Integrated Modeling and Technoeconomic Assessment of Electric Vehicle Community Charging Hubs

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Project ID: van047

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Overview

- **Timeline**

  - Project's start: 10/2020
  - Project's end: 09/2023
  - 50% completed

- **Budget**

  - Total UIUC project funding: $ 280,000 (DOE share)
  - UIUC cost share: $ 38,889
  - ANL project funding: $ 70,000
  - Total project funding: $ 350,000 (DOE share)

- **Barriers addressed**

  - Bridging gaps in modeling and technoeconomic assessment of electric vehicle charging hubs for Mutli-Unit Dwelling (MUD) residents

- **Partners**

  - UIUC: Dr. Kontou and research assistants Ruolin Zhang and Xi Cheng
  - ANL: Dr. Zhou and research assistant Noah Horesh
  - Research communication
    - Chicago Area Clean Cities Coalition
    - Illinois Department of Transportation through the EV Steering Committee

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Relevance

Community Charging Hubs

- Stations essential for residents of multi-unit dwellings (MUDs) due to a sparse network of charging infrastructure
  - Less than 50% of household vehicles have access to dedicated parking (Traut et al., 2013)
  - Limited access to reliable charging infrastructure could hinder electric vehicle adoption (Mersky et al., 2016)

Aligned with DOE Vehicle Technology Office's Mission

- Relevant to transportation fuel diversification, energy security, increased efficacy and affordability of the transportation/mobility system, and accelerating the development and widespread use of innovative transportation technologies

- Analytical modeling of community charging hubs, including their management and operations, is directly aligned with DOE EERE and VTO applied research objectives and investment into data-driven models of energy storage

Approach

Objectives of charging scheduling in MUDs

- The charging scheduling problem determines the **optimal schedule** of charging sessions among multi-unit dwelling residents' electric vehicles

Efficient operation of the hub

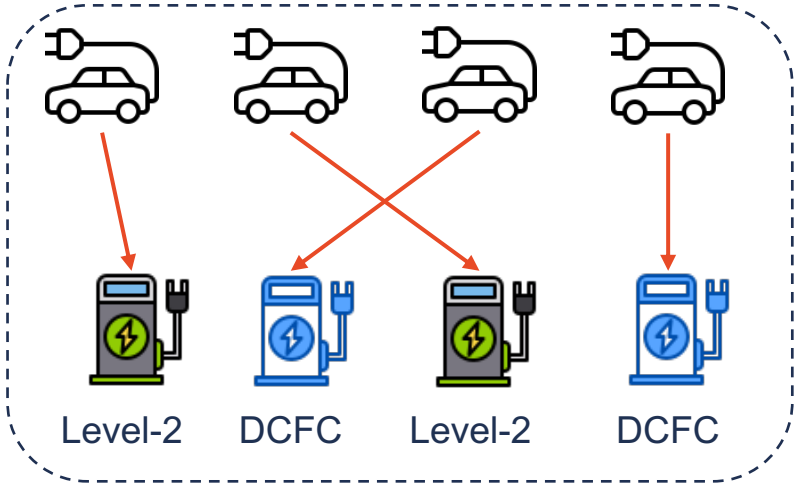
EV drivers' **satisfaction**

All icons are from https://icons8.com/

Inputs: Charging sessions (arrival time, departure time, state of charge, battery size); Charging stations (power level)
Outputs: Charging schedule

Preprocessing: Assign charging sessions to stations
Start with slower charging rates

- **Minimizing the makespan**
  - The makespan is equivalent to the time elapsing from the first to the last charging session in the charging hub's system
  - Minimum makespan suggests a good/high **utilization** rate of the charger(s)
- **Minimizing the total waiting time**
  - Minimum total waiting time can lead to a positive charging experience and **satisfaction**



