33rd Annual INCOSE international symposium

hybrid event

Honolulu HI USA

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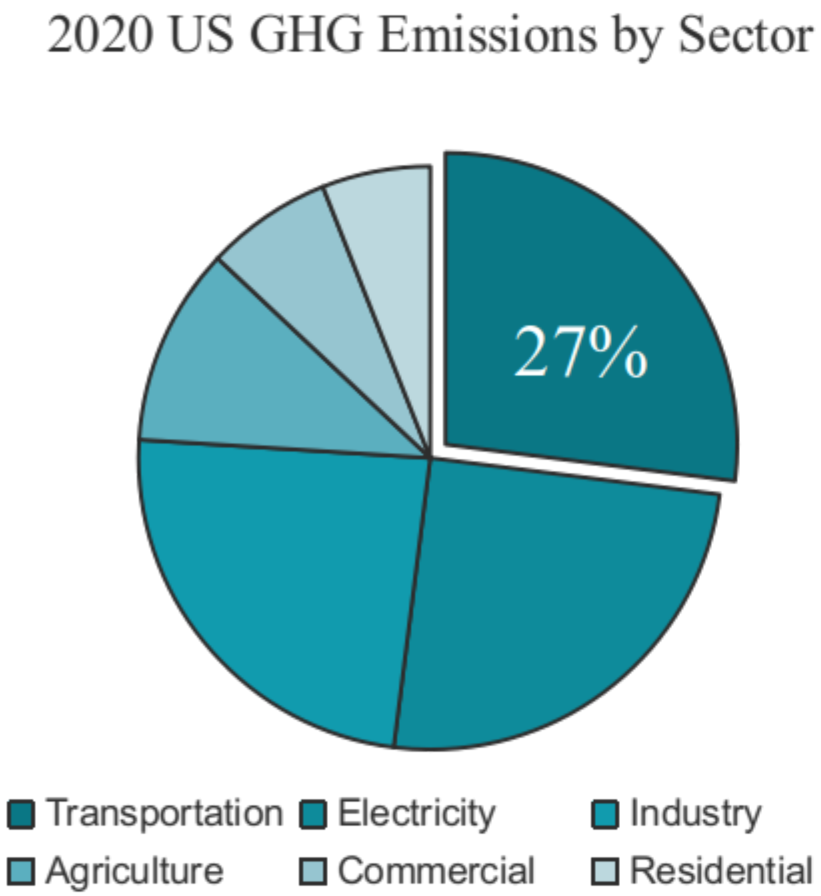
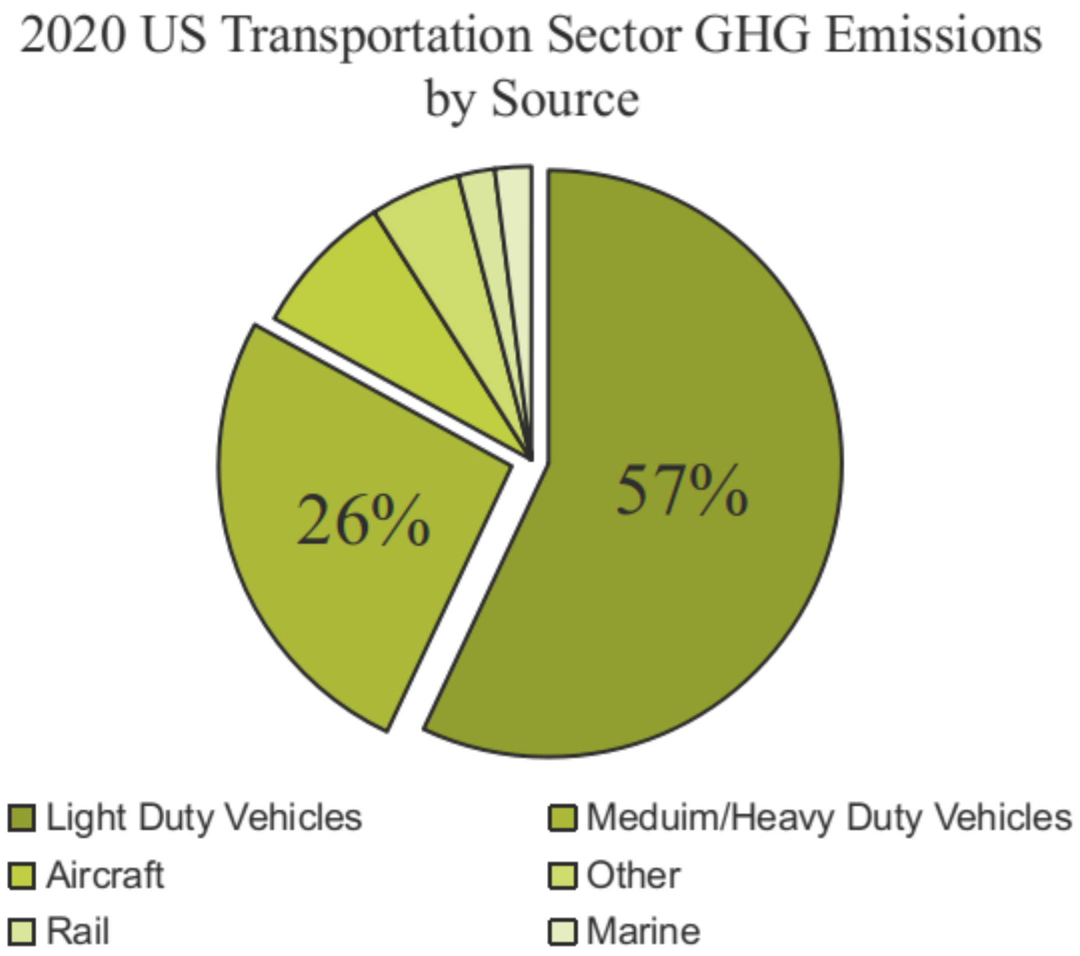
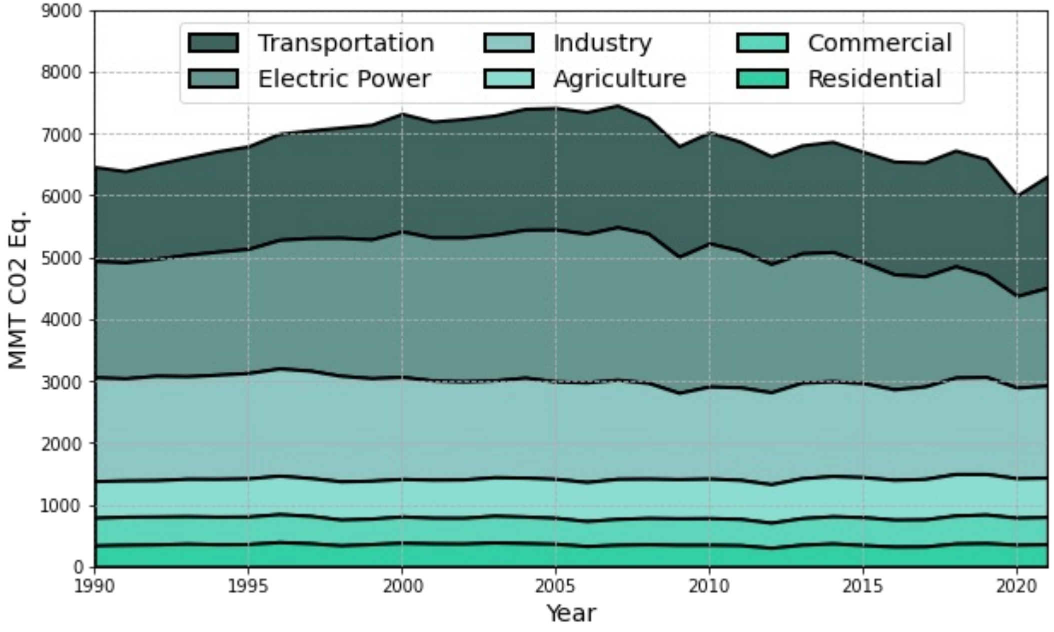
A Geo-Spatial Method for Calculating BEV Charging Inconveneince Using Publicly Available Data

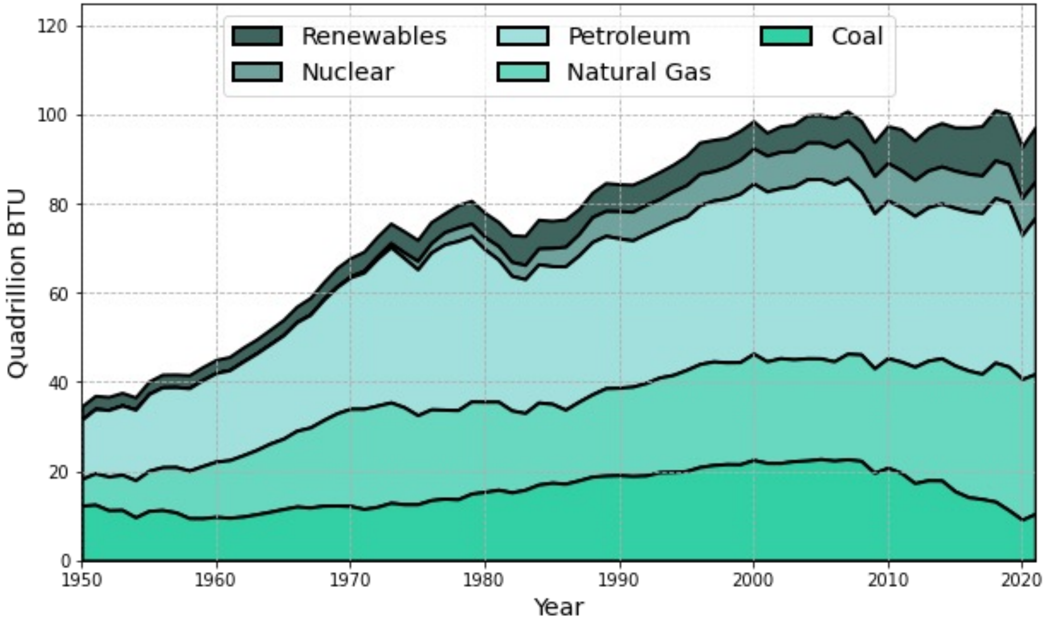
Introduction


2020 US GHG Emissions by Sector
27%
Transportation
Electricity
Industry
Agriculture
Commercial
Residential


2020 US Transportation Sector GHG Emissions by Source
26%
57%
Light Duty Vehicles
Meduim/Heavy Duty Vehicles
Aircraft
Other
Rail
Marine

