Technological Barriers to Electric Vehicle Charging at Multi-Unit Dwellings in the U.S.

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Summary

Vehicle Charging Innovations at Multi-Unit Dwellings (VCI-MUD) is a three-year project funded by the U.S. Department of Energy and led by the Center for Sustainable Energy (CSE) in collaboration with Forth and Energetics. Installing electric vehicle (EV) chargers at multi-unit dwellings (MUDs) requires overcoming a number of technological barriers, including but not limited to, architectural, ownership and management, cost, decision-making, and energy management. The project tested possible solutions for overcoming technological barriers of power supply, load control, access control, and billing. This paper describes the technologies explored, and discusses the policy and investment implications of the project's findings.

Keywords: charging, infrastructure, electric vehicle supply equipment (EVSE), power management, load management

1 About the Project

Approximately 31% of residences in the U.S. are MUDs, e.g., apartments and condominiums [1]. MUDs with five or more units account for approximately 45% of the more than 44 million U.S. rental households [2]. Although 80% of EV charging takes place at home [3], less than 5% of home charging takes place at MUDs [4]. The VCI-MUD project explores technologies that can help overcome barriers to EV charging at these types of homes. The primary types of barriers addressed by this project are those related to electrical capacity constraints, parking limitations, and decision-making. The project team identified numerous charging infrastructure technologies and matched them for in-use field demonstrations at MUDs.

Table 1: Summary of VCI-MUD technology demonstrations

Technology Provider	Technology Type	Location	Location Type	Charging Type
Cyber Switching	Shared Electric Circuit	Portland, OR	Condominium	Dedicated
OpConnect	Community Charging Station	Honolulu, HI	Condominium	Shared
PowerFlex	Power Management	San Francisco, CA	Condominium	Dedicated/ Shared
Liberty Plugins	Shared Electric Circuit	Atlanta, GA	Apartment	Shared
EVmatch	Community Charging Station	Campbell, CA	Apartment	Shared
Electric Vehicle Institute	Offsite Charging Station	Takoma Park, MD	Community Center	Offsite
Electric Vehicle Institute	Offsite Charging Station	Takoma Park, MD	EV Fueling & Service Station	Offsite
FreeWire Technologies	Mobile Charging	San Leandro, CA	Simulated MUD	Mobile

2 Project Design

2.1 MUD Charging Barriers Identification

One of the primary objectives of the project was to obtain a baseline understanding of EV charging at MUDs. The project team collected data at existing MUD chargers and analyzed utilization to identify trends. Key stakeholder groups across the U.S. were engaged to determine barriers experienced with MUD charging. This baseline research unveiled a critical finding: a lack of both information and awareness among all key stakeholder groups are barriers to the success of EV charging deployment at MUDs.

Stakeholder feedback and baseline research findings identified the following additional barriers:

- Capital constraints
- Network signal
  - Weak cellular and Wi-Fi signals in parking garages
  - Ethernet cables, Wi-Fi routers, and cellular repeaters are expensive to install
- Homeowners associations (HOAs)
  - Common area management
  - Approval difficulties and homeowner buy-in
  - Deeded parking spot negotiations
- Information and education
  - Building managers, owners, and HOAs need information on features and benefits
  - Assumption that installed shared chargers will be underutilized
- Electrical
  - May not have enough electrical capacity and require costly upgrades
  - Electrical panel may be a long distance from garage, increasing installation costs
  - Potential need to conduct expensive load study
  - Might need to wait for utility to upgrade service
- Operation and maintenance costs
  - Power management and subscription fees
- Parking operation
  - Drivers do not unplug when done charging

  - Outside free riders problem if parking is unsecured
  - Parking spots optimal or possible for EV charging are reserved
- Parking limitation
  - Limited parking spaces
  - Spaces far from electrical panel incur higher costs