Preprocessing Strategy Example

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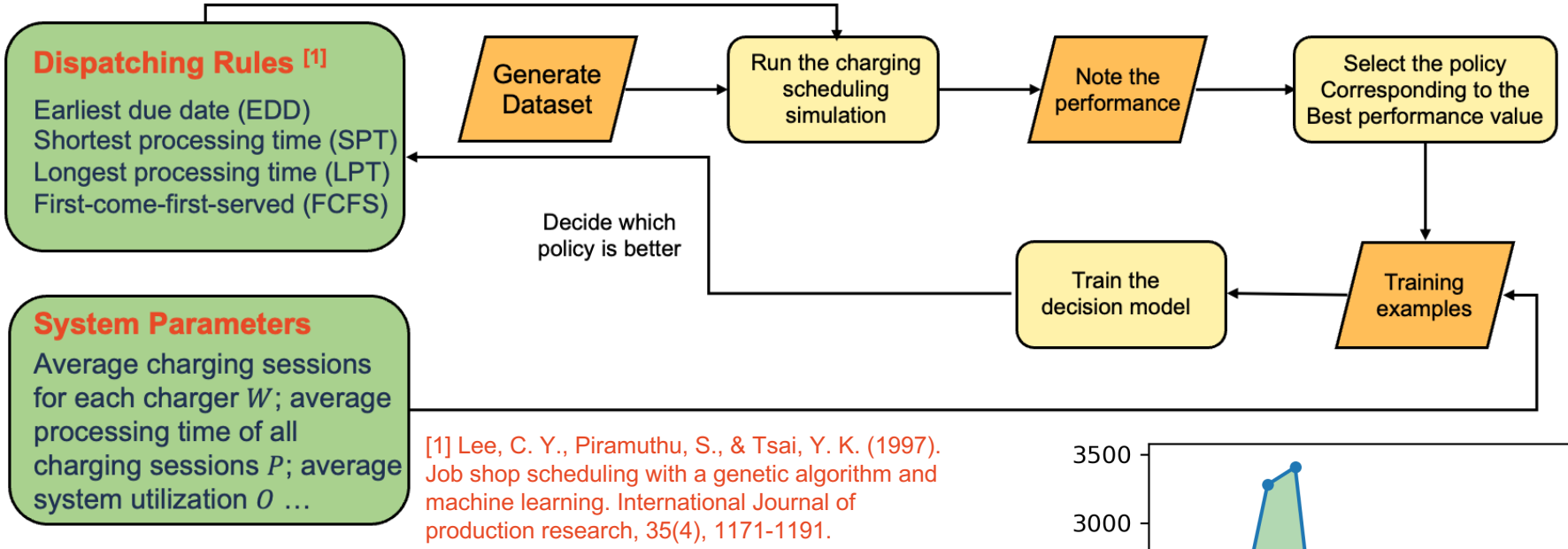
Approach

Schedule: Determine the sequence of charging sessions at each charging station based on **dispatching rules**



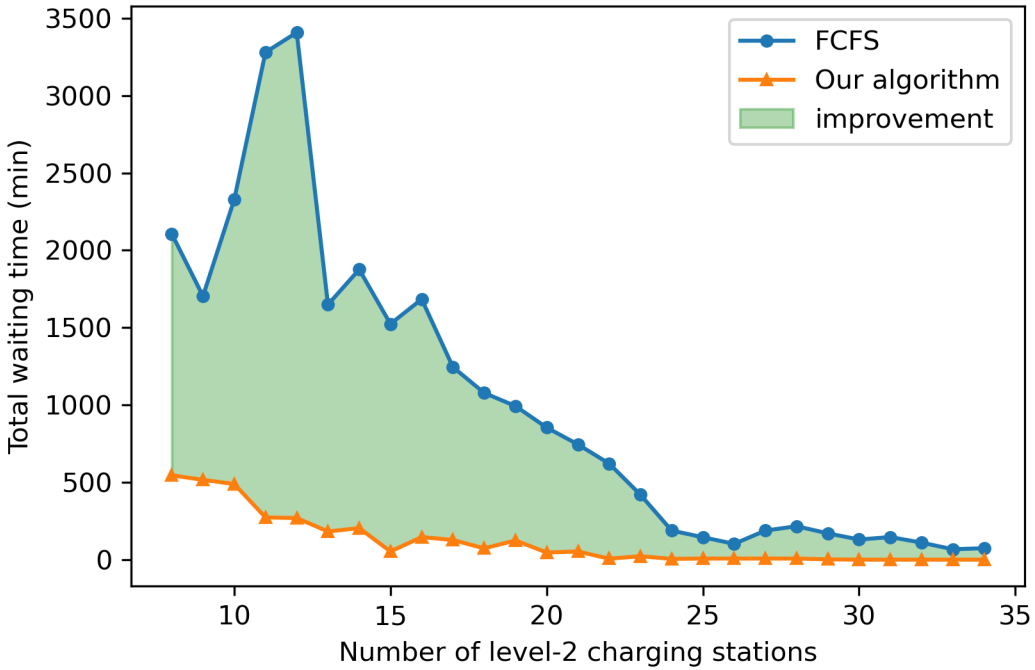
[1] Lee, C. Y., Piramuthu, S., & Tsai, Y. K. (1997). Job shop scheduling with a genetic algorithm and machine learning. International Journal of production research, 35(4), 1171-1191.

Improvement: Exchange several charging sessions in order to further reduce total waiting time

Charging hub performance:

Number of Level-2 chargers ranges from 8 to 35 (NYC MUD charging hub)

- Compared to a first-come-first-served (FCFS) strategy, **our algorithm improves the MUD charging hub's performance significantly**