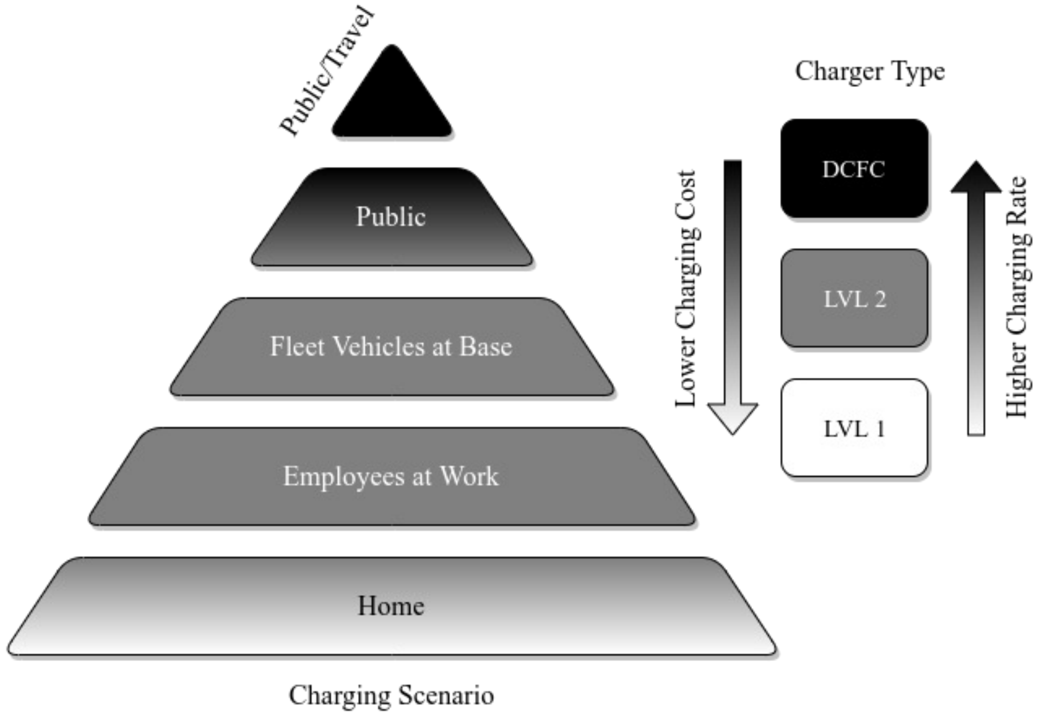
While emissions from transportation (and most other sectors) have remained stable or grown since 1990, the emissions from the energy sector have shrunk by **40%**



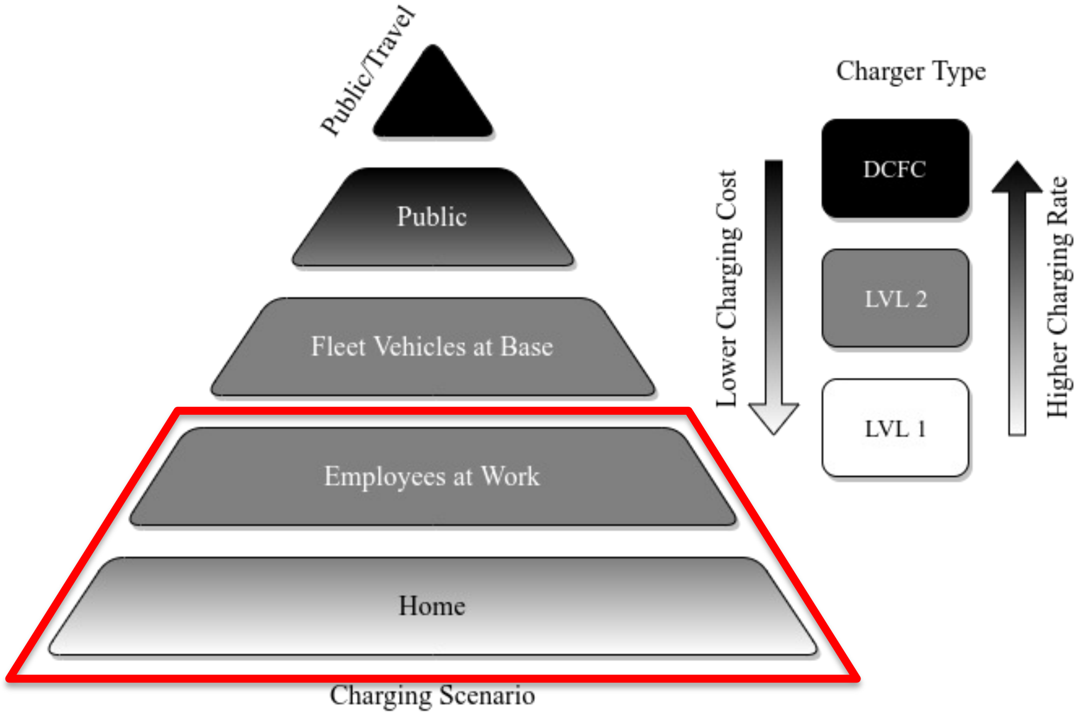


Electrification **decouples** power generation and locomotion

EV emissions per km can change over the course of the vehicle's life



Public/Travel
Public
Fleet Vehicles at Base
Employees at Work
Home
Charging Scenario
Charger Type
DCFC
LVL 2
LVL 1
Lower Charging Cost
Higher Charging Rate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Inconvenience Score

Postulate 1: BEVs are inconvenient to operate because of range limitations and charging times

I’m soooo bored

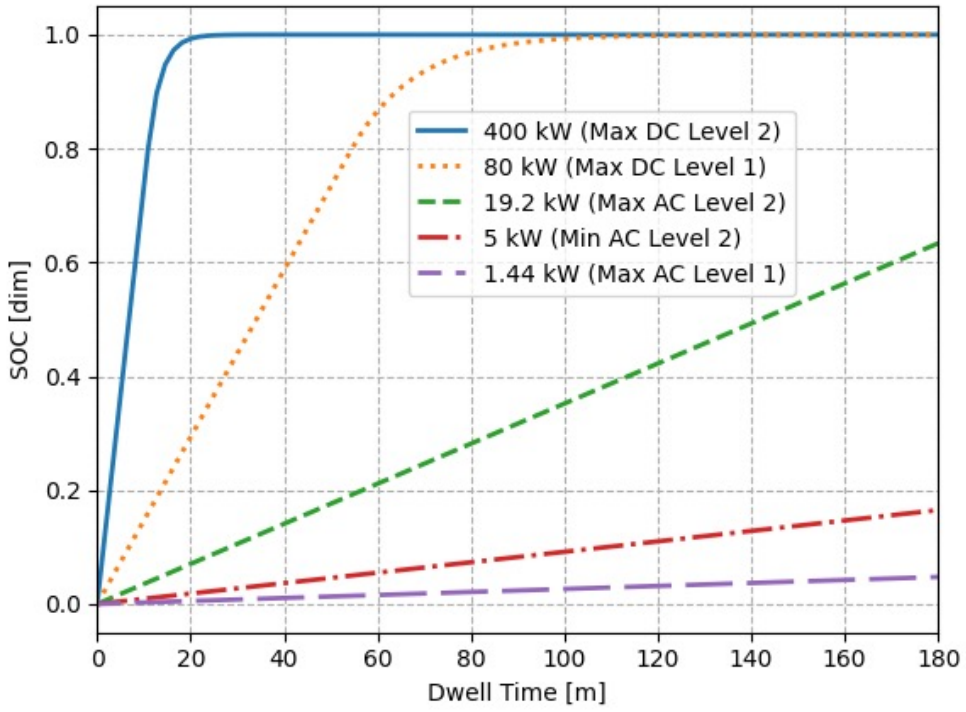
We should’ve taken my car

I wish we were doing literally anything else right now

Postulate 1: BEVs are inconvenient to operate because of range limitations and charging times

- Specific energy of current EV batteries is ~1000 kJ/kg; it's 457,200 kJ/kg for gasoline
- Highest DC Level 2 charging rates are around 350 kW; at 7 gallons/minute ICVs energize at 14.15 MW
- Electric drive is about 5 times more efficient than IC drive

So even at the fastest modern charging rates EVs add range about **8** times slower than ICVs



Charging traces for 80 kWh battery pack with various charging rates using CC-CV curves for DC charging (SAE J1772)

Postulate 2: Charging is only inconvenient if it requires the user to devote time to it

So much better than going to the gas station

Aren't you glad they installed these chargers?

Yeah, it's awesome!

Postulate 2: Charging is only inconvenient if it requires the user to devote time to it

- If you were going to dwell in a given location for a given time regardless then it is not inconvenient to charge in that area for that duration

- This applies for home, work, and other destination charging events

$$S_{IC} = \frac{\sum_{k=0}^{N} [D_{E,k} M_{E,k} + D_{T,k} M_{T,k} + D_{P,k} M_{P,k}]}{\sum_{k=0}^{N} L_k}$$

- S_{IC} - Inconvenience Score for itinerary. The time spent devoted to charging per kilometer traveled. [min/km]
- D_E - Duration of energizing event [min]
- D_T - Duration of travel to and from energizing event [min]
- D_P - Duration of payment process for energizing event [min]
- M_E, M_T, M_P - Multipliers for durations based on energizing event type [dim]
- L - Length of trip [km]

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Energizing Event Type	M_E	M_T	M_P
Home	0	0	0
Work	0	0	0
Destination	0	0	1
En-route	1	1	1

Home and work charging events do not incur inconvenience

$$S_{IC} = \frac{\sum_{k=0}^{N}[D_{E,k}M_{E,k} + D_{T,k}M_{T,k} + D_{P,k}M_{P,k}]}{\sum_{k=0}^{N} L_k}$$

Energizing Event Type	M_E	M_T	M_P
Home	0	0	0
Work	0	0	0
Destination	0	0	1
En-route	1	1	1

Destination charging events only incur inconveneince for the duration of the payment process

$$S_{IC} = \frac{\sum_{k=0}^{N}[D_{E,k}M_{E,k} + D_{T,k}M_{T,k} + D_{P,k}M_{P,k}]}{\sum_{k=0}^{N} L_k}$$

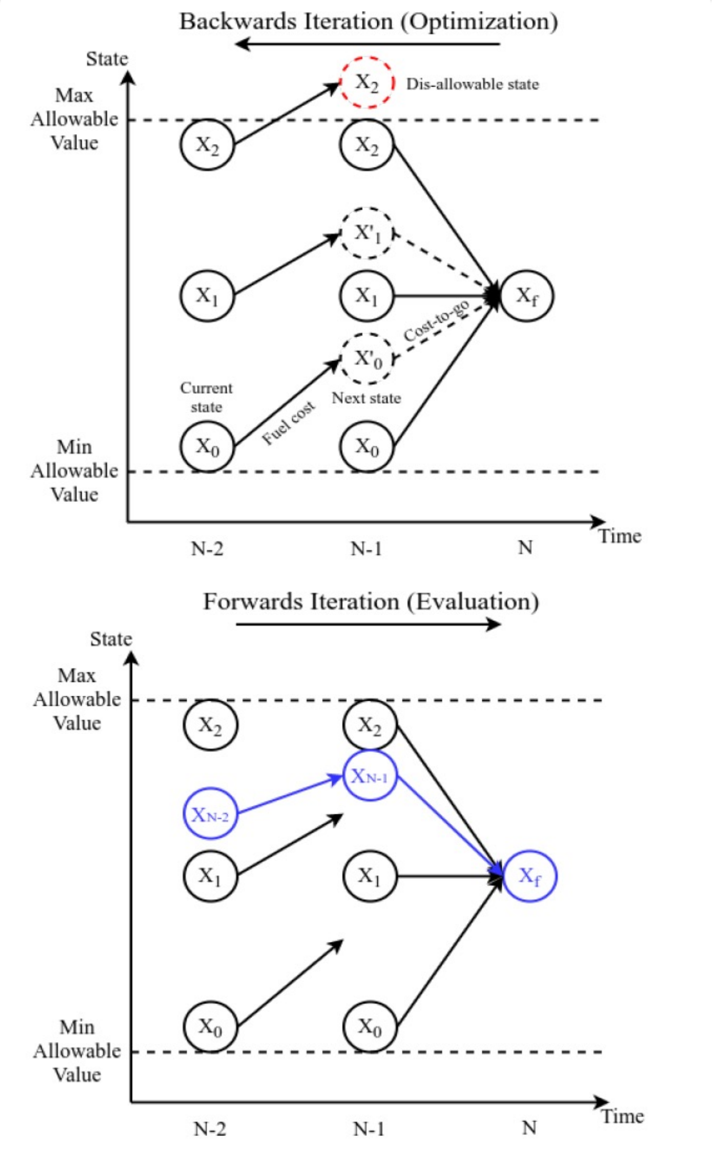
Energizing Event Type	M_E	M_T	M_P
Home	0	0	0
Work	0	0	0
Destination	0	0	1
En-route	1	1	1

