Corridor Charging Infrastructure: Accessibility and Redundancy

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The purpose of infrastructure is to provide access for people to opportunities

Transportation Accessibility:

“The ease with which individuals can access opportunities subject to the transportation system in the relevant area”

Transportation Accessibility definitions differ on the following points:

- What opportunities to consider?
- What transportation options to consider?
- What area to consider?

Transportation Accessibility | Circuit Analogy

"The ease with which individuals can access opportunities subject to the transportation system in the relevant area"

Push factors

Pull Factors

Aggregate population movement

$$I = \frac{\Delta V}{R} = \frac{V_i - V_j}{R}$$

Traversal difficulty

"The ease with which individuals can access opportunities subject to the transportation system in the relevant area"

Land-use / personal preference

Push factors

Pull factors

Aggregate population movement

$$I = \frac{\Delta V}{R} = \frac{V_i - V_j}{R}$$

Observed traffic

Transportation system

Traversal difficulty

- The main subject of debate is how to select opportunities. There are several approaches:
  - Nearest Proximity: Pick the closest opportunity.
  - Isocost: Pick all opportunities in an isocost polygon
  - Gravity/Entropy: Weigh all opportunities by mutual similarity
  - Discrete Choice: Fit a model to observed behavior

- The resistance component is universal - shortest paths
  - Shortest paths computed for each mode considered
  - *Sufficiently different cars should be considered as different modes*

- Modern BEVs have the range to be interchangeable with ICEVs for routine use
  - With reliable long-dwell charging they can even offer convenience and cost benefits

- However, for long road-trips, modern BEVs still lag behind. This is because BEVs have:
  - Lower maximum ranges
  - Lower range-addition rates
  - Less mature supply infrastructure

- The longer the trip the more disadvantaged the BEV is. This hinders goals like:
  - *Single ICEV dependence* to *single BEV dependence*
  - *Mixed household fleets* to *BEV only household fleets*

Road-Trip Accessibility: "The ease with which all important locations within a region can be reached by a given individual using a given road-vehicle"

- Land-use: how big is the region and how spread-out are its population centers?
- Transportation: Layout of roads and distribution of supply stations
- Individual: What are the capabilities of cars driven and how risk tolerant are drivers?
- Temporal: Traffic patterns and seasonal infrastructure

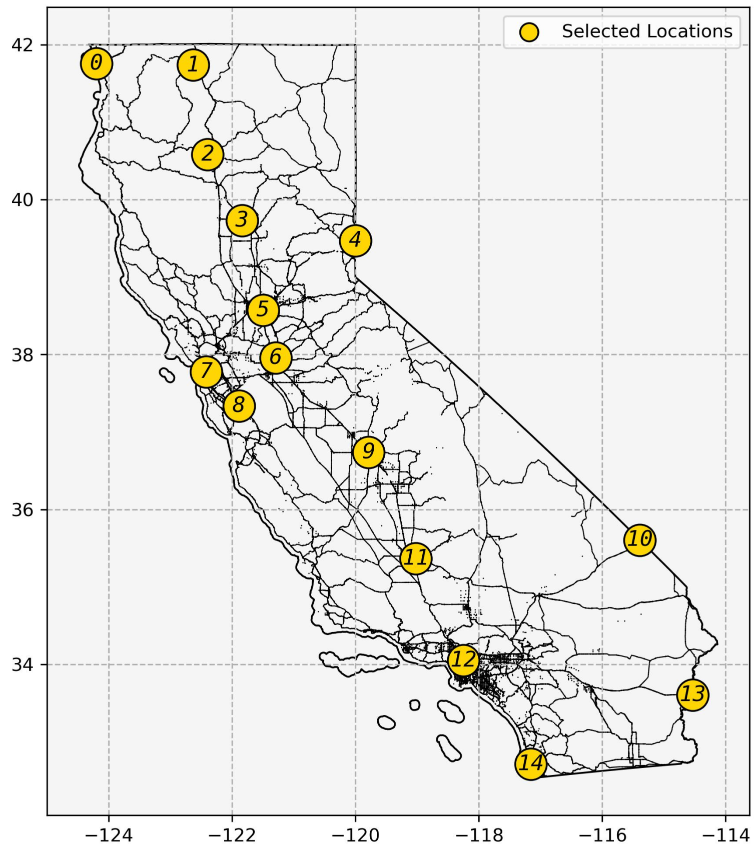
$$A_{rt} = \frac{1}{N^2} \sum_{i=0}^{N} \sum_{j=0}^{N} W_i W_j C(O_i, O_j)$$