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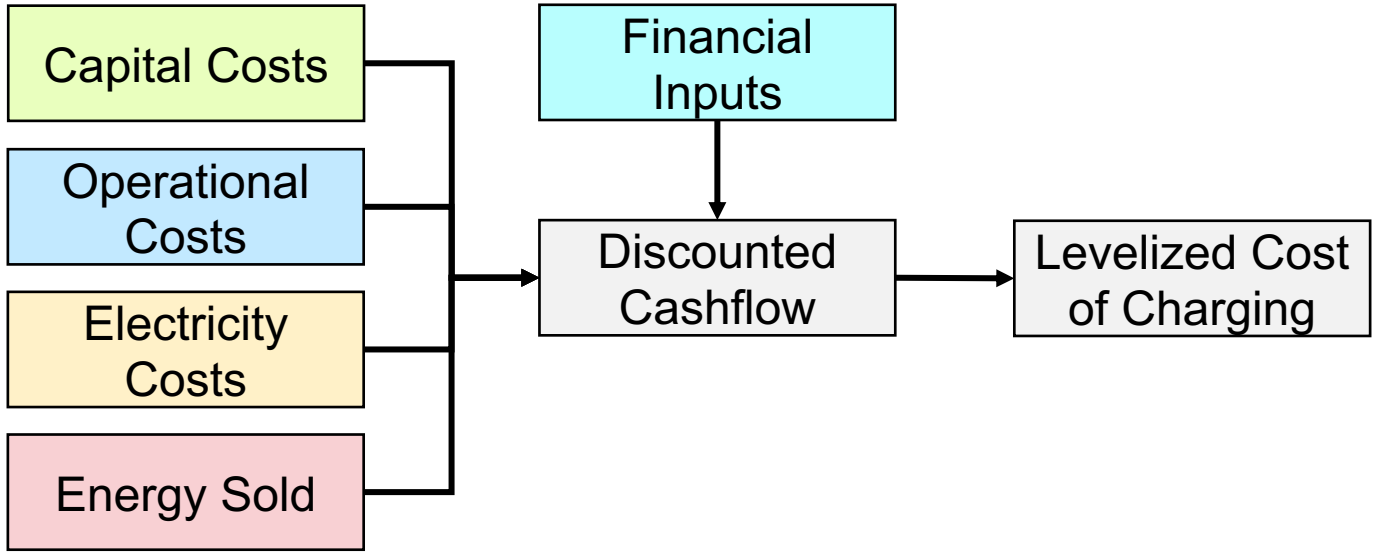
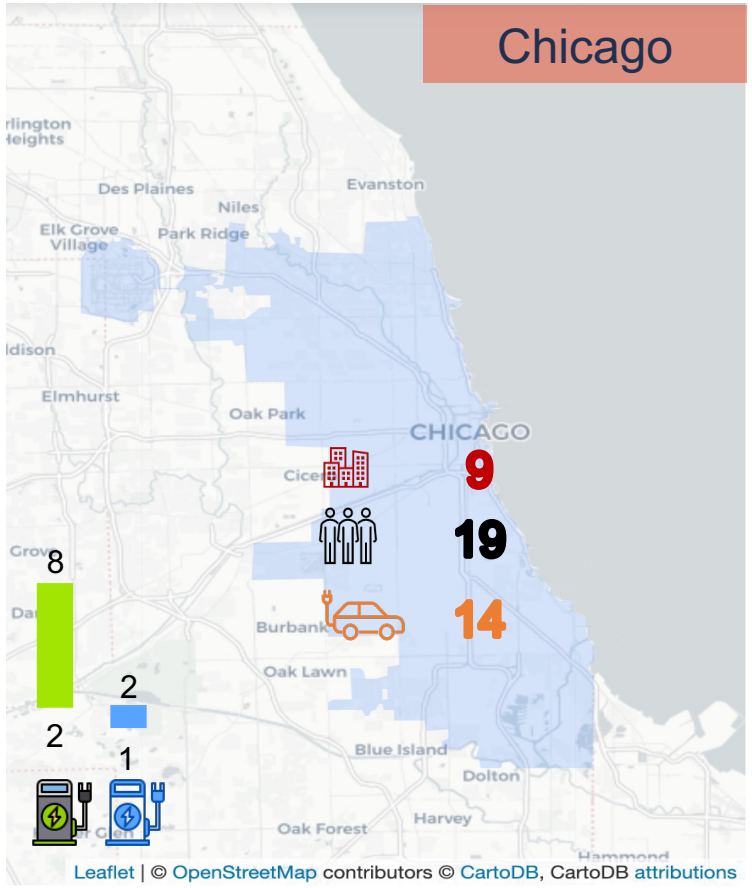
Approach

