations and further subdivision of error rates.

Assessment Based on Power and Energy Delivery

Quantifying sessions based on stop codes offers a broad overview of unsuccessful charging behavior but is limited to network providers that report this data field. This approach is also subject to the network provider software's interpretation of session termination triggers, based on the electrical signals it receives.

Research conducted by Gamage et al. (2023) at the University of California, Davis, suggests four main categories of charging failure states.[ii] Of note for this analysis are the criteria for "*throttled charging*" and "*no-charge events*" (referred to as "point errors" in the UC Davis study). Nearly all charging stations in the EV WATTS database quantify and report the transfer of power, so the EV WATTS team could leverage this same approach to examine a much larger sample of sessions—the full 13,192,532 noted above.

Throttled Charging

A common problem with EV charging occurs when the station dispenses energy at a slower rate than expected, referred to as "throttled charging." The EV WATTS database reports power rating at the port level for both AC Level 2 stations and DC fast chargers. Using the metrics reported in the EV WATTS data, the researchers were able to determine the expected power delivery per port, based on the number of ports associated with each charger and the nameplate power rating of each charging unit. Below are the criteria for identifying a throttled charging session:

- Session average power (defined as $\frac{\textit{Energy dispensed (kWh)}}{\textit{Charging time (h)}}$) is <70% of the nameplate power of a charger, or
- For dual-port chargers, the session average power is <70% of one-half of the nameplate power of a dual-port charger.

In other words, if a session at a single-port, 50 kW DC fast charger averaged more than 35 kW over the time the vehicle spent charging, it was considered a normal session. Conversely, if a power-sharing dual-port 50 kW DC fast charger averaged less than 17.5 kW (70% of 25 kW) over the time the vehicle spent actively charging, the session was considered "throttled."

No-Charge Events

The UC Davis study classifies charging sessions that do not transfer significant energy to vehicles as "*point error*" sessions (referred to here as "no-charge events"), regardless of session length. A minimum energy threshold was not specified in the study. Under EV WATTS reporting methodology, the minimum energy threshold for a meaningful session was set at 0.3 kWh, and that threshold was adopted for the current study.

Limitations and Assumptions

This analysis of the EV WATTS session data results in a broad assessment of a driver's ability to charge an EV once it is plugged in. The EV WATTS team acknowledges the following limitations and assumptions in this study:

- The dataset captures only instances when drivers successfully connect their vehicles to the chargers, meaning the dataset does not reflect times when chargers are obstructed or offline due to a power or network outage.

- The dataset does not capture any charging at non-networked stations.
- The dataset consists primarily of sessions from a single charging provider; smaller providers are not particularly well-represented in the dataset, and thus any reporting characteristics specific to the primary charging provider may be disproportionately represented.
- Private stations were excluded from the analysis.
- Of the 11.97 million charging sessions at public charging stations with some plug-in duration, 9.53 million sessions (79.64%) do not report an *ended_by* code.
- The data do not provide sufficient granularity to identify when power transfer is being shared between ports at a single station. This was found to have a measurable but insignificant effect on the analysis results.

Findings

In the examination of 2.4 million sessions that reported stop codes, 15,926 (0.7%) reported termination by abnormal codes. **Table 3** provides a breakdown of reported abnormal stop codes.

When looking at the actual session behavior, however, the apparent number of problematic sessions increases. When applying criteria from the UC Davis study to the larger sample of EV WATTS data, the analysis shows that 3,541,192 AC Level 2 sessions and 1,296,555 DC fast charging sessions meet the criteria for throttled charging–representing 37% of sessions analyzed. In most of these cases (99% overall; 91% for DC fast charging; 99% for AC Level 2 charging), the stations did not report abnormal stop codes. **This suggests that more than 1 in 3 charging sessions dispenses power at a slower-than-expected rate**, which may or may not indicate an error.

The impact on the user experience in these cases is moderate, with lower impacts likely at AC Level 2 stations, as a driver using long-dwell charging is generally less sensitive to the charging speed. While the EV driver likely expected to receive more of a charge than was delivered, the battery state of charge (SoC) did increase, and additional driving range was achieved. However, it should be noted that charging speed can be influenced by many external factors not captured by EV WATTS

Table 3. Count of Abnormal Stop Codes

Stop Code	Count
Electrical Fault or Failure	4,820
Plug Removed during Reboot	3,979
Station or Outlet Unreachable/ Offline	2,370
Vehicle Triggered Emergency Stop	1,950
Unknown	1,330
Timeout	910
Physical Fault or Failure	567
Total	**15,926**

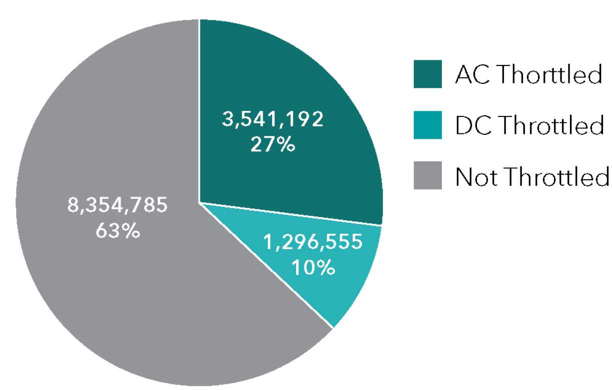

Figure 2: AC Level 2 and DC fast charging session throttling

data, including vehicle SoC, power-splitting starting or terminating partway through a session, active demand management, or limited vehicle charging capacity (which may not be equal to DC fast charging stations' charging speed).