- A_{rt} - regional road-trip accessibility
- N - number of locations
- W -weights for locations (all 1 here)
- C - cost (time) for traversal of O/D arc (i, j)

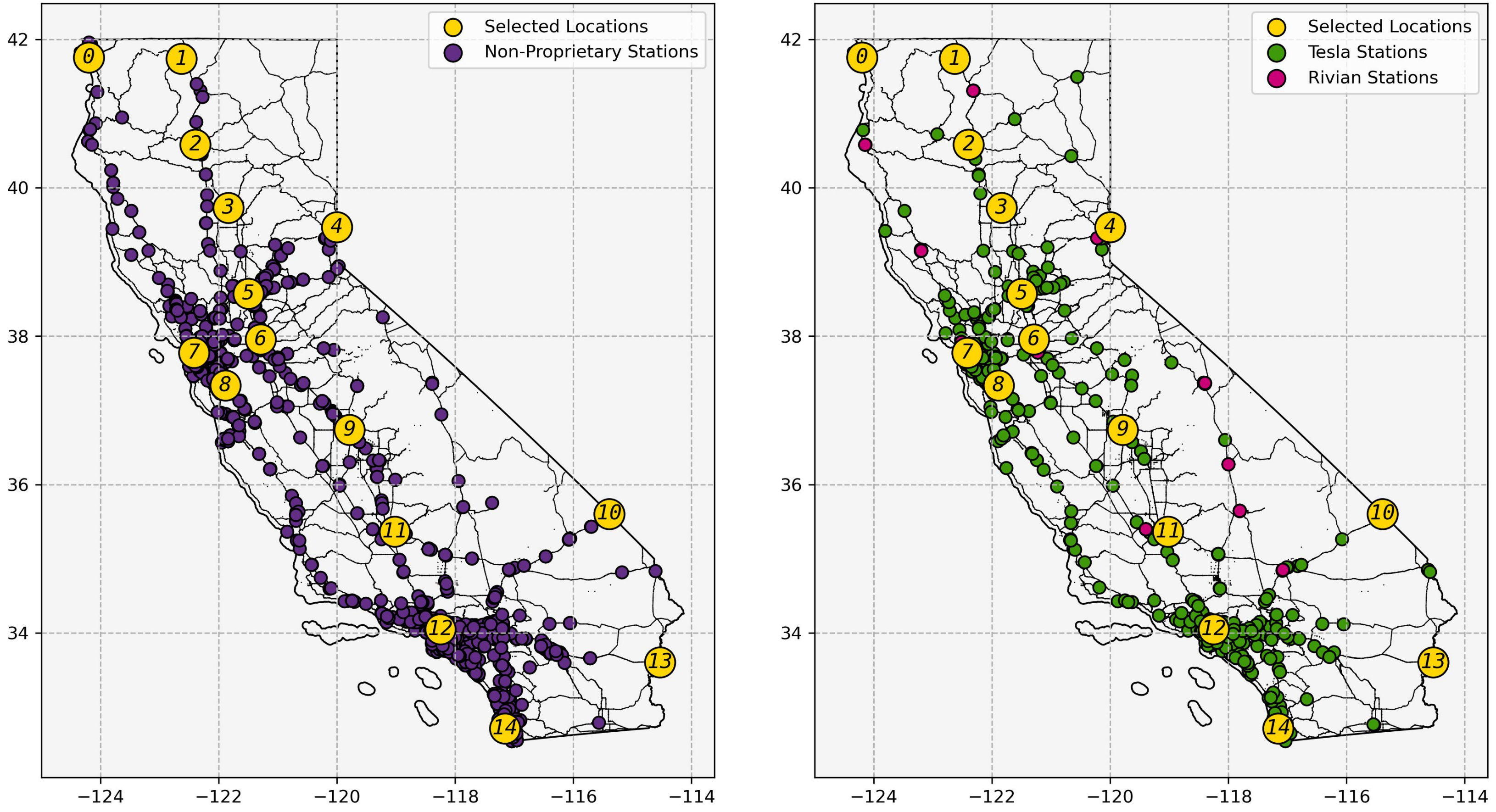
California's Regional Land-Use

For purposes of evaluation, the following 15 locations were selected as origins/destinations:

Index	Location
0	Crescent City
1	Yreka
2	Redding
3	Chico
4	Reno (State Line)
5	Sacramento
6	Stockton
7	San Francisco
8	San Jose
9	Fresno
10	Las Vegas (State Line)
11	Bakersfield
12	Los Angeles
13	Phoenix (State Line)
14	San Diego



California contains 10+ Non-Proprietary and 2 Proprietary Networks combining for ~1,900 DCFC stations



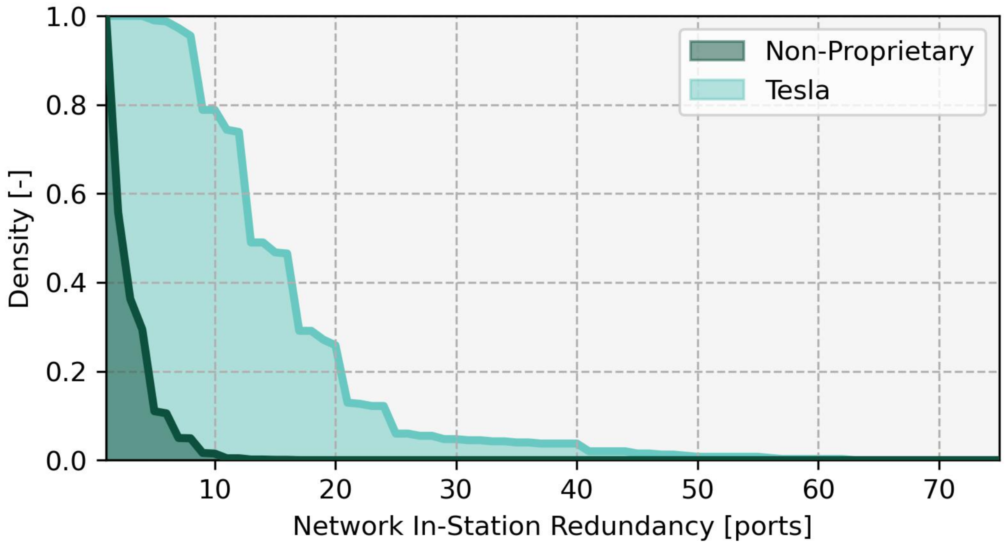
California also contains ~8,000 gas stations

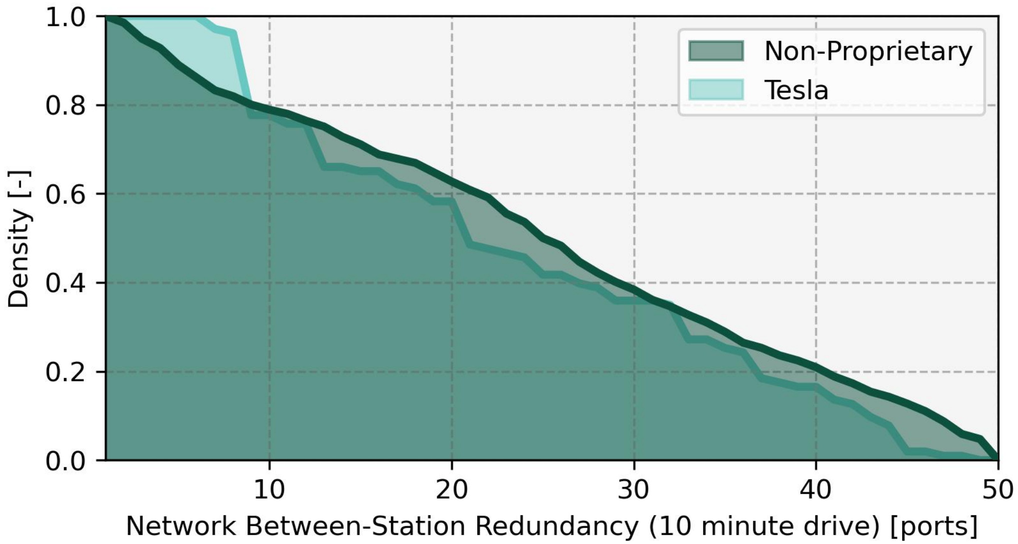
The purpose of charger networks is to provide redundancy