En-route charging events incur inconvenience at all stages - note that virtually all ICV fueling event are en-route

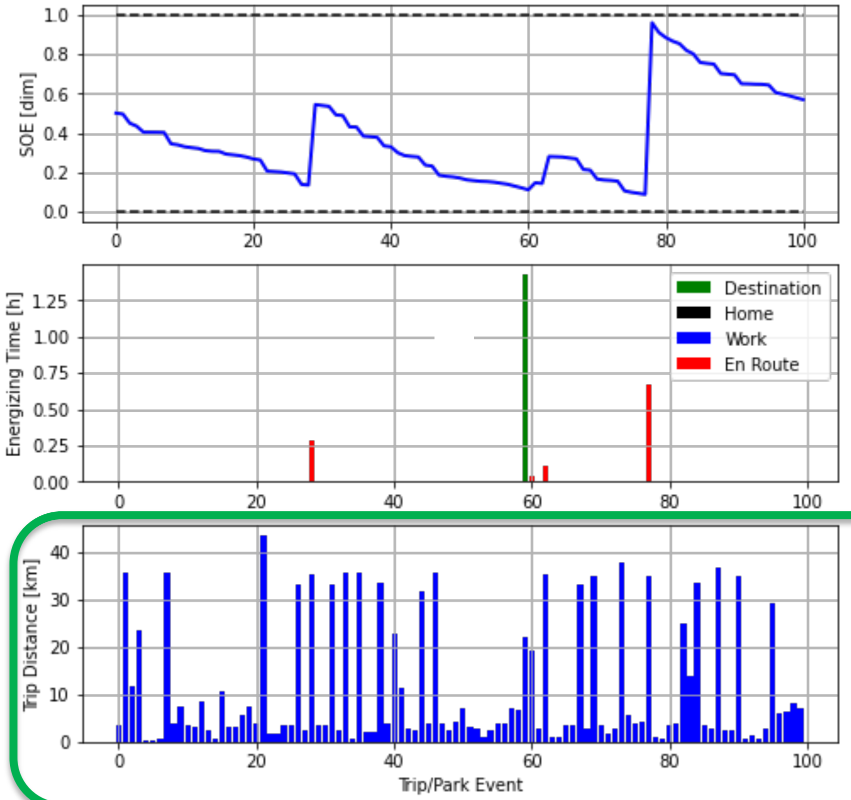
Calculation

Postulate 3: For a given itinerary, the characteristic inconvenience is the minimum inconvenience

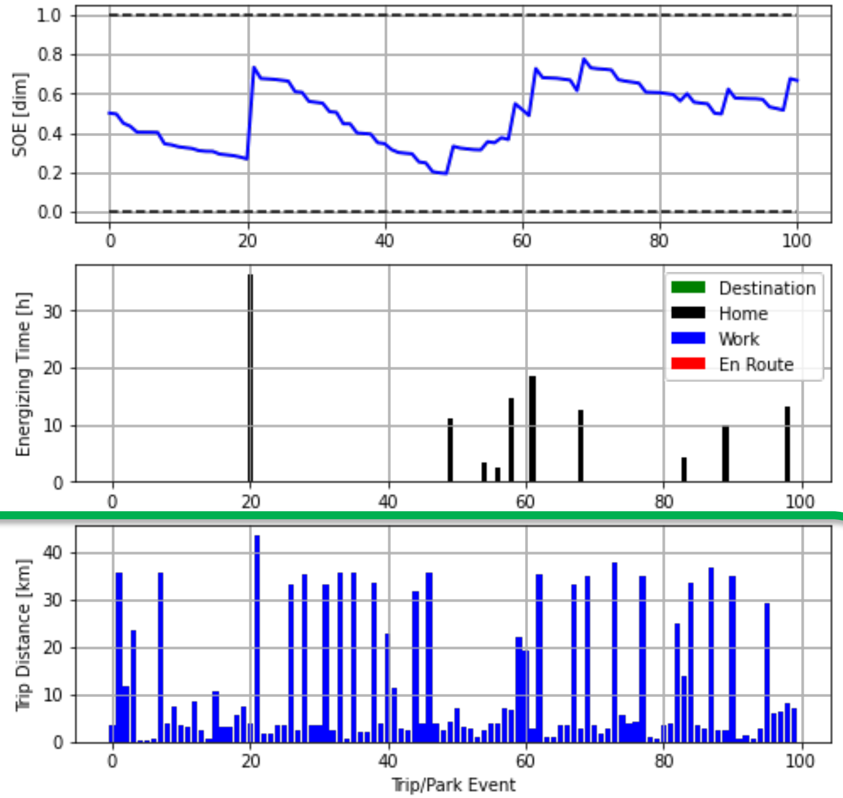
- No established model for how humans decide to schedule charges - certainly varies person to person
- Every itinerary will have a globally Optimal Charge Schedule (OCS) which will result in a globally minimum S_{IC}
- Dynamic Programming (DP) can be used to find said OCS



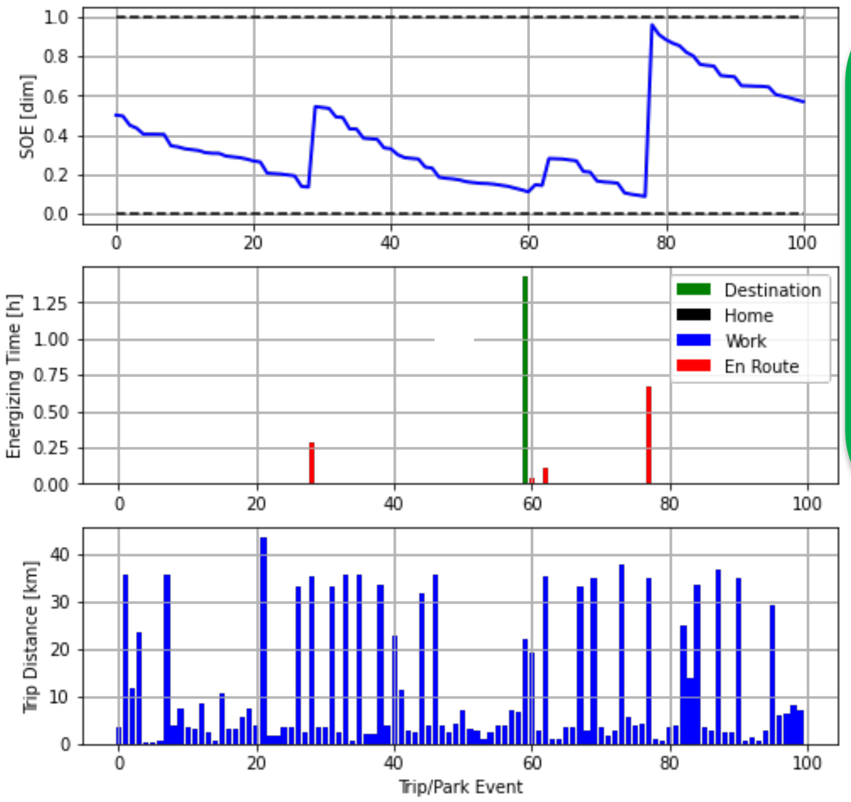
Top-Down DP Schematic



No home or work charging available (S_{IC} = 0.120 min/km)



Home charging available (S_{IC} = 0.000 min/km)



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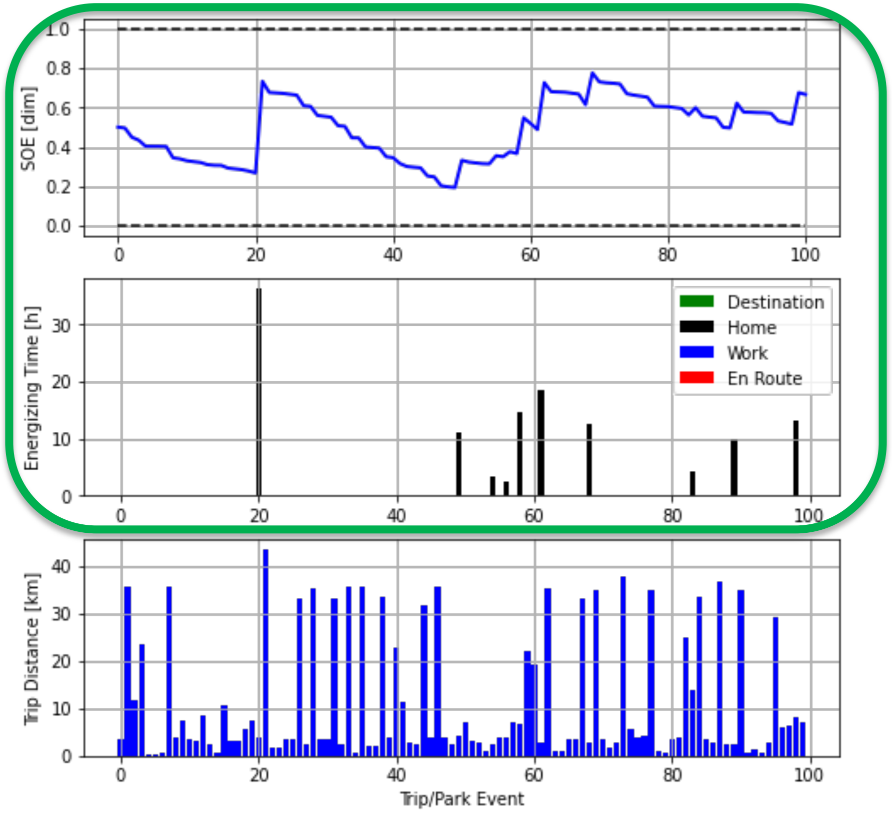