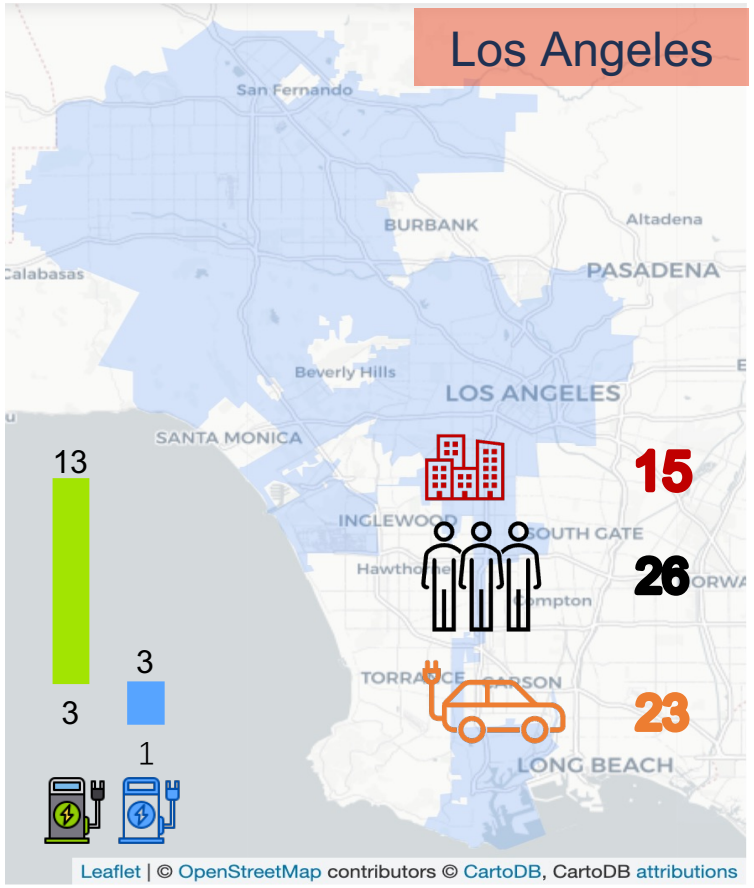
Technoeconomic assessment of MUD charging hubs

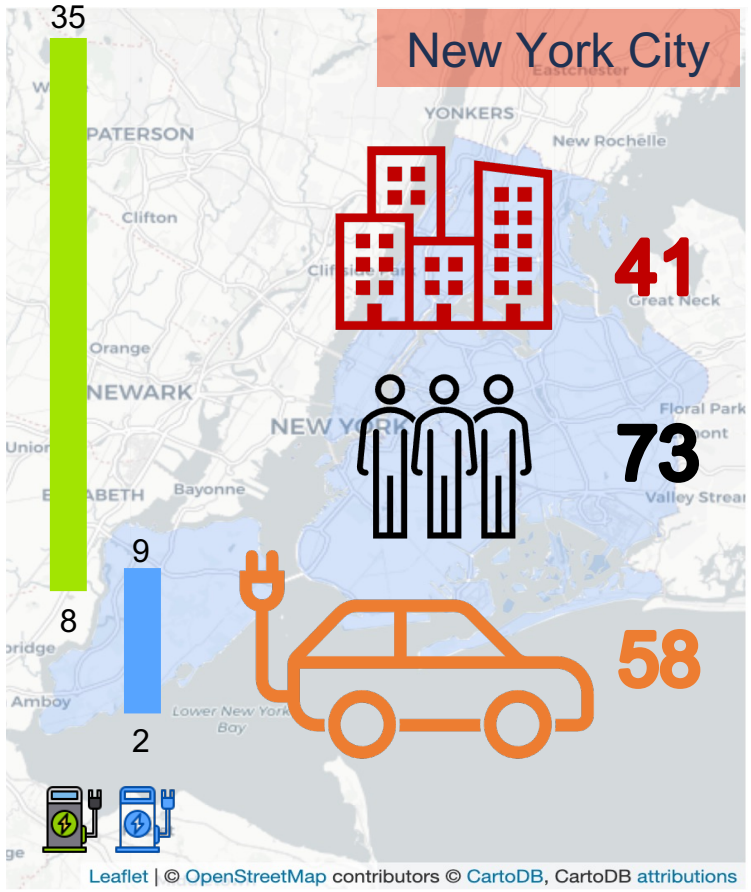
- Discounted cashflow rate of return analysis
  - Solve for **levelized cost of charging** with fixed Internal Rate of Return (IRR) and analysis period
- **Three** MUDs charging station **ownership/business models**, each relevant to different settings
  - Residential, Utility, Private Company