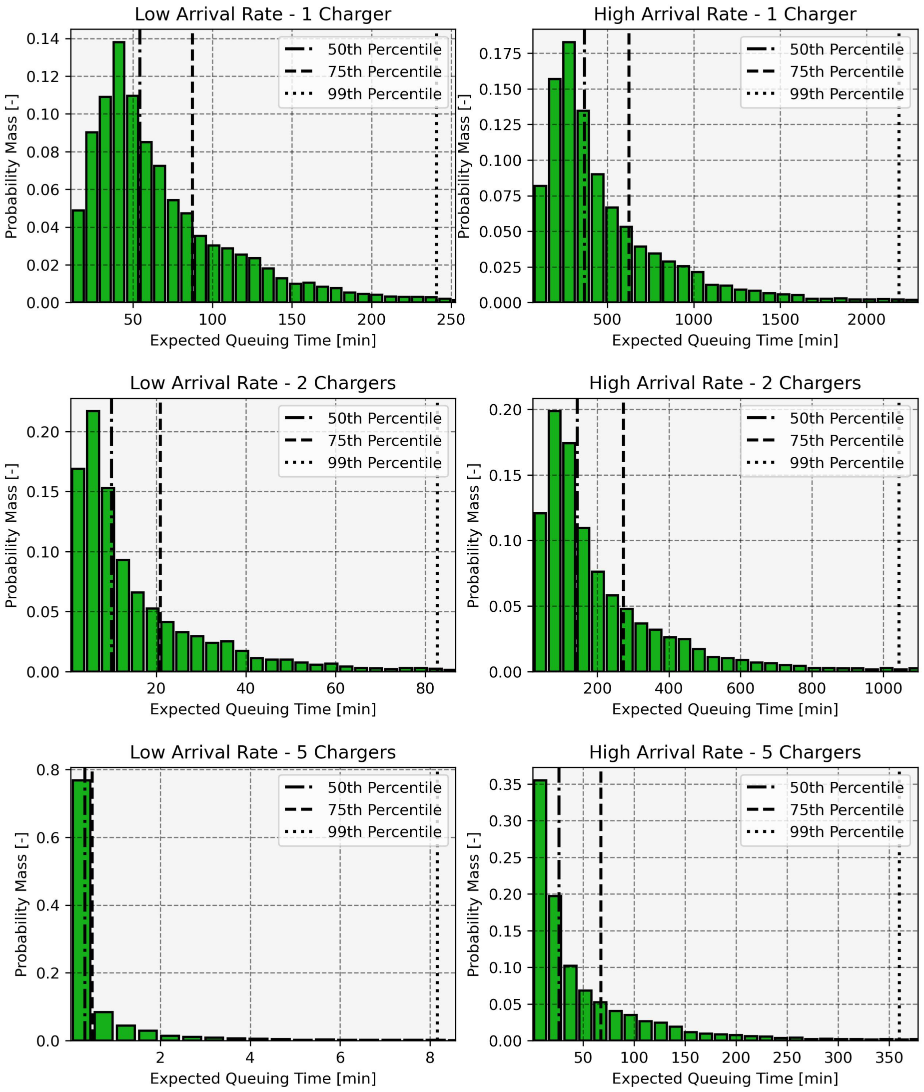
Roughly speaking, California's DCFC stations can be divided into Tesla and Non-Tesla networks

These are largely separate and unequal networks which lead to unequal experiences because they have *different levels of and approaches to redundancy*

- Tesla has 6,277 chargers concentrated in 403 stations
- Non-proprietary networks have 3,667 chargers spread among 1,425