Separately, 308,325 AC Level 2 sessions and 76,003 DC fast charging sessions (2.9% of sessions analyzed) were found to meet the criteria for no-charge events, i.e., less than 0.3 kWh was dispensed to the vehicle. This indicates that **roughly 1 out of every 30 charging sessions dispensed a negligible amount of power to the vehicle**. In most of these cases (95% overall; 65% for DC fast charging; 97% for AC Level 2 charging), the stations did not report abnormal stop codes. While the number of incidents could be considered relatively low, the negative impact on the user experience is high because the driver may have been unaware of the issue until returning to the vehicle and discovering the unexpectedly low increase in battery SoC.

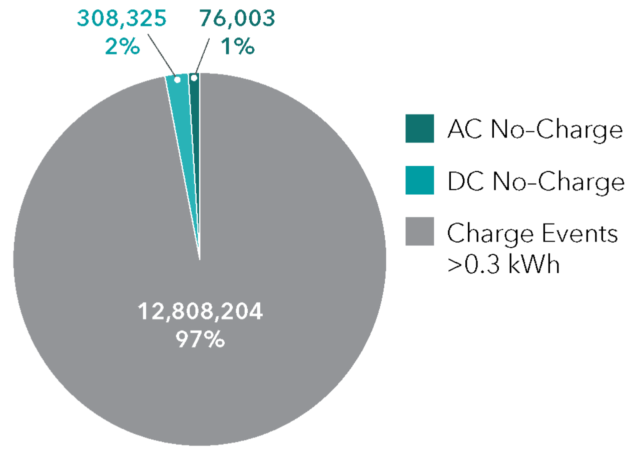

Figure 3: AC Level 2 and DC fast charging no-charge events

Summary

Initiating a charge at an EV charging station requires a series of internal checks and communication exchanges that could involve multiple external entities, including network service providers, payment authorization services, electrical utilities, and the vehicle being charged. Each of these touchpoints provides an opportunity for an error or failure. The EV WATTS researchers found that relying solely on error codes to gauge abnormal or unsatisfactory charging station behavior likely undercounts the number of issues experienced by EV drivers. The potential for low estimates has significant implications for entities that operate EV chargers, as proactively monitoring and repairing charging stations is critical to maintaining reliable charging infrastructure. Figure 4 shows that while charging sessions within the EV WATTS dataset are largely successful, chargers frequently dispense at power lower than 30% of rated capacity, frustrating drivers who anticipate charging at the advertised speed.

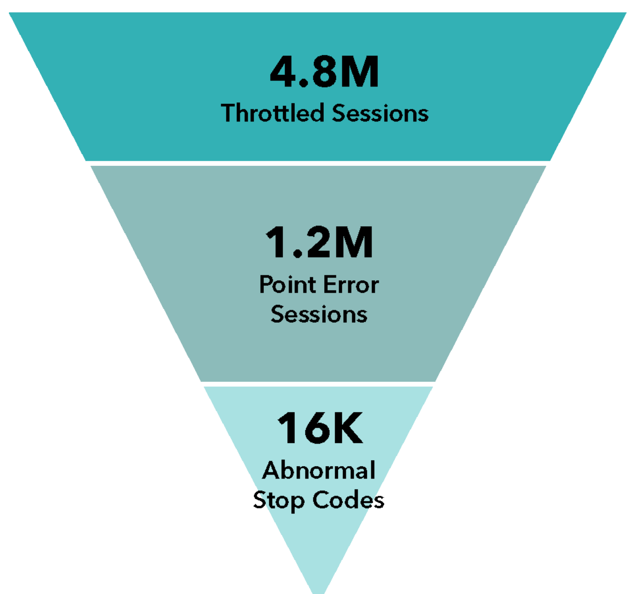

Figure 4: Session count pyramid showing the stages of analysis and their associated numbers of sessions

Immediate next steps for this work may include exploring another dimension of charging reliability outlined in the UC Davis study: identifying sessions in which the charging process is interrupted prematurely. One approach is to quantify the number of sessions with extremely short idle times, i.e., the time difference between the cessation of active charging and the termination of the session itself. Some amount of idle time is normal, but extremely short idle times may indicate a session that is terminated unexpectedly, i.e., while the charger is actively transferring energy to the vehicle.

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Endnotes

[i] J.D. Power. “Public Charging Issues May Short-Circuit EV Growth, J.D. Power Finds.” August 16, 2023. **https://www.jdpower.com/business/press-releases/2023-us-electric-vehicle-experience-evx-public-charging-study**.

[ii] Tisura Gamage, Alan Jenn, and Gil Tal. “Reliability of Corridor DC Fast Chargers and the Prevalence of no-Charge Events.” 36th International Electric Vehicle Symposium and Exhibition (EVS36) Sacramento, California, June 11–14, 2023. **https://evs36.com/wp-content/uploads/finalpapers/FinalPaper_Gamage_Tisura.pdf**.