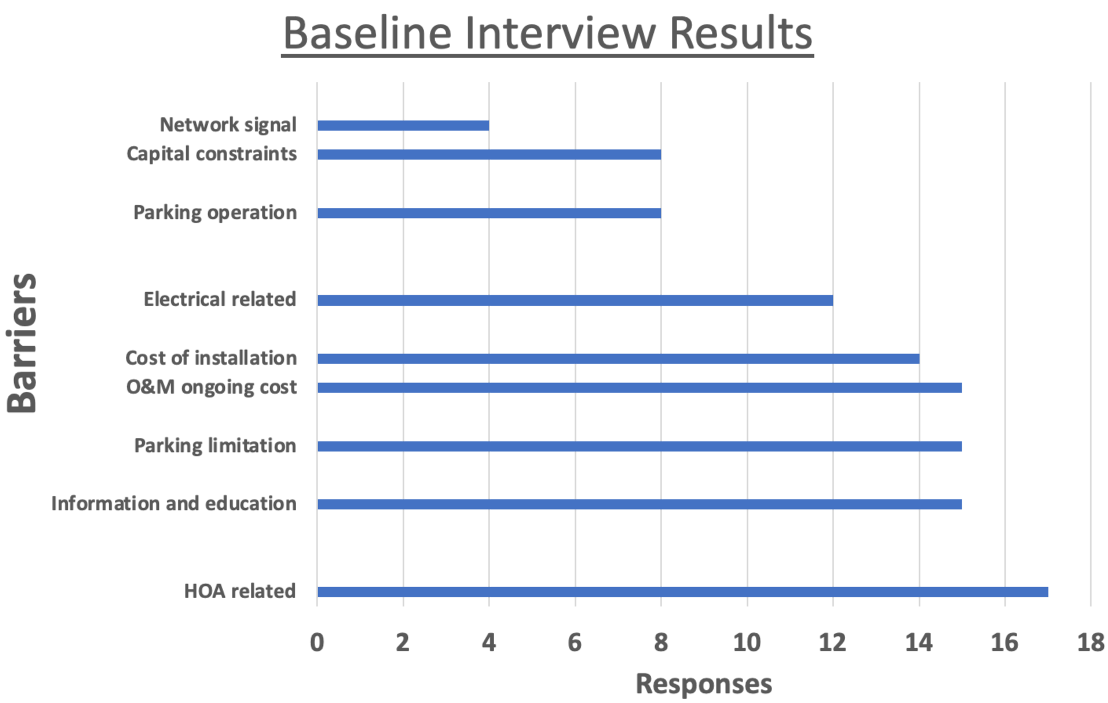

Figure 1: VCI-MUD Baseline Interview Results

Our approach was to use technological solutions and educational approaches to address the majority of the barriers. The project team identified commercially available, innovative EV charging technologies that offered possible solutions.

2.2 Technology Demonstrations

After identifying barriers, the next objective of the VCI-MUD project was to demonstrate technologies capable of addressing some of the barriers. The project team evaluated a range of technologies for inclusion in the demonstration that could address the issues of power supply, load control, parking constraints, operations, and billing. In order for the technologies to be practically useful in supporting rapid adoption at MUDs, the project team limited options to those that are commercially available, user-friendly, cost-effective, and feature app- or web-based interfaces. The following categories of technological solutions were selected to explore in the field:

Community Charging Station Management
Products demonstrated: OpConnect, PowerFlex, EVmatch
These technologies provide complex usage controls for non-networked and simple networked chargers, including: access control; usage fees (by time, energy use, and different user groups); session reservations; notification systems to let users know when their car is done charging or their session has ended; idle fees; data

collection; system usage dashboards; and account billing. Some systems also include load management to reduce demand charges and demand response capabilities to support electrical capacity limitations, grid flexibility, and provide revenue.