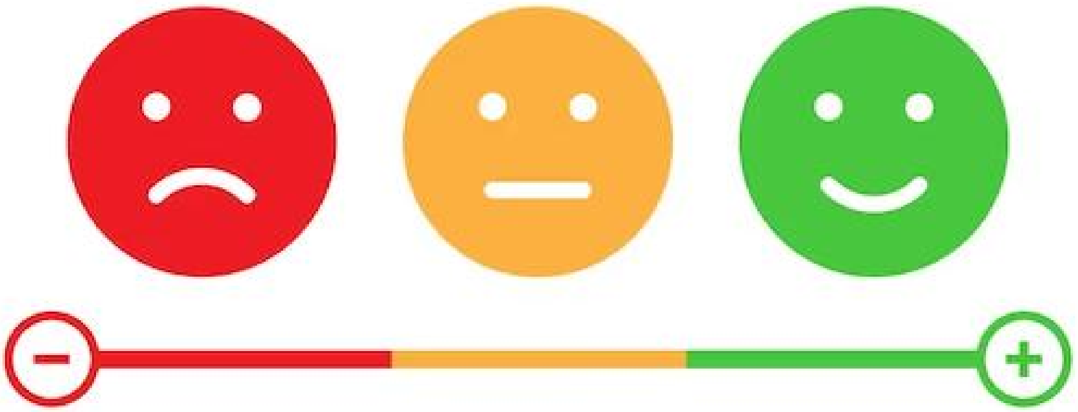


- Redundancy matters because it allows for demand to be spread among ports.
  - If demand exceeds redundancy a queue will form
  - The most important factor in reducing expected queue length is port redundancy

- Redundancy in-station is different than between-station for two reasons:
  - Information: Little information is available about status of chargers that you can't physically see
  - Latency: A charger in a different station which is free now might be occupied by the time you drive to it.

Driver Risk-Attitudes

Cautious decision-makers will focus on bad outcomes



Aggressive decision-makers will focus on good outcomes

Neutral decision-makers will weight all outcomes

We can represent this dynamic with the Superquantile Risk function which is used to inform optimal routing

$$S(D, p_0, p_1) = \frac{1}{p_1 - p_0} \int_{p_0}^{p_1} Q(D, \alpha)\, d\alpha$$

Specific Accessibility Example | Different Drivers from Fresno

Consider, as an example, the following four scenarios for a driver based out of Fresno:

- Risk neutral driver using a generic ICEV
    - Takes “direct path”
- Risk neutral driver using a Tesla Model 3
    - High range
    - High charger reliability
- Risk-cautious driver using a Chevrolet Bolt EV
    - Low range
    - Low charger reliability
- Risk-aggressive driver using a Chevrolet Bolt EV
    - Low range
    - Low charger reliability

Index	ICEV	Model 3 Neutral	Bolt Cautious	Bolt Aggressive
0	8.79	9.28	15.58	13.66
1	6.73	7.07	13.31	10.04
2	5.28	5.60	8.78	8.35
3	4.40	4.54	7.54	5.96
4	4.63	4.74	7.85	6.34
5	2.79	2.82	4.01	4.17
6	2.09	2.09	2.09	2.09
7	3.08	3.18	4.34	4.50
8	2.71	2.71	2.71	2.71
9	0.00	0.00	0.00	0.00
10	5.86	6.13	8.88	9.05
11	1.64	1.64	1.64	1.64
12	3.32	3.32	4.72	4.73
13	6.80	7.31	11.21	10.50
14	5.29	5.47	8.41	8.32

Hours to traverse arcs

Specific Accessibility Example

Different Drivers from Fresno

Little difference on short arcs

Major difference on long arcs

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Hours to traverse arcs

How easy are BEV long trips in California? A full-factorial study was conducted on the following parameters:

- Vehicle range - [200 miles, 300 miles, 400 miles] - (maximum charging speeds scale with capacity)
- Charger network access - [Tesla, Non-Tesla, Combined]
- Charger equipment reliability - [50%, 75%, 99%]
- Driver risk-attitude - [Cautious (worst 50% of outcomes), Neutral (all outcomes), Aggressive (best 50% of outcomes)]

- State-wide Road-Trip Accessibility was computed for each case

Linear Regression based on Road-Trip Accessibility metric produced the following significant terms:

Parameter	β	p-value
Intercept	6.678	0.000
Range	-0.903	0.035
Attitude	2.633	0.000
Attitude:Range	-2.570	0.000
Attitude:Reliability	-2.028	0.003
Attitude:Non-Tesla Access	1.406	0.021

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All else being equal, BEV travel takes more time than ICEV travel

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Increasing range can often mean dropping one charging event

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More cautious decision-makers will be put off by the immature DC charging network, especially in the more rural areas of the state. Better vehicles and networks can help alleviate this.

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Tesla's DC charging network provides the best redundancy and this matters to more cautious drivers.