Technical Accomplishments and Progress







All icons are from https://icons8.com/

Average MUD size

Number of residents per building

Number of electric vehicles per building

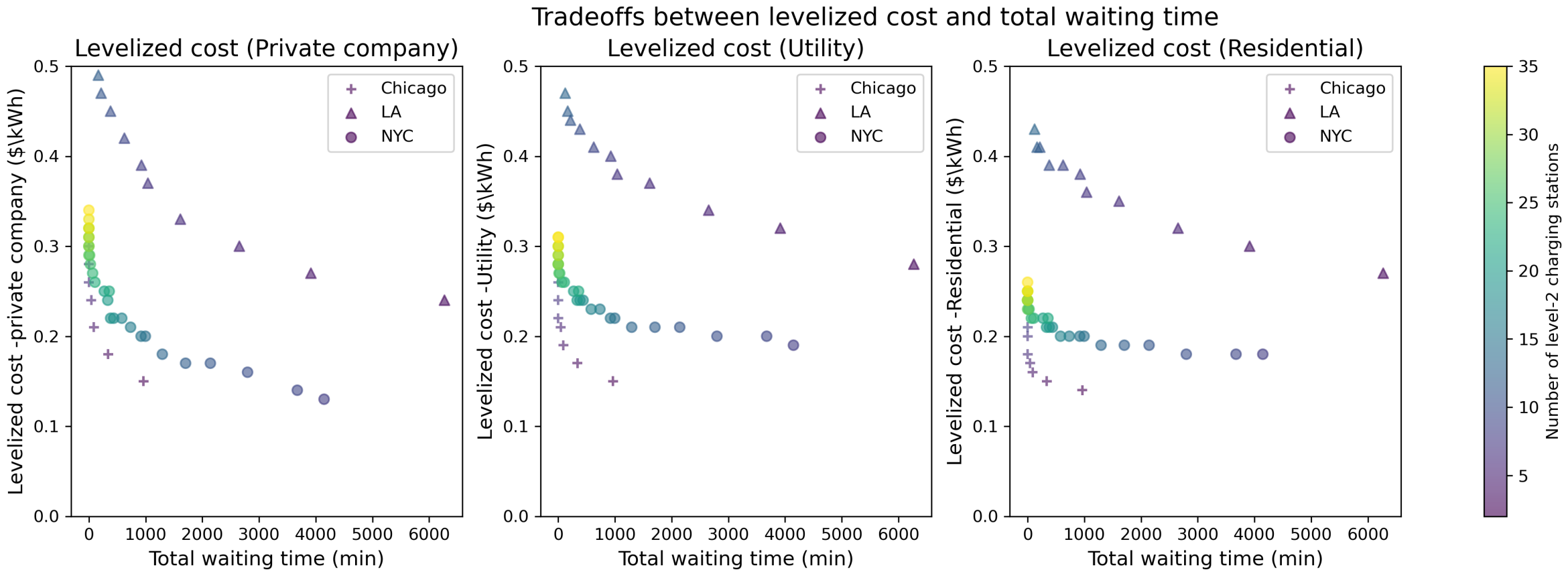
Level-2 charger

DCFC station

Data sources

- American Housing Survey (AHS) https://www.census.gov/programssurveys/ahs.html
- 2017 National Household Travel Survey, household file, U.S. Department of Transportation

Technical Accomplishments and Progress



46 scenarios in 3 populous US cities

- **Chicago**: Number of level-2 charging stations ranges from 2 to 8
- **NYC**: Number of level-2 charging stations ranges from 8 to 35
- **LA**: Number of level-2 charging stations ranges from 3 to 13

- As more level-2 charging stations are enabled, the total waiting time **decreases** while the levelized cost **increases.**
- The waiting time reduction starts **steep** and later **flattens**.
- Given the number of level-2 charging stations, usually, levelized charging cost for a private company is **greater than** the same cost for either a utility or residential station ownership model.
- Levelized cost for Los Angeles is **greater** than for NYC and Chicago.