- Often used in MUDs that have multiple EVs and not enough electrical capacity to supply each parking spot with maximum power at the same time
- Can be used for both long-dwell parking situations (e.g., overnight parking) and shorter stays (e.g., short resident charge sessions or visitors)
- Some systems use a reservation system to maximize charging station throughput
- Usage and idle fees are set by the MUD property and can be tailored based on energy, time of day, and user group (e.g., resident or visitor)

Power Management Systems

Products demonstrated: OpConnect, PowerFlex

These technologies provide large-scale adaptive load management to control power to a group of EV chargers. These systems maximize electrical capacity utilization by spreading out the charge sessions to flatten and lower the peak power demand, while ensuring vehicles are charged when users need them.

- Used for both long-dwell parking situations (e.g., overnight parking) and shorter stays (e.g., short resident charge sessions, shared-use charging stations, and visitors)
- Often does not require charged vehicle to be moved after finished charging

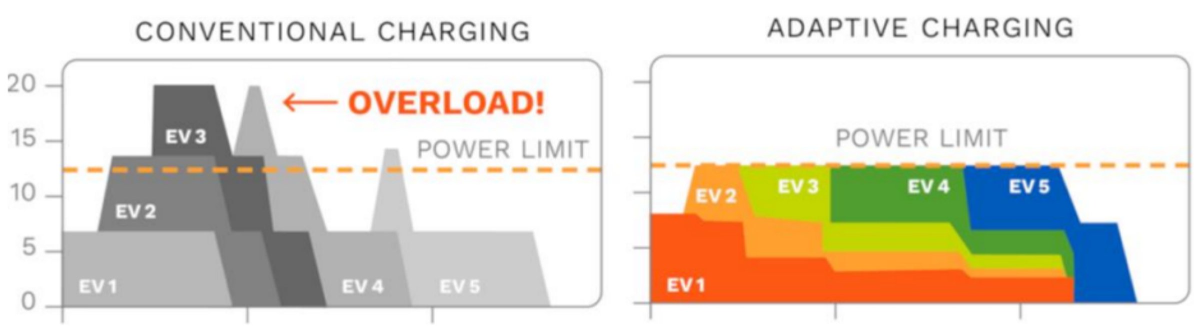

Figure 2: Visualization of PowerFlex ADR load management. (Source: PowerFlex)

Shared Electric Circuit–Rotational Charging

Products demonstrated: Cyber Switching EV Master Controller and Liberty Plugins HYDRA-R

These innovative systems provide a cost-effective management system for electrical circuit sharing using multiplexing to control low-cost, non-networked charging stations. They maximize circuit utilization by only charging connected vehicles that need a charge and delivering the power in a rotational sequence.

- Reduces electrical infrastructure requirements
- Compatible with non-networked EV charger models
- Facilitates power-sharing from one electric circuit between multiple charging ports
- Positive user experiences in long-dwell parking situations

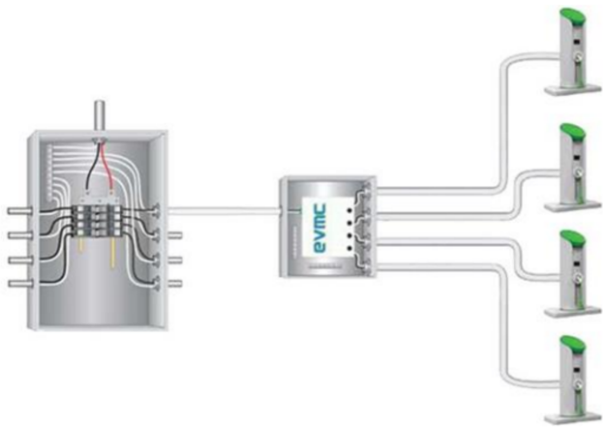

Figure 3: Cyber Switching charging station power wiring scheme (Source: Cyber Switching)

Mobile Charging

Products demonstrated: FreeWire Technologies Mobi

As an alternative to installing a fixed charger, the mobile charger moves to wherever EVs are parked. The Mobi charges up to two EVs at a time using a standard 6.6 kW AC Level 2 (L2) power output. The mobile charger's battery capacity determines the total amount of energy supplied per charge of the unit.