Changing the regressors to include Redundancy In-Station and Between-Station directly

Parameter	β	p-value
Intercept	6.800	0.000
Range	-0.921	0.012
Attitude	3.640	0.000
Attitude:Range	-3.559	0.000
Attitude:Reliability	-2.772	0.000
Attitude:Redundancy-IS	-1.339	0.026
Attitude:Range:Reliability	2.754	0.002

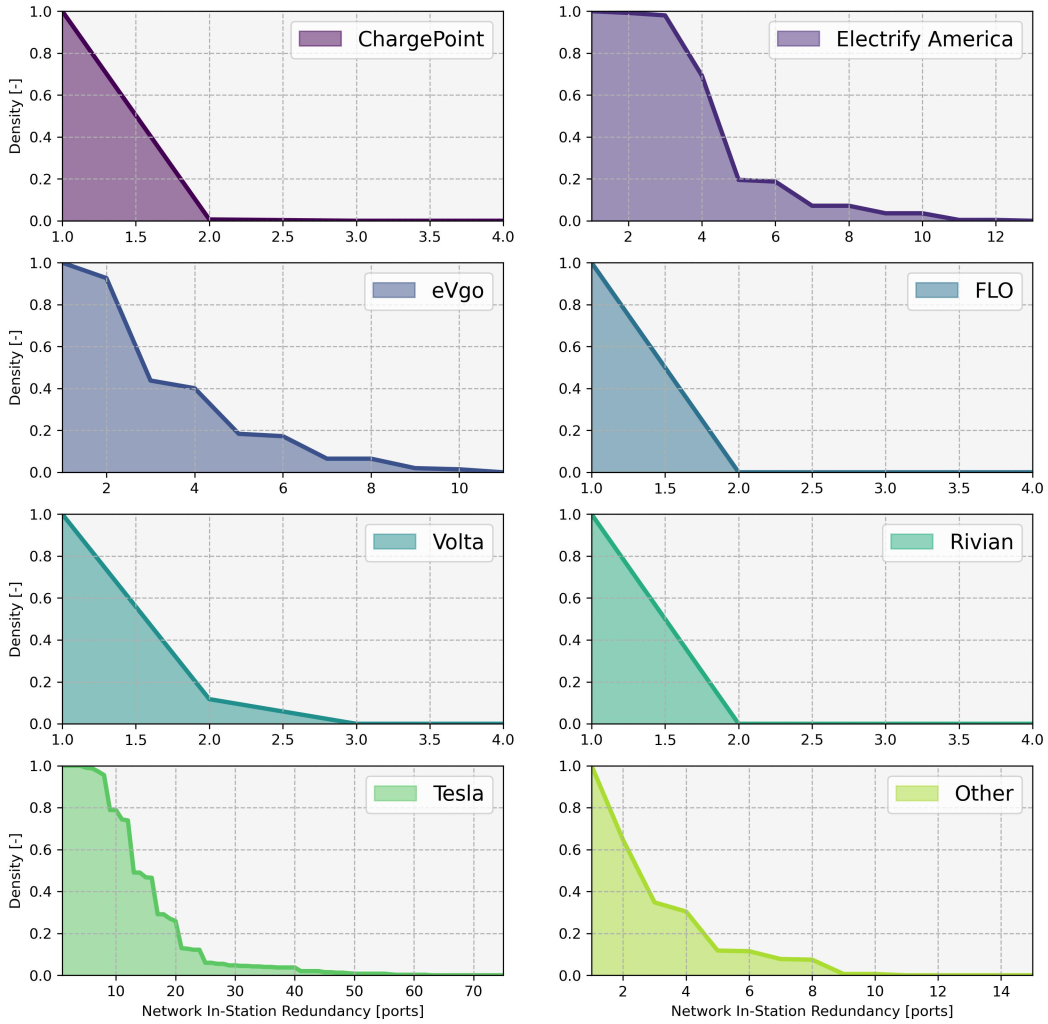
Redundancy In-Station is significant but Redundancy Between-Station is not

Conclusions

- DC charging is needed to enable long road-trips for BEVs
  - People tend to over-weigh long trips in purchasing decisions compared to their frequency
  - In the US, a mode switch will usually be to a higher emission mode

- DC charging networks are not yet mature
  - Speeds and redundancy need to improve to approach ICEV parity
  - At the moment information and latency issues make concentrated networks more beneficial for long road-trip travel
  - Tesla’s network is currently the most useful - might be a good model

- Generally better utilization and reliability data will enable better analysis and better operation



Q & A