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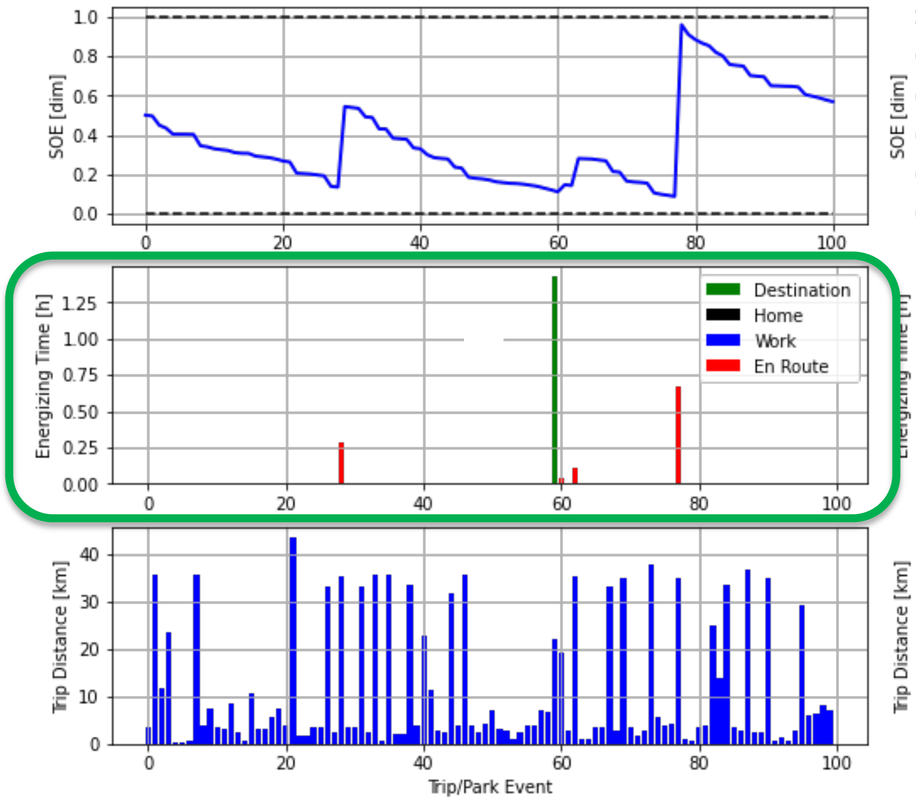

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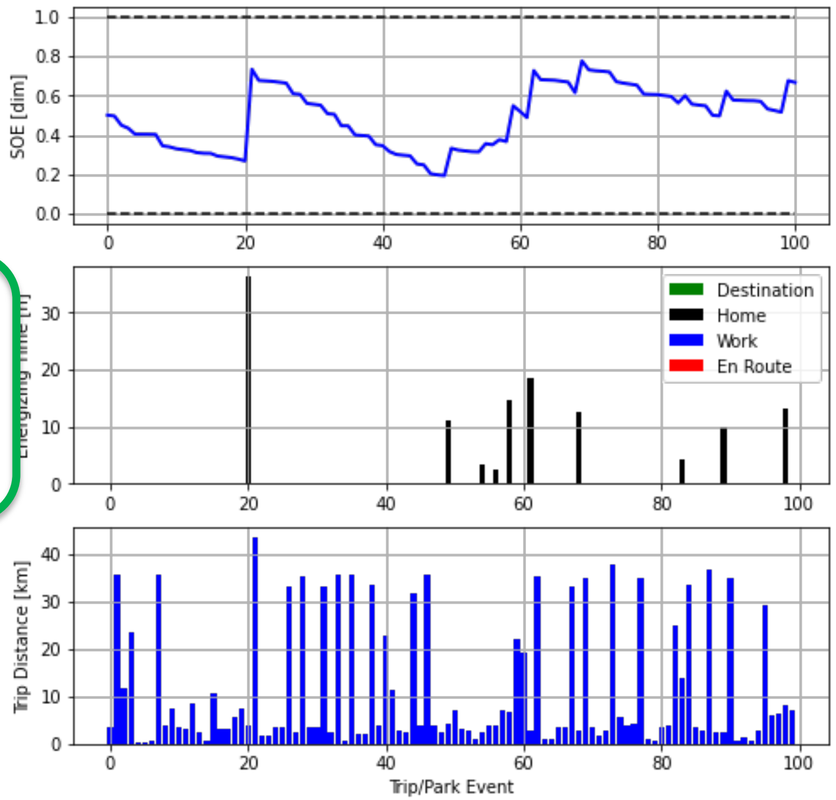

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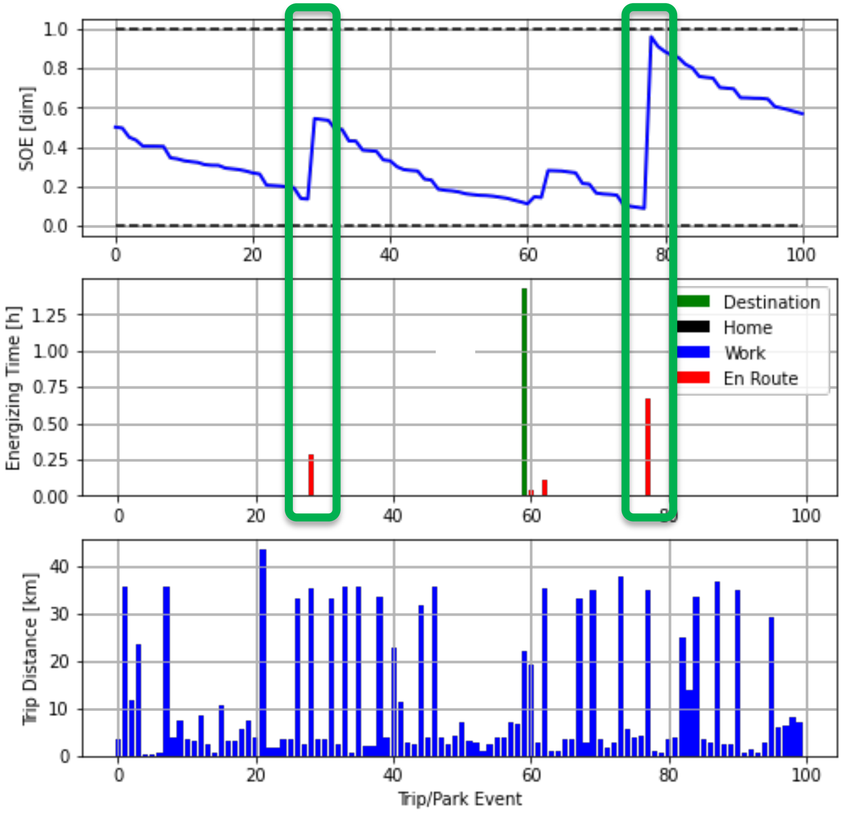

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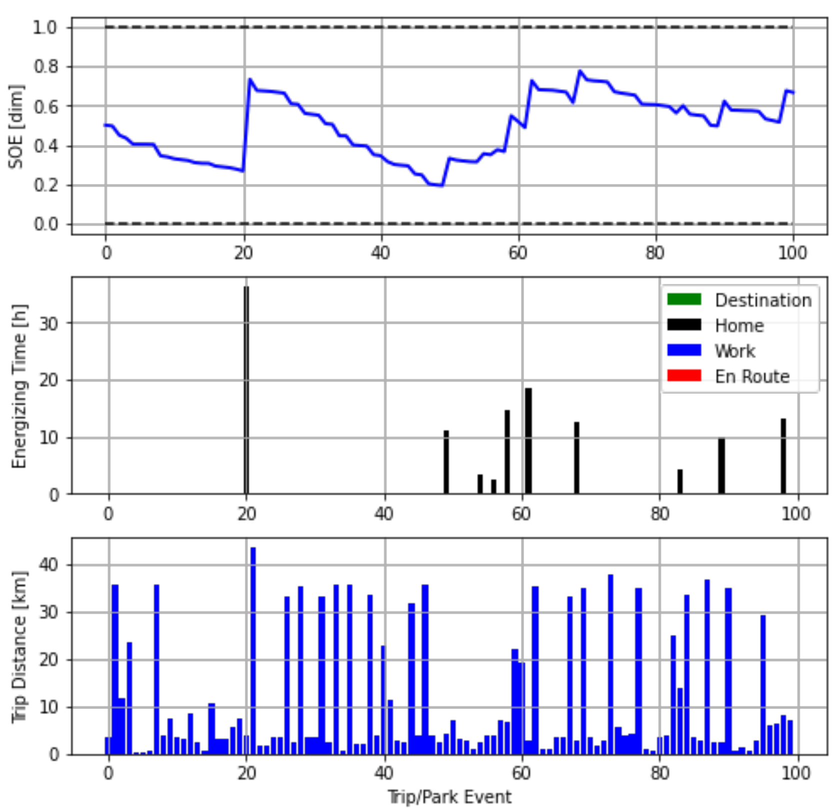

Home charging available (S_{IC} = 0.000 min/km)

Empirical Formulae

In order to understand how parameters effected S_{IC}, a full-factorial designed experiment was conducted using the following levels:

Parameter	Levels	Unit
Home Charging (HC)	[False, True]	Boolean
Work Charging (WC)	[False, True]	Boolean
Battery Capacity (BC)	[40, 80, 120]	kWh
Destination Charger Likelihood (DCL)	[0, 7.5, 15]	%
En-Route Charging Rate (ERCR)	[50, 150, 250]	kW
En-Route Charging Penalty (ERCP)	[15, 30, 45]	min

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Idaho National Laboratory

- Proprietary dataset provided by INL which contained longitudinal tracking data from 2,177 vehicles over 2 years
- No publicly available equivalent but some regional equivalents (NREL TSDC)
- Driving patterns in the dataset matched well with national averages
- Data was extremely biased towards southern California

NHTS

- Public dataset containing 1 day survey results for 117,222 housholds with 219,194 persons and 153,351 vehicles
- Spread among all 50 US states and DC
- Includes demographic data and non-specific location information such as states for home locations
- Survey is filled manually so data is not precise

Battery Capacity (BC)

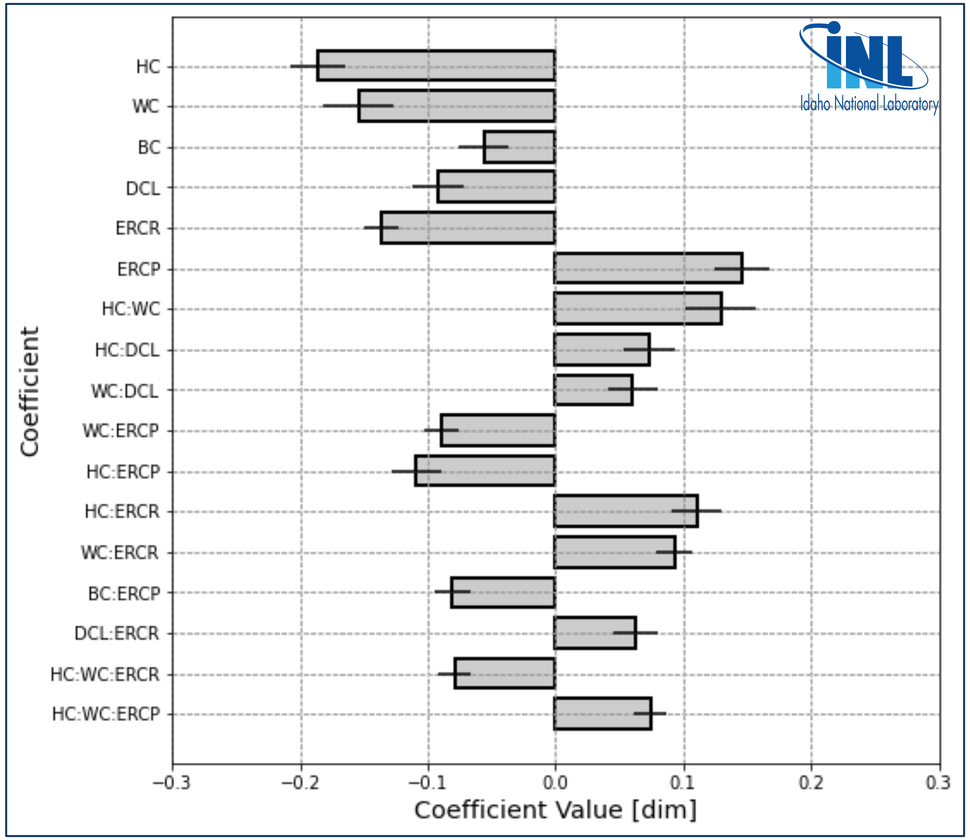
Home Charging (HC)