- Best used in access-controlled garages for dedicated or shared parking spaces
- Flexible for both long-dwell parking and shorter stays
- Internal battery pack charges via a standard L2 charger
- The unit is easy to use, but requires someone to navigate the charger wherever it goes
- Best used in parking situations with a garage attendant (staff), but possible to train residents to use
- Does not require charged vehicles to be moved
- Can be a final solution, a temporary supplement, or be used to evaluate charging demand

Figure 4: Mobi EV Charger plugged into a vehicle (Source: FreeWire Technologies)

Offsite Owned-Operated Charging Stations
Products demonstrated: Electric Vehicle Institute
This approach is unique compared to the other technology approaches in the VCI-MUD project because an independent company installs, owns, and operates the chargers. Located close to MUDs, the chargers are available to MUD residents and to the public.

- Can be either DC fast chargers (DCFCs) or L2 chargers
- Requires partnership and communication with external property owners to identify a charging station location(s)
- MUD owner or manager may be unable to influence the installation of offsite chargers
- Usage fees may be higher than a MUD-located station to compensate for the owner-operator's installation costs

In several instances, innovative technologies in the program include several of the above approaches in their products. Although some technologies have similar functionalities, each provider implements their technologies and business models in different ways. Ultimately, VCI-MUD developed and operated demonstrations using seven different products at eight demonstration sites across the U.S.

2.3 MUD Charging Education

For MUD charging to become widely adopted, key MUD stakeholder groups, i.e., MUD owners and managers, HOAs, and residents, need to be well-equipped with information and resources to develop an individually tailored charging program suited to their property needs.

The final VCI-MUD project objectives involve first compiling the project findings into an easy-to-use online toolkit for key stakeholder groups, and then disseminating the resources across national, regional, state, and local channels. The key project output, a MUD charging toolkit, guides the key stakeholder groups through the steps they need to take in order to design a custom charging program. It also provides resources such as fact sheets, case studies, demand estimation survey templates, and more. Specifically, the resources in the toolkit empower decision-making stakeholders to:

- Understand their property's electrical and parking conditions
- Understand the technology and features available to support various electric vehicles
- Allocate costs equitably
- Anticipate resident demand and utilization for an EV charger program
- Optimize rates, idle fees, and related policies to ensure a successful program
- Communicate with residents, homeowners, and management, including templates to support building a case and obtaining support
- Install EV chargers confidently

3 Methods and Data

3.1 Methods

To obtain the baseline data, the project established data-sharing agreements with existing relevant EV charging providers. The project used the following criteria to locate MUD host sites:

- Basic non-networked ("dumb chargers") charging stations on site
- Varying property sizes (small to large)
- Limited electrical infrastructure (desired, not required)
- Multiple charging stations or potential near-term plans to add charging stations
- Varying electricity rates (e.g., $/kWh, time of use, demand charges)

During the demonstration period, charging station usage and business case data were collected at each site. Data were analyzed to quantify the usage and performance of each technology. In several cases, data from existing MUD charging installations were used instead; this was especially beneficial due to the timing of the COVID-19 pandemic and its impact on vehicle usage. The demonstrations tested whether and how technologies could reduce MUD charging costs, increase the number of chargers available, increase utilization, and ease management barriers.

3.2 Quantitative Data

3.2.1 Baseline Data

The project sought to collect quantitative data that would provide insight into the demand of EV charging utilization as well as inform the business case for installation of EV charging at MUDs. The project team established a baseline of MUD charging infrastructure by collecting and analyzing usage data from a total of 1,474 ports over 79,312 charge sessions at locations across the U.S. from 2015 through 2019, with partial data from 2020. Some findings from the baseline data include:

Charging sessions varied based on location. Charging sessions on MUD premises were significantly longer than those at MUD-supporting locations, that is, off-premises but located nearby and used by residents.

