Resilience of Electric Vehicle Charging Infrastructure During Natural Disasters: Insights from Hurricane Beryl

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A. JAMES CLARK SCHOOL OF ENGINEERING

NHERI Natural Hazards Engineering Research Infrastructure

2025 NATURAL HAZARD Annual Meeting

July 13-17

Broomfield, Colorado

BACKGROUND AND MOTIVATION

- Rapid growth of EV sales introduces challenges for grid operators, policymakers, charging providers, and users under disaster conditions *(IEA 2024; Li et al., 2023; Almutairi et al., 2022).*
- EV charging infrastructure is vulnerable to hazards such as flooding, power outages, and road blockages, disrupting service availability and limiting emergency mobility during disasters (Essus and Rachunok 2024; Raman, and Peng 2022; Li, Ma, and Mostafavi 2025a).
- Current EV infrastructure planning lacks sufficiency and resilience during disasters, leading to unavailability of charging ports and interrupting emergency mobility *(Babaei and Wong 2024).*
- Understanding spatiotemporal patterns of EV charging behavior during disasters is essential to guide recovery planning and the development of redundant, resilient, and equitable EV charging networks *(Movahedi et al. 2024; Adderly et al. 2018; Feng et al. 2020).*
- **Case Study:** Examining EV charging usage within **Harris County, Texas** before, during, and after **Hurricane Beryl's landfall on July 8, 2024**, capturing disruption and recovery patterns under disaster conditions.

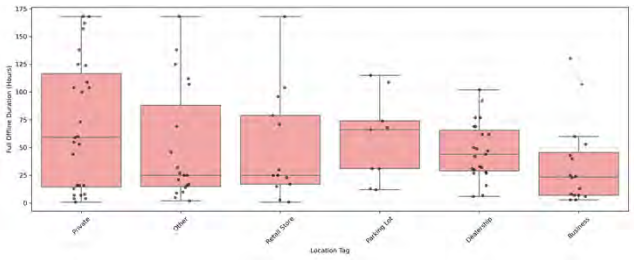
RESEARCH QUESTIONS

- How do EV charging station usage dynamically change across time during a course of a disaster?
- What are the recovery trends of EV charging station usage across spatial scales, and how are spatially clustered stations impacted by disasters?

Data & Methods

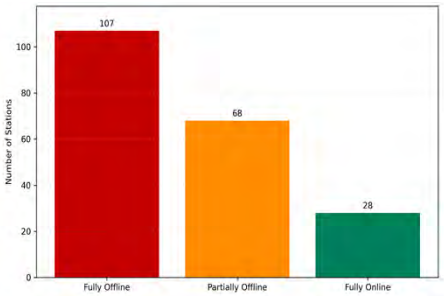
1. **Data Source:** Collected 10-minute interval charging port availability data for ~65% of public charging stations in Harris County (April 1 – July 21, 2024).
2. **Panel Data Structure:** Transformed raw data into station-date panel data with daily profiles of available and in-use ports.
3. **Study Period**: April 7-14 was considered as disaster period, while other dates were considered normal situations.
4. **Station availability status**: Charging stations have been categorized as fully offline, partially offline, or fully online during July 7–14 based on at least two hours of unavailability
5. **Temporal Clustering:** Applied k-means clustering to 4-hour averaged z-scores of usage to identify temporal usage patterns.
6. **Spatial Clustering:** Grouped stations into 20 geographic clusters using spatial proximity and cross-referenced with temporal clusters to analyze spatiotemporal patterns of disruption and recovery across Harris County.