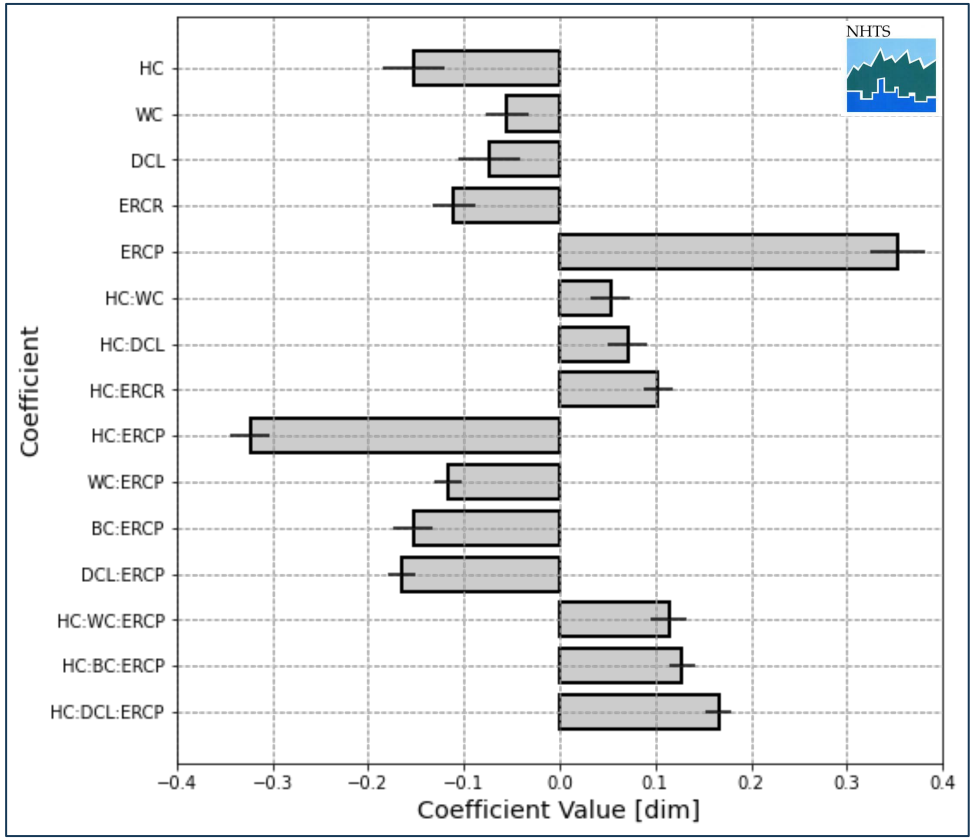
Work Charging (WC)

Destination Charging Likelihood (DCL)

En-Route Charging Rate (ERCR)

En-Route Charging Penalty (ERCP)





Normalized significant terms (99% confidence) from regressed S_{IC} equations

Battery Capacity (BC)

Home Charging (HC)

Work Charging (WC)

Destination Charging Likelihood (DCL)

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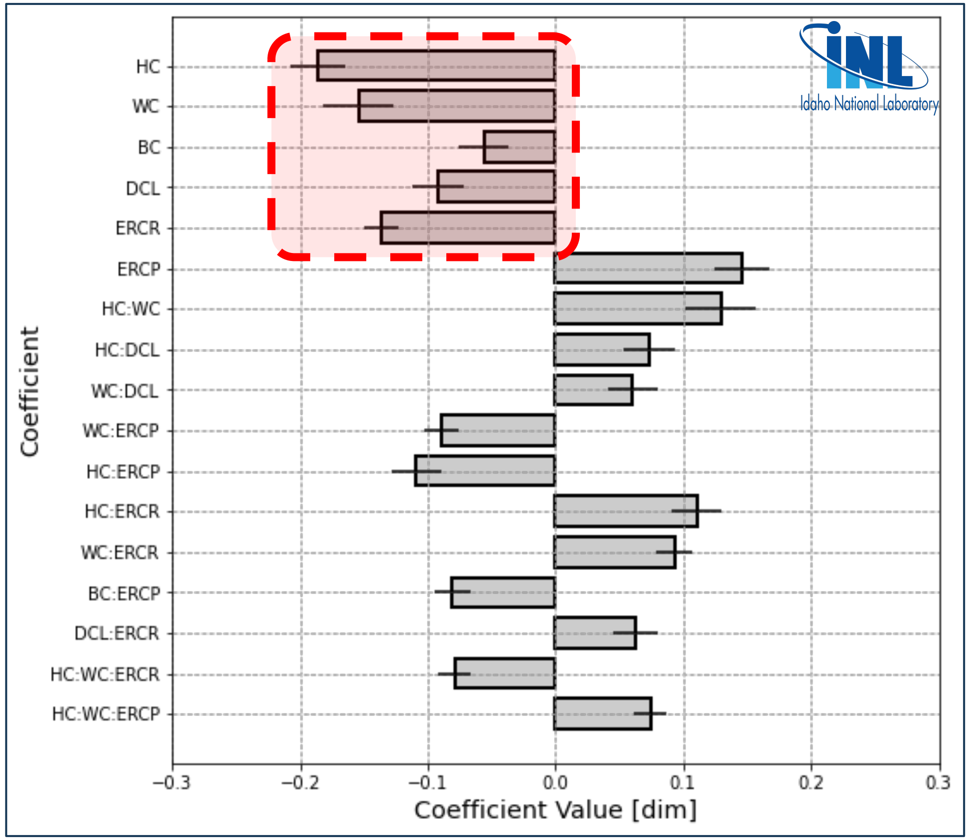

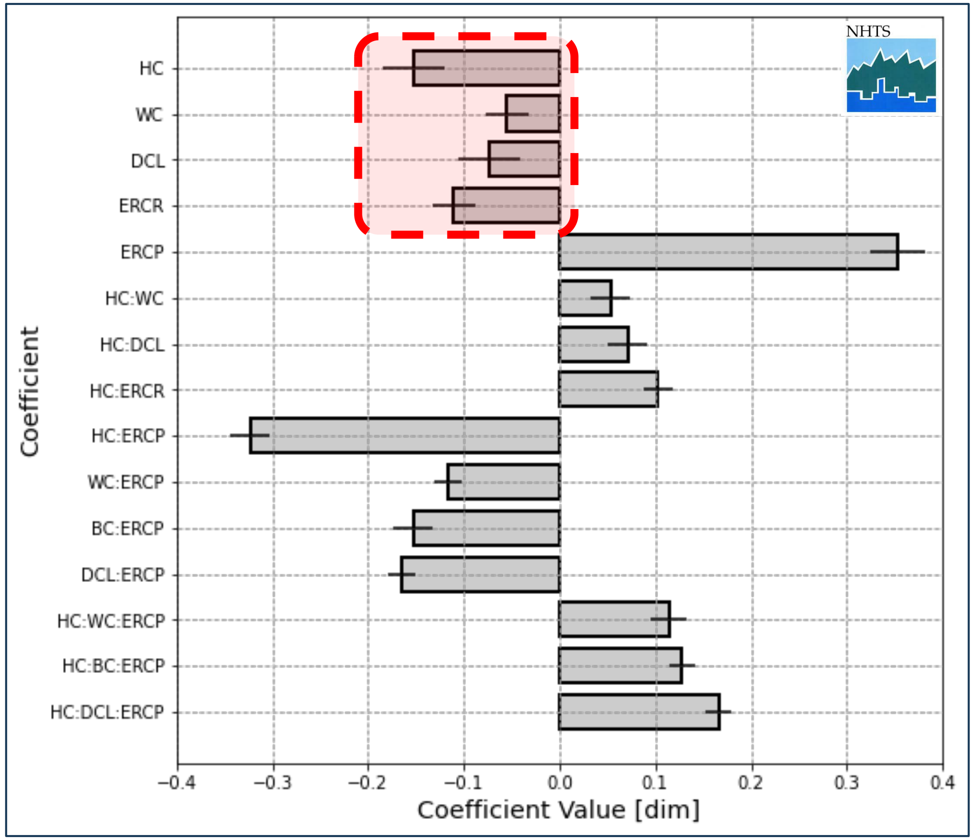

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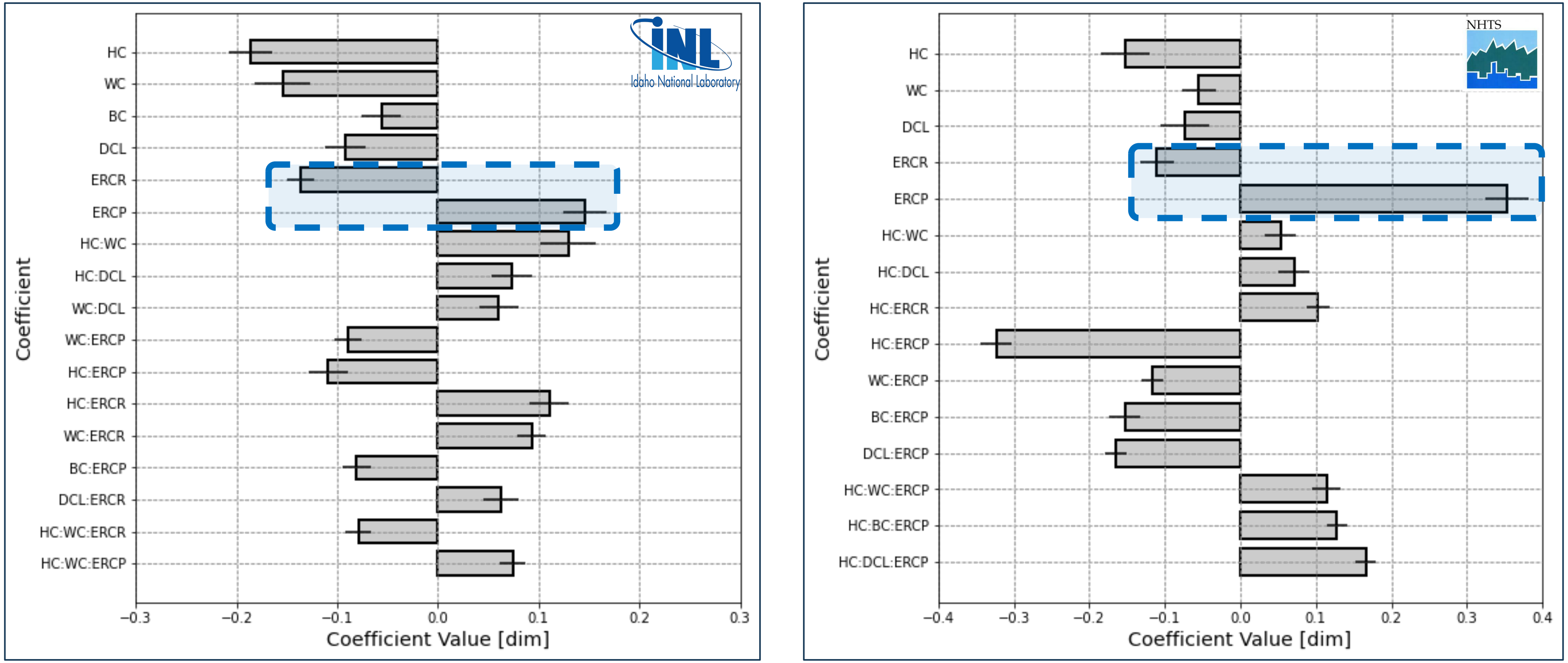