- MUD-located = 12.2 hour average charge duration
- MUD-supporting public L2 = 2.9 hours average charge session
- MUD-supporting public DCFC = < 30 minutes average charge session

Charging duration tracked closer to the charging session based on the location and type of port.

- MUD-located = 3.6 hour average charge duration
- MUD-supporting public L2 = 2.2 hours average charge duration
- MUD-supporting public DCFC =< 30 minutes average charge duration

Most sessions provided 10-20 kWh of power regardless of whether ports were shared, dedicated, or public.

3.2.2 Demonstration Data

During the demonstrations, the project team collected the same usage data as the baseline, e.g., charging sessions, charging duration, location. Due to COVID-19 stay-at-home orders, EV charging station use varied from the expected usage at all locations.

MUD-located demonstrations
Two demonstrations were held at MUD properties with dedicated-use chargers. At the San Francisco site, a mixed-use development that has over 100 installed power-sharing ports, only about 30 of them were in use at any given time. The average daily charging session was 18-24 kWh. At the Oregon site, a high-rise building

that has 123 units and eight installed charging stations demonstrated an average daily use of typically below 10 kWh and not more than 20 kWh.

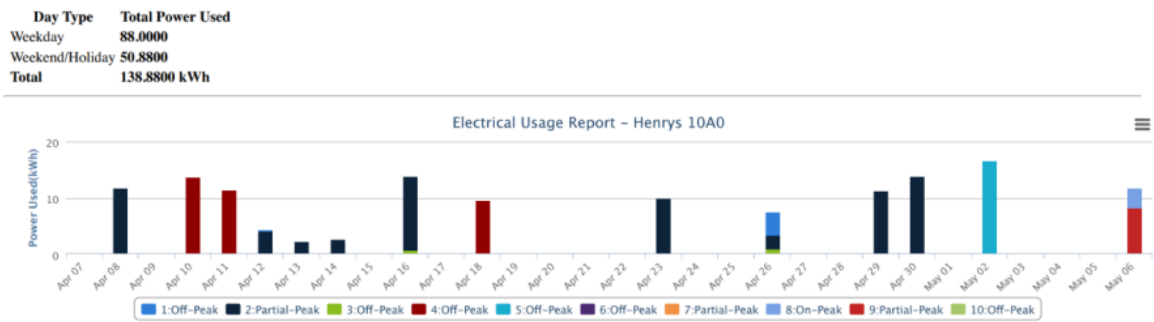

Figure 5: Monthly charging session data from Portland, Oregon Cyber Switching demonstration

Three demonstrations took place on MUD premises featuring shared chargers, however, the installation of chargers at one site was significantly delayed due to COVID-19 and has been excluded from the data set. In the remaining two locations, only residents were allowed to use the chargers (all L2). In contrast, at the mixed-use development in Georgia, there are only two installed ports utilized by 15 unique EV drivers. Here, the daily charging session was 11 kWh. At the Hawaii condominium building, there were three charging ports serving the building's 37 or so residents with EVs. Daily charging sessions averaged 12.7 kWh.

MUD-supporting demonstrations

The two demonstrations of Electric Vehicle Institute technology took place at public locations in Takoma Park, Maryland. At the first location, a community center near more than 10 MUD properties, there were three L2 chargers and one DCFC. Usage at the L2 chargers was limited to a maximum of four hours. The second location was a converted gas station located near a MUD along a major commuting street into Washington, DC. This location has four DCFC chargers and two L2 chargers.