Distribution of full outage durations by location tag for fully offline EV charging stations

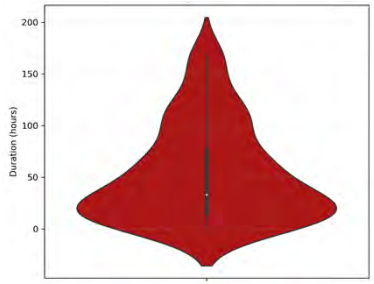


Results

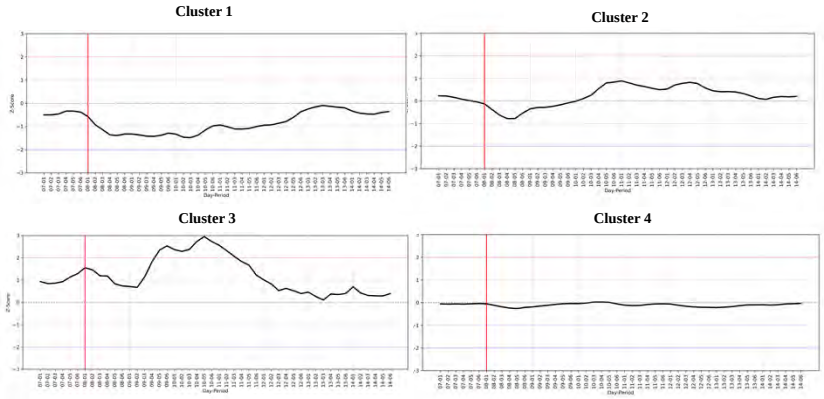
Station's offline status during July 7-14



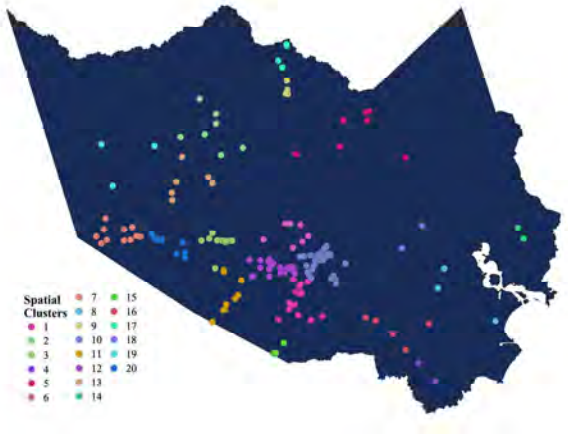
Distribution of offline hours for fully offline stations



Temporal usage patterns of EV charging stations during Hurricane Beryl, 2024

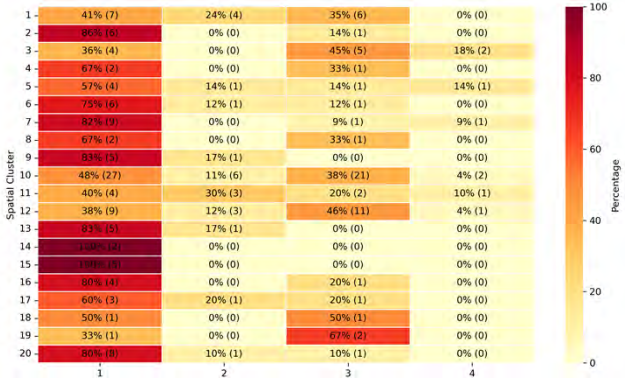


Geographic distribution of 20 spatial clusters of EV charging stations across Harris County, based on station proximity



Results

Heatmap showing the percentage of stations in each spatial cluster that exhibited one of the four temporal usage patterns



DISCUSSION AND CONCLUSION

- Nearly **75%** of EV charging stations experienced operational disruptions during Hurricane Beryl.
- Temporal clustering revealed **1) stability, 2) sustained decline, 3) post-outage rebound, and 4) immediate post-landfall surges** in usage.
- Stations at **public, visible** locations recovered faster than those at residential or less-publicized sites.
- Cross-referencing spatial clusters with temporal patterns revealed location-specific recovery trajectories, with some areas showing stable usage while others had delayed recovery or contrasting station behaviors nearby.
- Stations in **northern and peripheral** areas faced more complete outages, while central/southern urban areas displayed mixed statuses, reflecting disparities in grid robustness and recovery prioritization.
- Findings support targeted interventions, such as prioritizing high-use zones for fast charging, backup power, and microgrids while reinforcing underperforming areas to improve resilience and equitable EV charging networks.
- **Future Research Needs:** Calls for integrating physical damage data, mobility behavior modeling, and multi-event/region analysis to identify resilience patterns and guide equitable infrastructure investments.

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