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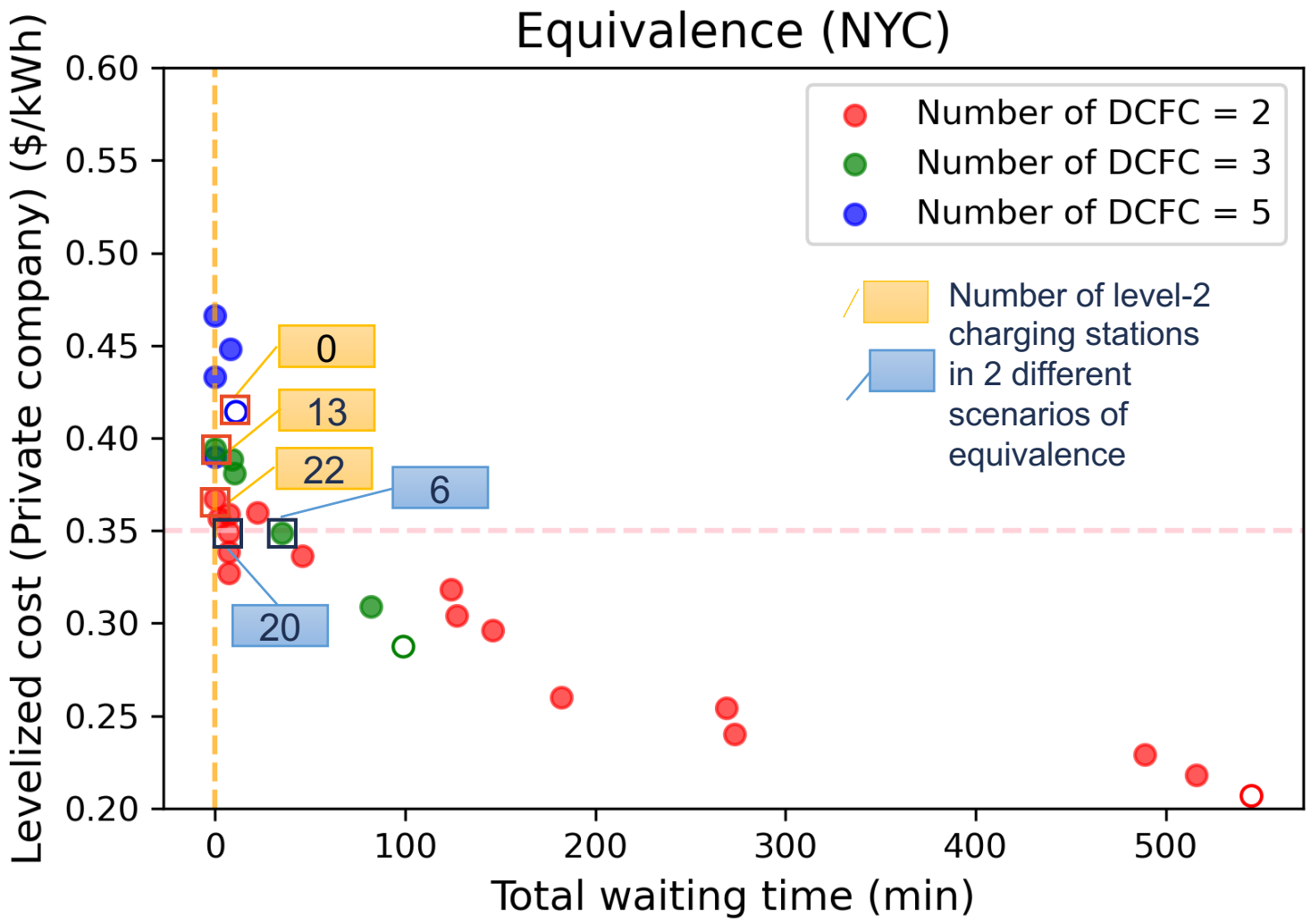
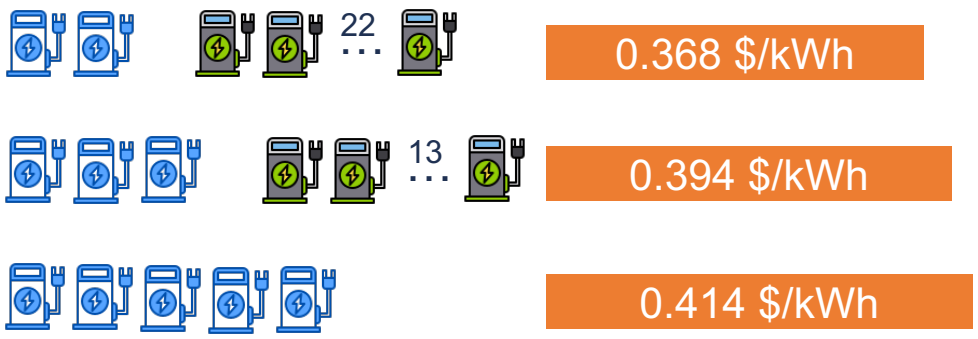
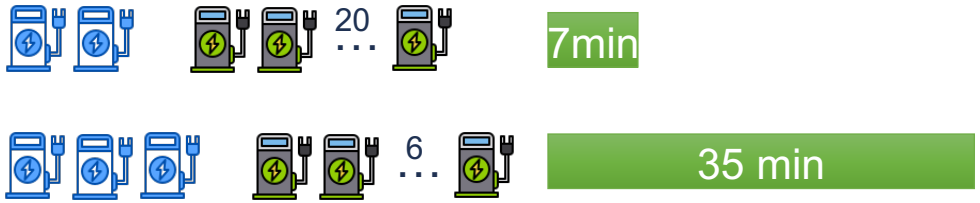
Technical Accomplishments and Progress



Total waiting time ≈ 0 (**Same performance**)



Levelized cost ≈ 0.35 $/kWh (**Same cost**)



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- The left figure displays the map of **equivalence,** considering either equivalent **performance** (total waiting time) or **cost** (private company levelized charging cost) for the scenarios pertinent to **NYC**.

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Responses to Previous Years Reviewers' Comments

- This is the first year that the project has been reviewed.

Collaboration and Coordination with Other Institutions

Academia and National Laboratory Collaboration

- Argonne researchers are leading **techno-economic assessment tools for EV charging**
- Research articles will be **openly accessible to key stakeholders** (e.g., charging network providers)
- Analysis brief to publicize findings and **engage communities of renters and MUD property managers**

Collaboration and Engagement with other Entities

- Connections and feedback from **Clean Cities Coalition** (Chicago Area)
- Local connections with Illinois **Department of Transportation** through their EV steering committee

Proposed Future Research

Community Charging Hubs – Network Level Analysis

- **Modeling networks of community charging hubs in MUDs for a city**
  - Improve the MUD charging hub system performance
  - Optimize MUD charging hub operations across various use cases in mixed land use
    - e.g., night home charging by residents, daily fast charging by other users

- **Addressing key uncertainties of techno-economic assessment**
  - Economic features (e.g., electricity rates)
  - Technological features (e.g., electric vehicle technologies specifications)
  - Behavioral features (e.g., daily energy use variations)

Any proposed future work is subject to change based on funding levels.