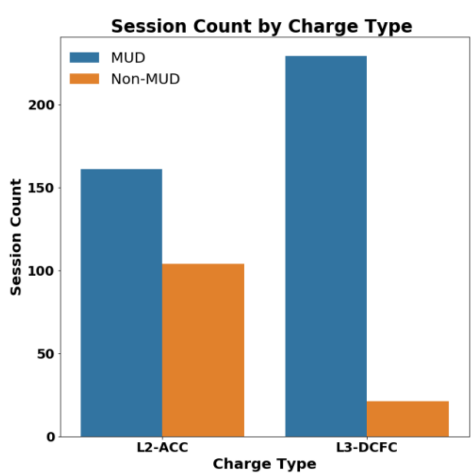

Figure 6: Electric Vehicle Institute session count by charge type and MUD status

Mobile charging demonstration
The mobile charging demonstration took place at the headquarters of FreeWire Technologies (a workplace) as a surrogate for an MUD. Workplace and home charging have similar long-dwell parking and usage patterns but are offset in time. For a 45-day period, FreeWire employees used a Mobi, a mobile L2 charger. The demonstration showed that the Mobi could easily serve 4-5 charging sessions per day. The Mobi dispensed nearly 50 kWh on its highest usage days, well below the unit's 80 kWh energy capacity.

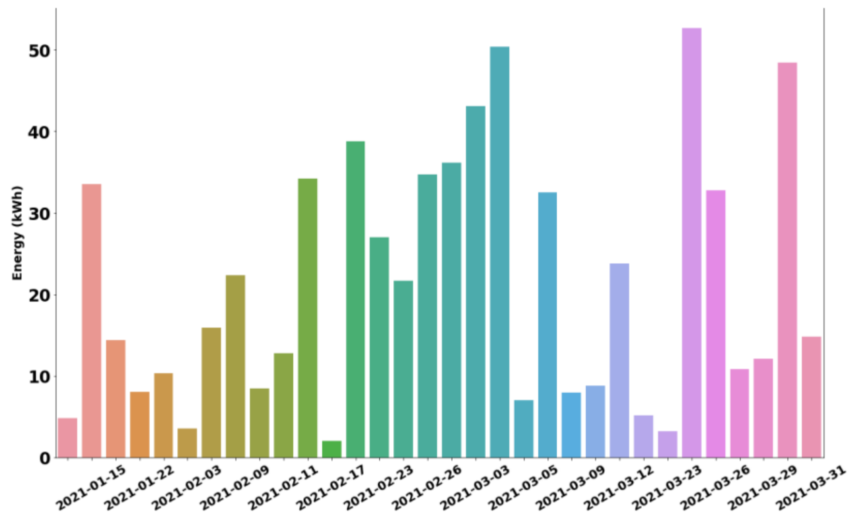

Figure 7: FreeWire Technologies Mobi energy use over 45-day demonstration period

3.3 Qualitative Data

3.3.1 Baseline

The baseline research also included qualitative data analysis. Interviews and surveys were conducted with apartment building owners, apartment building managers, HOAs, MUD residents (both EV owners and non-EV owners), and developers.

As noted in section 2.1, this research uncovered many complex barriers to installing EV chargers at MUDs.

3.3.2 Demonstration

At the time this paper is being written, qualitative data is still being conducted and aggregated, including post-demonstration phone interviews with the MUD property managers and resident surveys. Interviews will collect feedback about the stakeholders' experiences, what was learned from the technology demonstration, and how the demonstration impacted its EV charging infrastructure planning. Resident surveys are collecting input from all demonstration site residents, including people with EVs, conventional vehicles, and with no vehicle. The surveys ask questions about vehicle ownership, typical daily mileage, vehicle purchase plans, availability of work charging, fair pricing options, and more. The results from the phone interviews and web surveys will be summarized and included in case studies for each demonstration.

4 Conclusions and Policy Implications

4.1 Conclusions

Analysis of both the baseline data and demonstration data yielded the following conclusion:

Shared L2 chargers are often underutilized by residents. In some shared-charging locations, opening these chargers up to public access during certain hours of the day could increase utilization and result in a faster return-on-investment (ROI).