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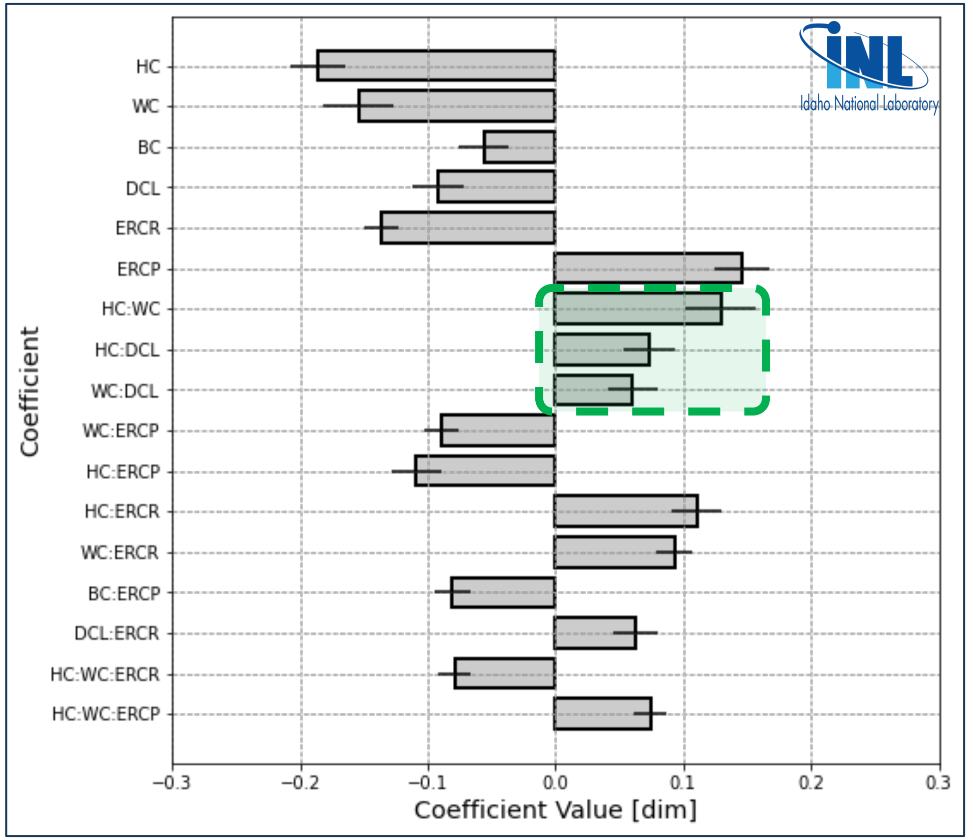

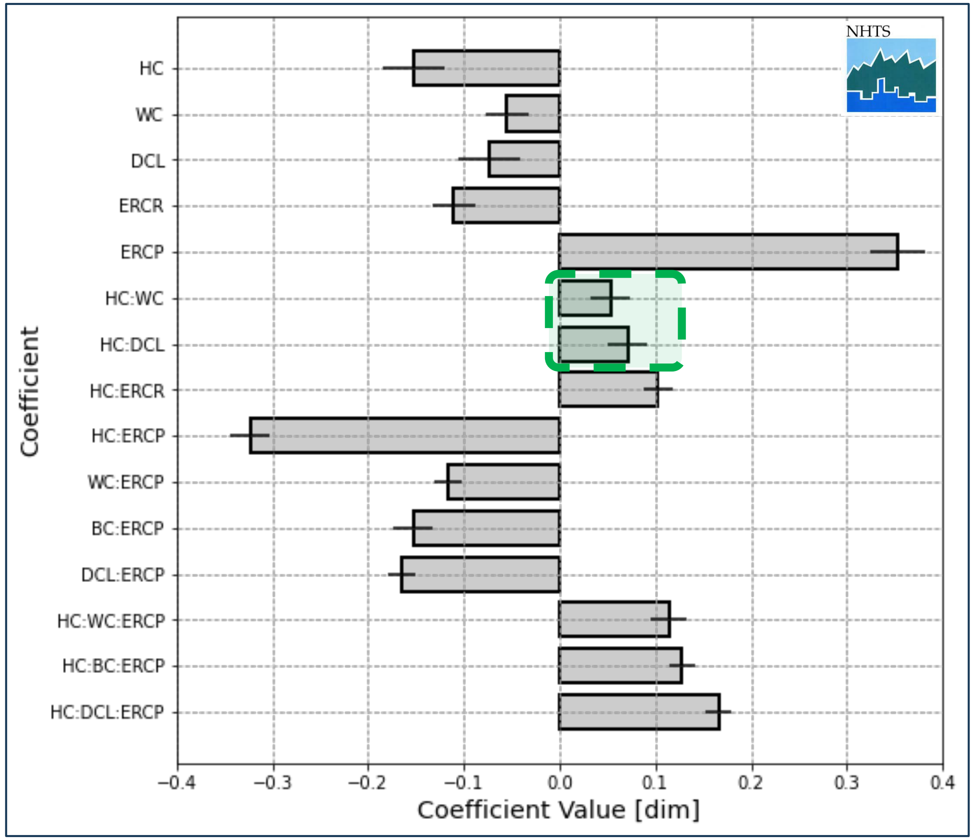

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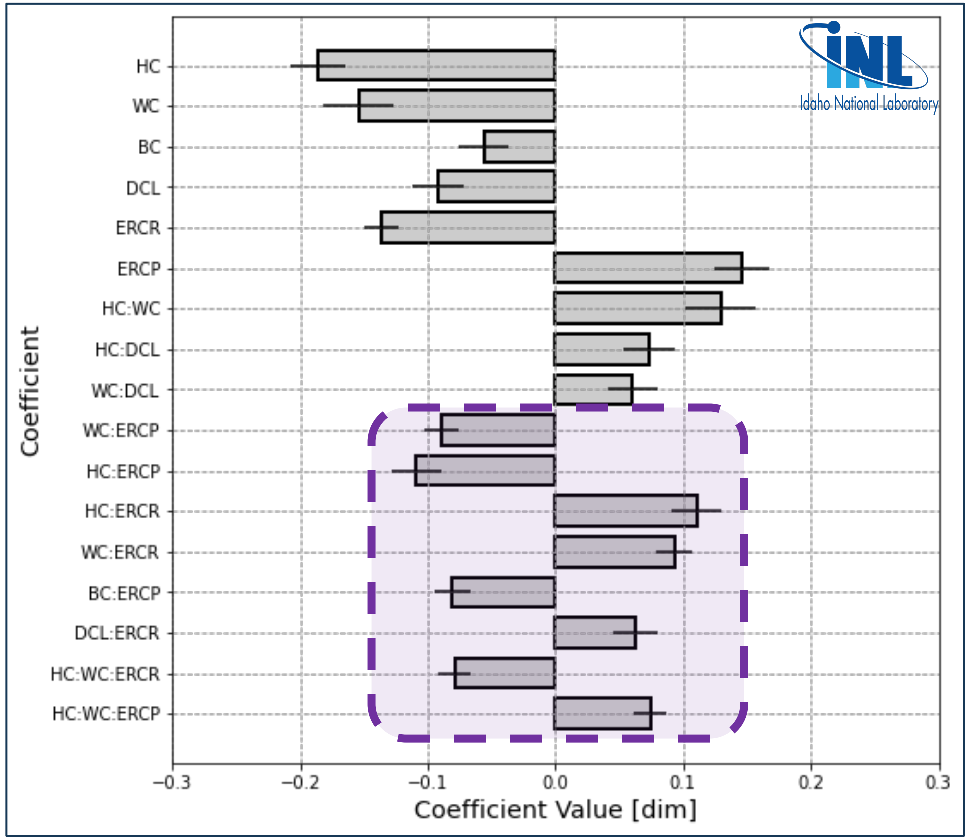