Summary

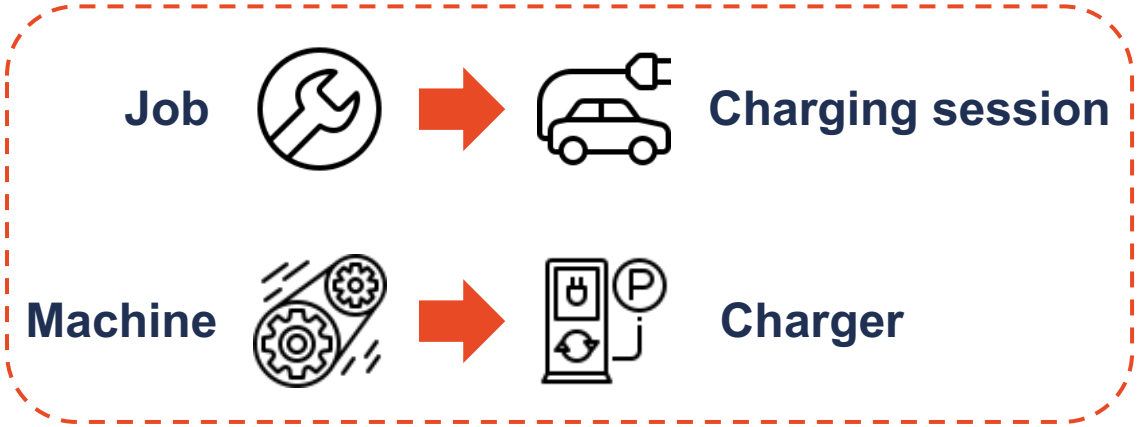
- **Relevance**
  - Modeling and techno-economic assessment of MUD charging hubs' operations can serve as tools to **support greater deployment of charging stations for renters and low-income communities**
  - Aligned with VTO mission of accelerating the development and widespread use of innovative transportation technologies and enabling equitable access to electric vehicle charging
- **Conclusions**
  - Trade-offs between **MUD charging hubs' economics and operation performance** quantified
  - Performance- or charging cost-equivalent solutions for stations with charging power level alternatives can accommodate electric vehicle charging needs at MUDs
- **Milestones**
  - FY 20-21 MUD residents' travel patterns analytics
  - FY 21-22 MUD charging scheduling models and techno-economic assessment
- **Accomplishments**
  - Journal article submitted on MUD residents' travel analytics
  - Journal article to be submitted on MUD charging scheduling and techno-economic assessment

Technical Backup Slides

Technical Backup Slides

Modified Job Shop Scheduling Problem (JSP) for electric vehicle charging scheduling in MUDs

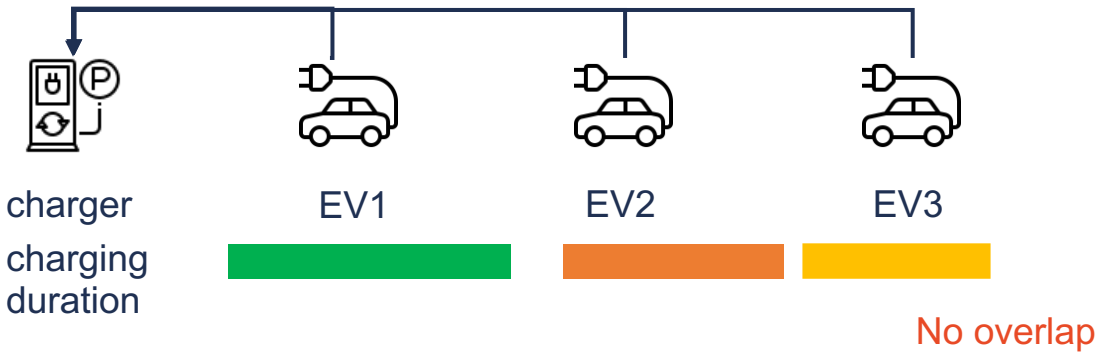
- The traditional job scheduling problem is determining the **best sequence** to process **jobs** on **machines**
- The charging scheduling problem determines the **optimal schedule** of charging sessions among multi-unit dwelling residents' electric vehicles.



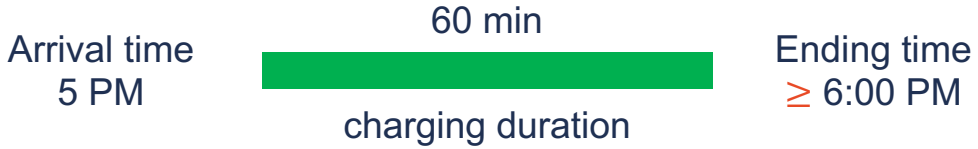
All icons are from https://icons8.com/

Constraints

- One electric vehicle is assigned to only one charger; only one electric vehicle can be charged on the charger at one point.



- The ending time for a charging session to be at least as late as its arrival time plus the charging time.



- Charing session i is only allowed on charger k after charging session j has ended, if i succeeds j.