Idle fees can have significant effects on how long residents charge. At the Honolulu, Hawaii site, four hours of charging was made free for residents, but a US$25 idle fee was assessed if someone overstayed their session. This policy resulted in no idle fees being billed during the demonstration period and illustrates that economic incentives can work extremely effectively to drive turnover.

Power-sharing and load-management solutions can maximize the number of chargers that can be installed at locations with an electrical capacity limitation. These solutions are important, as most existing MUDs were not built with EV charging in mind. Most MUDs do not have excess panel capacity for more than a few chargers' worth of power and so power-sharing and load-management solutions can go a long way to providing access to charging where it would not have been possible otherwise. Shared chargers that do not power-share are similarly capable of providing access to charging for more residents, but that assumes there are available parking spots and people are able and willing to move their cars after the time limit is up or their car is done charging. Different barriers can be addressed by power-sharing and load-management solutions, and it is important to recognize these technologies can go a long way to supporting charging at MUDs.

Other conclusions from the VCI-MUD project include:

- Charging technologies
  - While mobile charging is not currently cost competitive, mobile charging could become a viable option for MUDs as battery and charging technologies improve and decrease in cost
  - Off-site solutions are potentially an excellent MUD charging solution if the chargers are fast chargers and are accessible, cost-competitive, and strategically placed
  - Off-site solutions require a different funding strategy and source than MUD-located chargers due to the capital costs
- Cost-benefit
  - Load management benefits are more apparent at a larger scale
  - While many of the technologies add some upfront cost, they make up for it with their ability to scale up more affordably and provide access to more chargers than would have been possible otherwise
- HOA and owner benefits
  - At the Oregon site, units with assigned EV chargers sold for US$5,000 to US$8,000 more
  - The abundant L2 chargers at the San Francisco site are a selling point, as many condo-owners drive EVs
  - Scalable solutions are extremely valuable for preparing for imminent future EV adoption

Putting chargers exactly where people park while they are at home is optimal. Home charging is the most convenient and inexpensive way for people to charge their EVs. However, installing chargers precisely where drivers park every night is not always the most cost-effective solution for MUD property owners and residents. Regardless of the barriers, the VCI-MUD project demonstrations show there are technological solutions to support charging at MUDs.

4.2 Policy Implications

Closing the education and information gaps is a key objective for public policy consideration. But how should governments reach property managers, individual HOAs–which are managed by volunteer boards of directors–and building owners? Local governments and electric utilities may not have a direct line of communication to these entities, which raises the question of how to communicate the present-day value of providing an on-site or nearby supporting charging program for MUD residents–as well as the future imperative to do so. Where utilities do have a direct line of communication with MUD property managers and tenants through their monthly utility bills, they could be a conduit to both educate and incentivize MUD managers and owners, HOAs, and residents.

Local and regional planners can enact–and in many U.S. municipalities, are enacting–new building codes to require EV charging readiness (i.e., the necessary electrical components needed for a future charger installation) or EV charger installation for new construction of MUDs. Some U.S. jurisdictions have passed "right to charge" legislation that prohibit HOAs or landlords from arbitrarily blocking charging [5].

Policy makers need to pay special attention to planning policies and incentive programs to ensure they don't serve primarily affluent MUD locations. Public investment programs for both installation and continued operation and maintenance may be needed to ensure that all MUDs–including those with low-income residents, rural properties, and publicly subsidized housing–benefit from such programs. Locating publicly funded EV charger installations, such as corridor DCFCs, where they can support nearby MUD residents will help support the business case for such charging locations as well as increase accessibility and promote adoption of EVs.

4.3 Areas for future study

Demonstrations in the VCI-MUD project provided a wide variation on the quantity of data. Some providers offered session counts in the thousands, while two did not reach one hundred sessions. Future study could group apartment complexes by their number of units to determine differences in the EV charging needs for smaller units versus larger ones. This project tended to include MUDs in more affluent, higher income communities. Analyzing MUDs of different values, especially between rental units and owned units, is another area for future study.

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