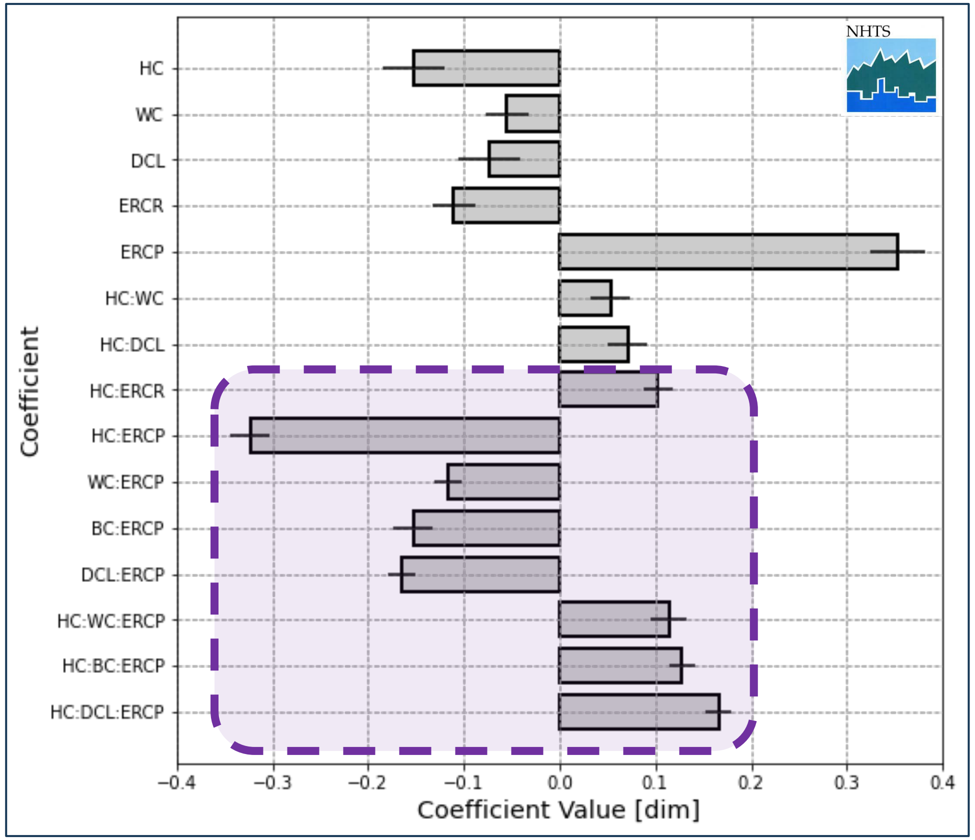

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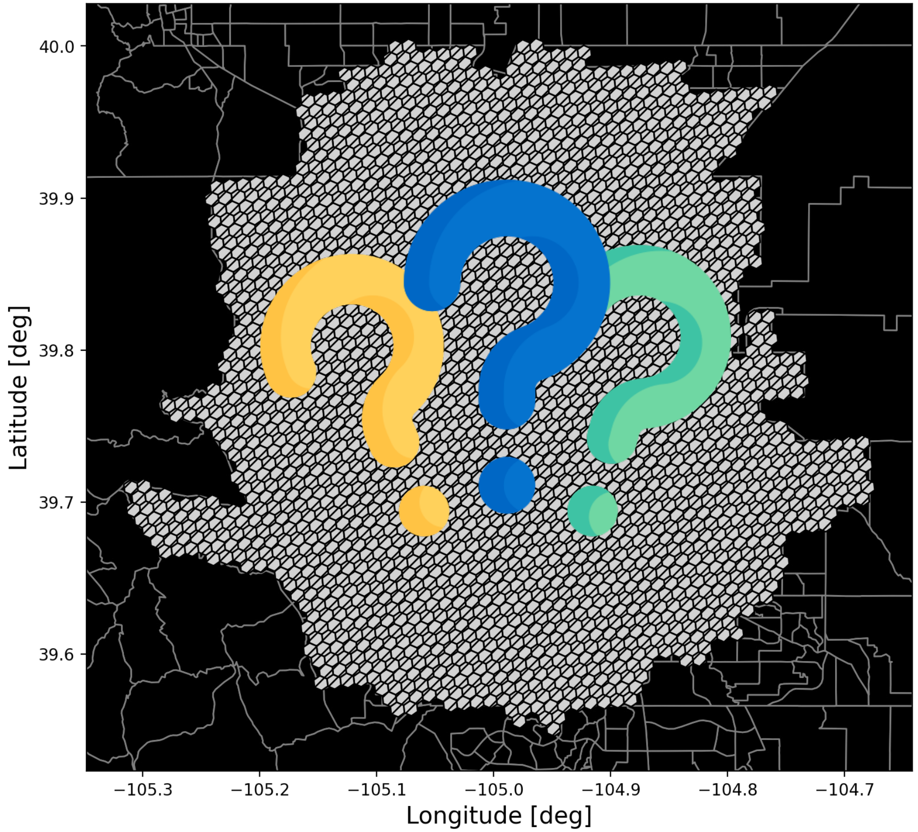
Geo-Spatial Implementation

- Thus far, inconvenience analysis has been applied in the abstract with assumed values for some quantities.

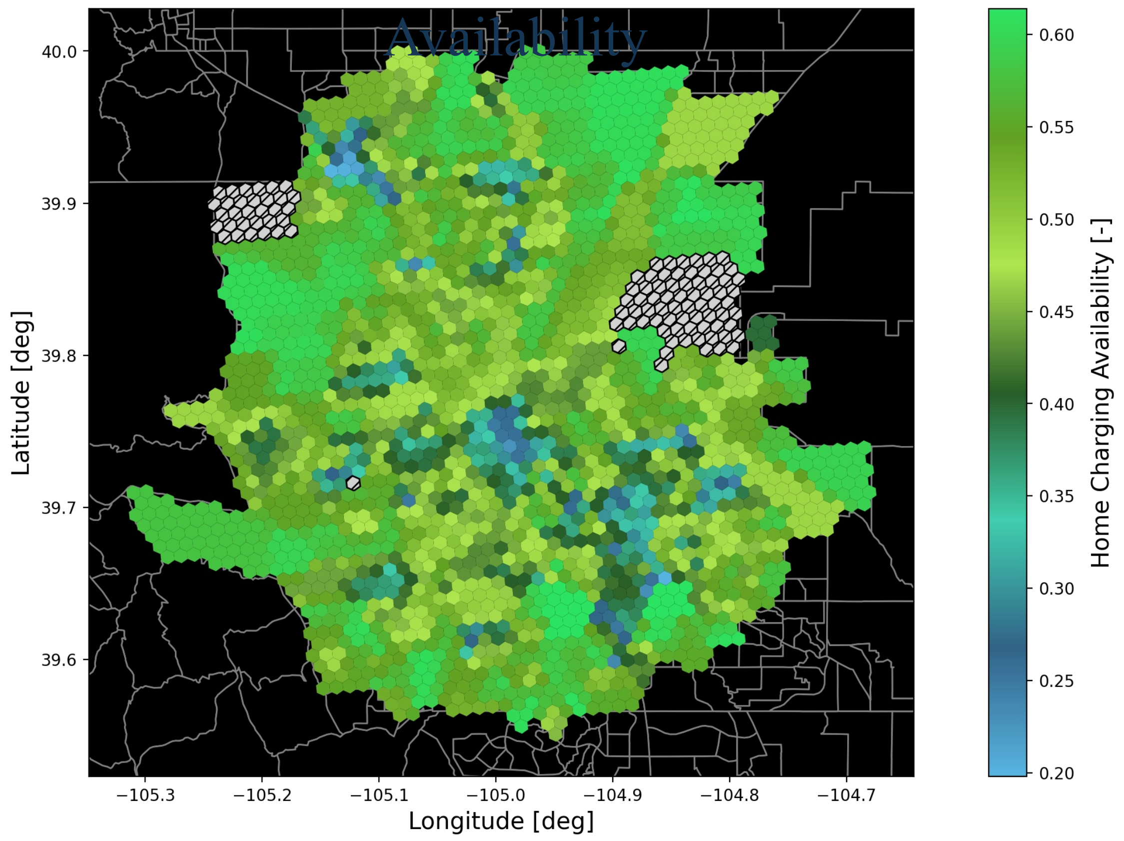
- Enabling a geo-spatial calculation of S_{IC} will allow for:
  - Analysis of geographical inequities
  - Evaluation of specific policies in given areas

- As an example, lets look at the urbanized area surrounding Denver, CO



- Using public data, real values for the following quantities can be computed on a geo-spatial basis:
  - Home Charging (HC): This can be estimated by housing type and tenure statistics
  - Destination Charger Likelihood (DCL): This can be computed from locations of chargers and popular destinations
  - En-Route Charging Penalty (ERCP): This can be computed using high-rate charger locations
- Assumptions still need to be made for Work Charging (WC), Battery Capacity (BC), and En-Route Charging Rate (ERCR).

Home Charging Availability



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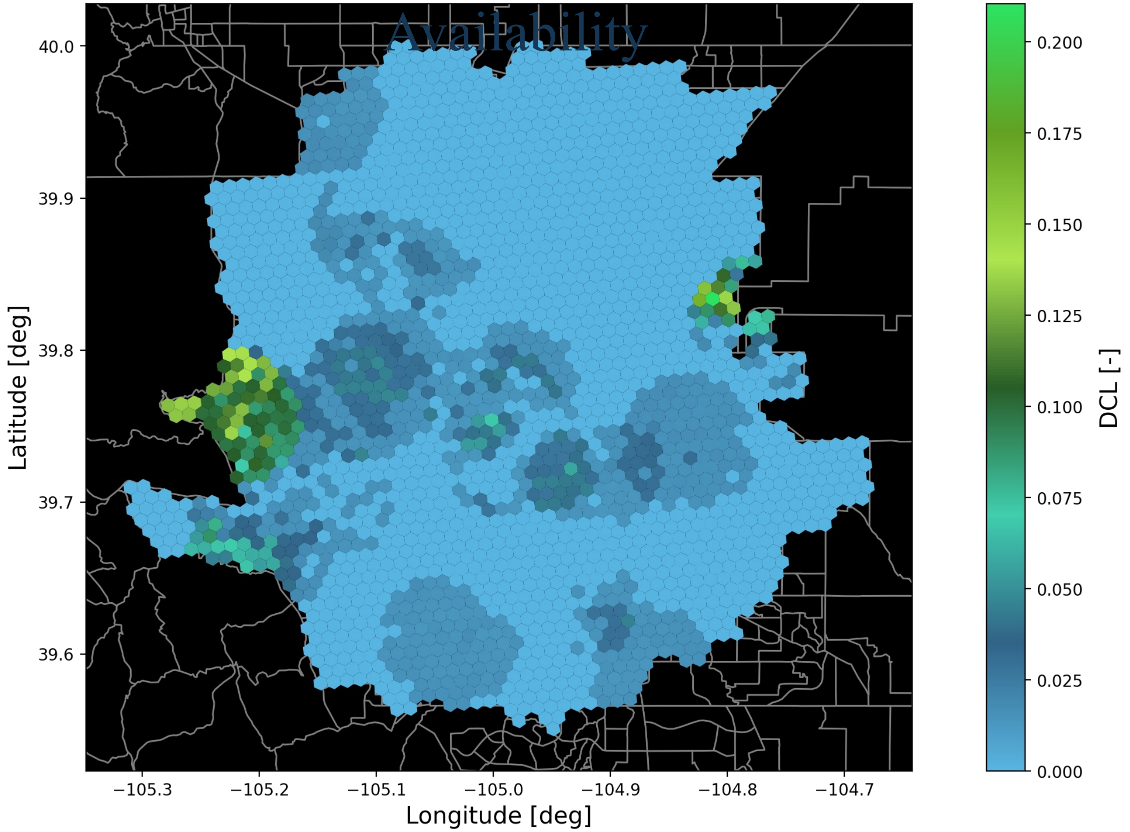
Destination Charging Availability



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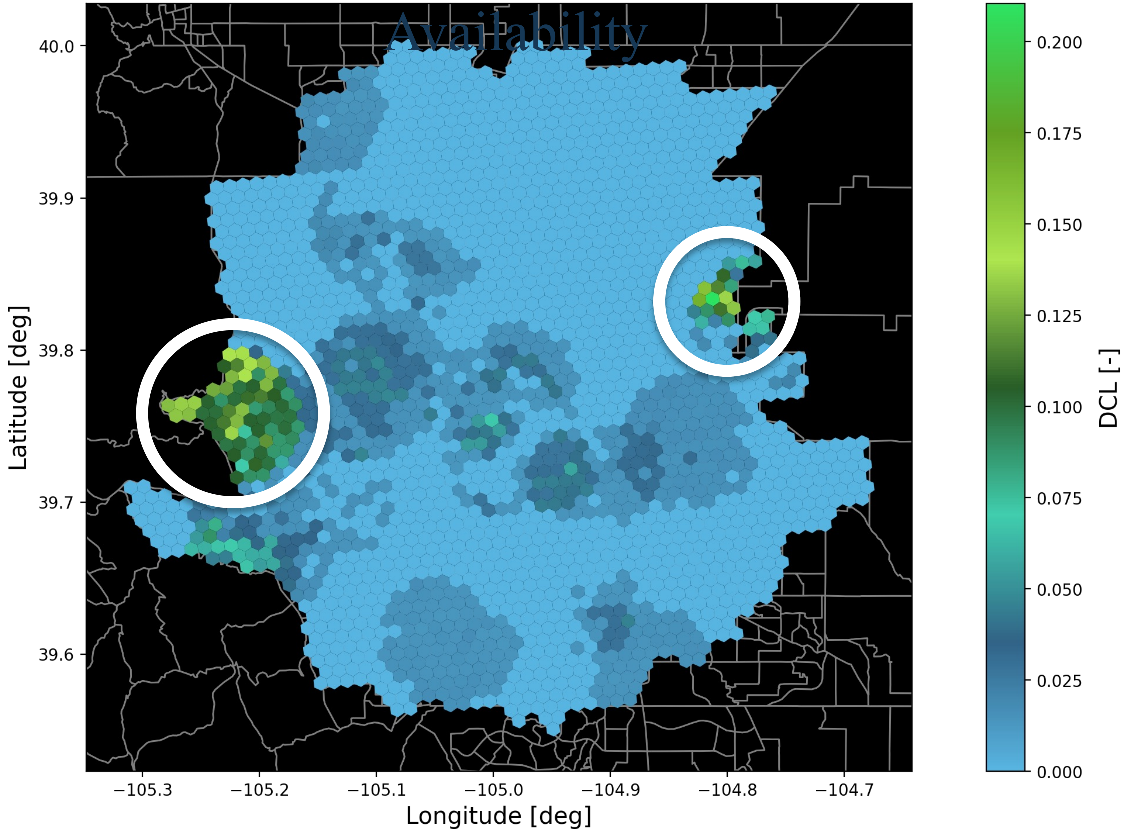