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Technical Backup Slides

Dispatching Rules

- **Earliest due date (EDD):** Prioritize the charging session with the earliest due time
- **Shortest processing time (SPT):** Prioritize the charging session with the shortest charging time
- **Longest processing time (LPT):** Prioritize the charging session with the longest charging time
- **First-come-first-served (FCFS):** The first-come, first-served rule attempts to implement an unbiased conflict solver because it neglects properties of charging sessions and the state of chargers

	EV1	EV2	EV3
Arrival time	17:30	17:32	17:35
Charing duration	120min	85min	83min
Due time	19:30	18:57	18:58

These electric vehicles all arrive at an MUD charging hub between 17:30~17:35 pm. They compete for one charger.

Earliest due date (EDD)

17:32 | EV2 | EV3 | EV1 | 22:20

Total system waiting time 252 min

Shortest processing time (SPT)

17:35 | EV3 | EV2 | EV1 | 22:23

Total system waiting time 259 min

Longest processing time (LPT)

17:30 | EV1 | EV2 | EV3 | 22:18

Total system waiting time 318 min

First-come-first-served (FCFS)

17:30 | EV1 | EV2 | EV3 | 22:18

Total system waiting time 318 min

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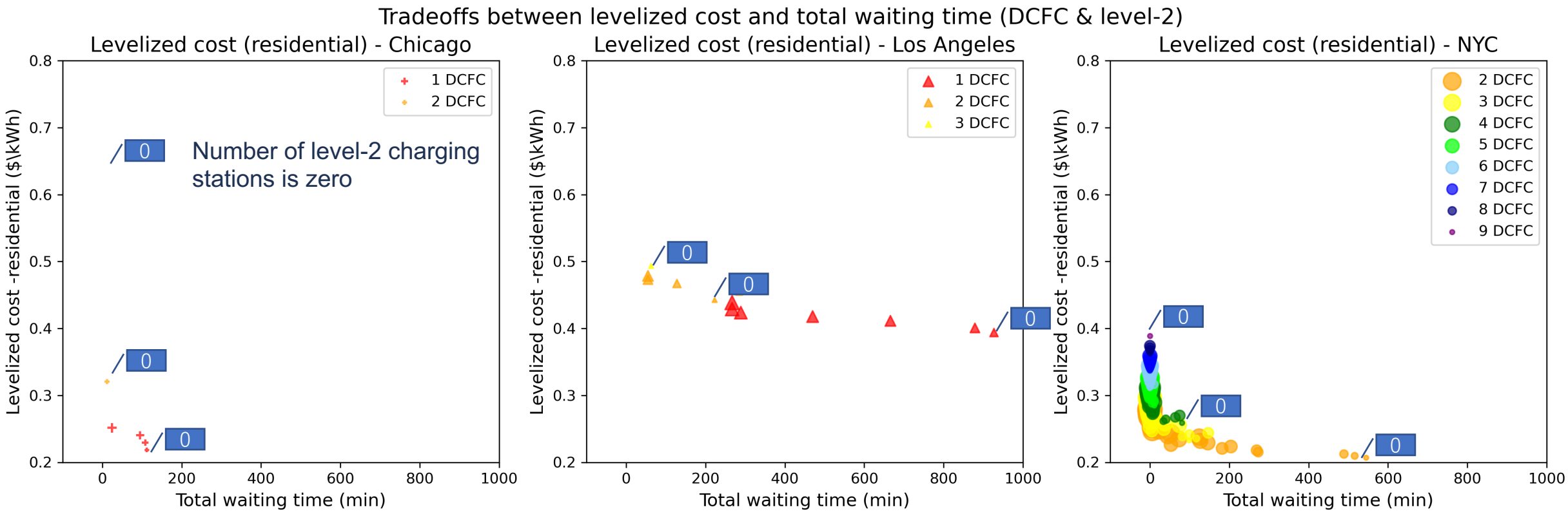
Key Ownership Model Assumptions for MUD Charging Hubs

- Ownership model determines who pays for charging infrastructure at MUDs and how the charging station is managed

  - **Residential**
    - Add to existing **residential load** which has no demand charge
    - No network and data contracts
    - Owned by a group of residents, home-owners association, or property owner
  - **Utility**
    - Add to existing **residential load** which has no demand charge
    - Network and data contracts
    - Owned by the utility company that already provides electricity service to the building
  - **Private company**
    - New **commercial load** which has a demand charge
    - Network and data contracts
    - Owned by a charging station vendor, investor, or automaker

Technical Backup Slides



139 total scenarios of charger power level combinations:

- **Chicago**: number of DCFC charging stations ranges from 1 to 2
- **LA**: number of DCFC charging stations ranges from 1 to 3
- **NYC**: number of DCFC charging stations ranges from 2 to 9

- Given the number of DCFC stations, as more level-2 charging stations are deployed, the total waiting time **decreases** and the levelized charging cost **increases.**
- When only DCFC stations are sited, as more DCFC stations are deployed, the total waiting time **decreases** and the levelized charging cost **increases.**
- Levelized cost of Los Angeles is **greater** than NYC and Chicago.

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