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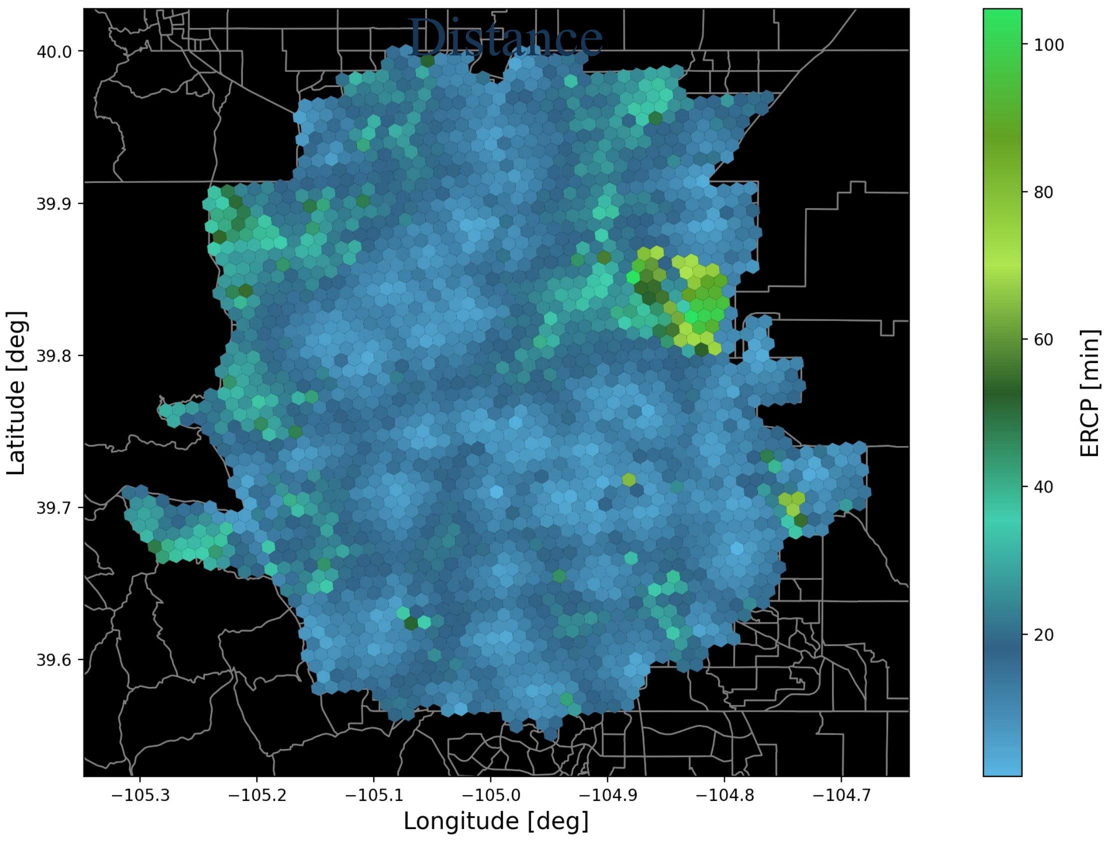
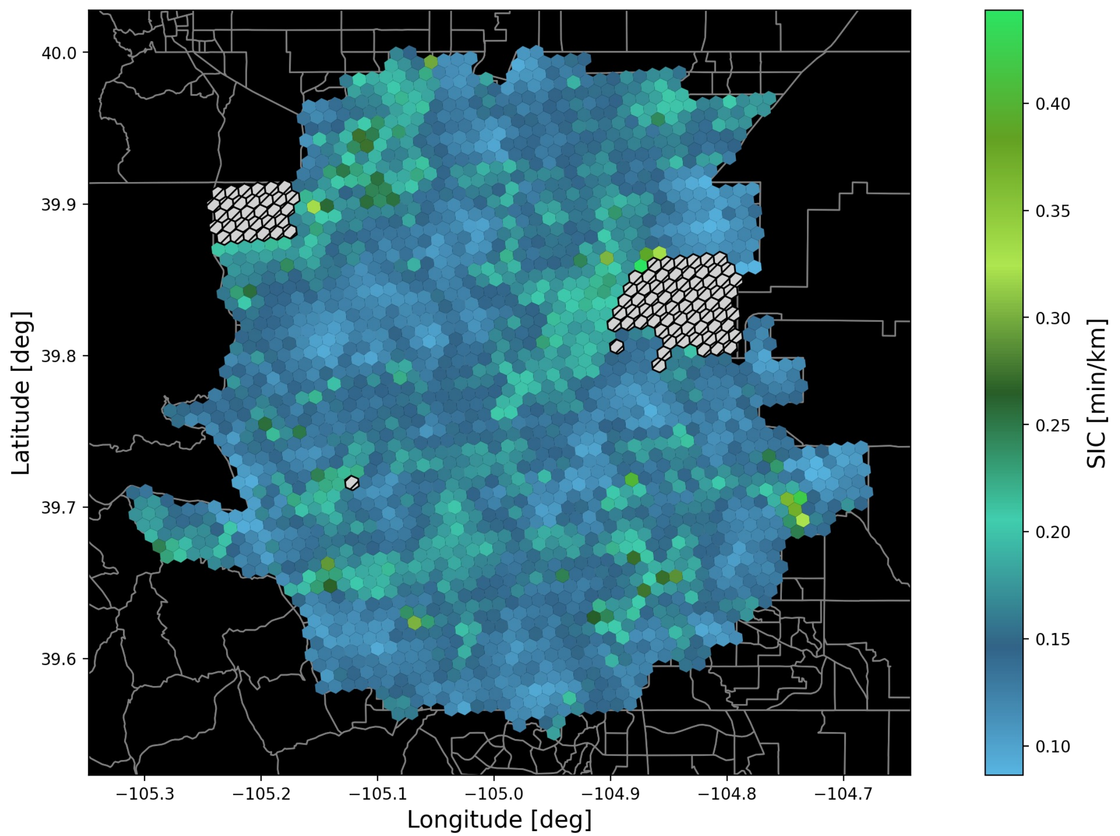
En-Route Charging



- BEV operational inconvenience is highest in high density areas
- Access to highways reduces operational inconvenience
- A high level of low-rate public charging availability is enough to offset high density housing
- Mean expected S_{IC} is considerably higher than for equivalent ICV
- Significant positive skew - long tail above the mean

Operational Inconvenience



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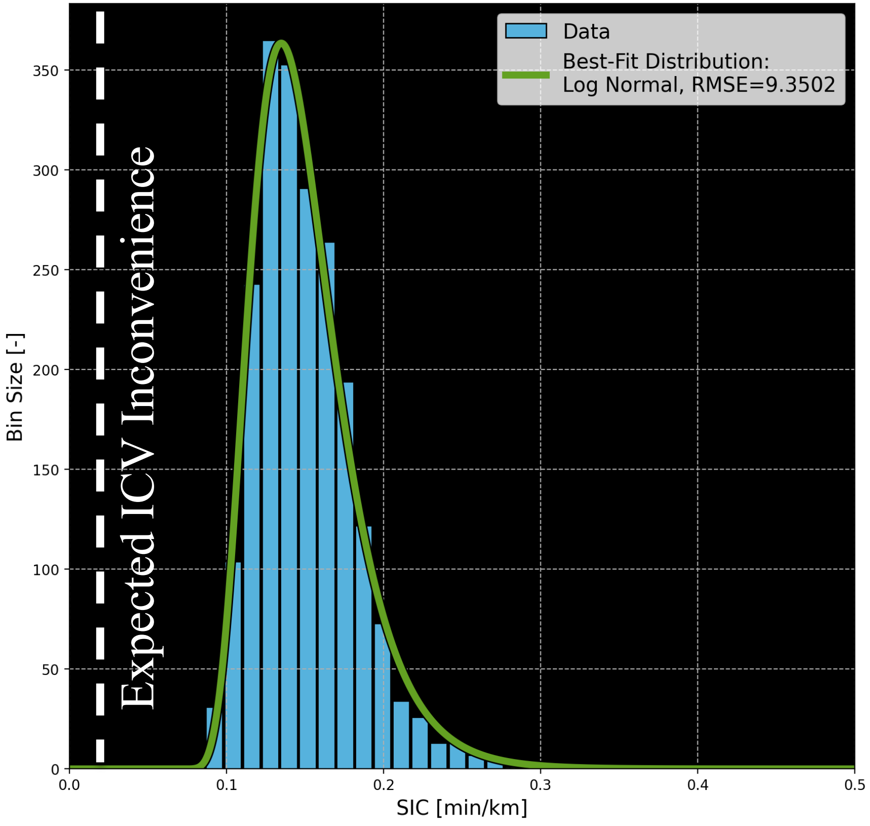
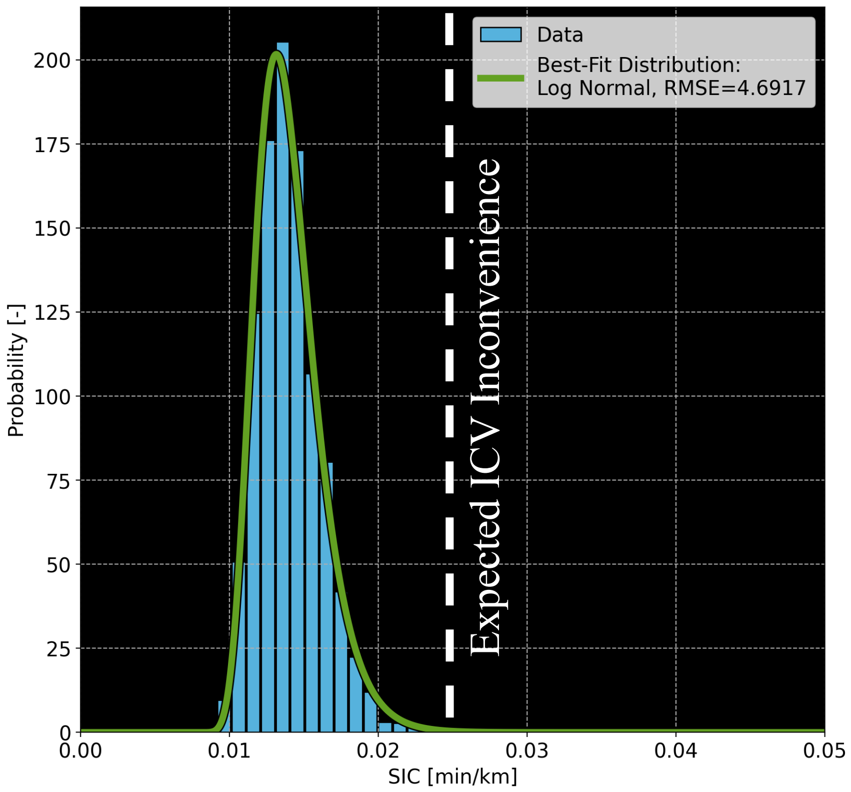
Cell-Wise Expected Operational Inconvenience

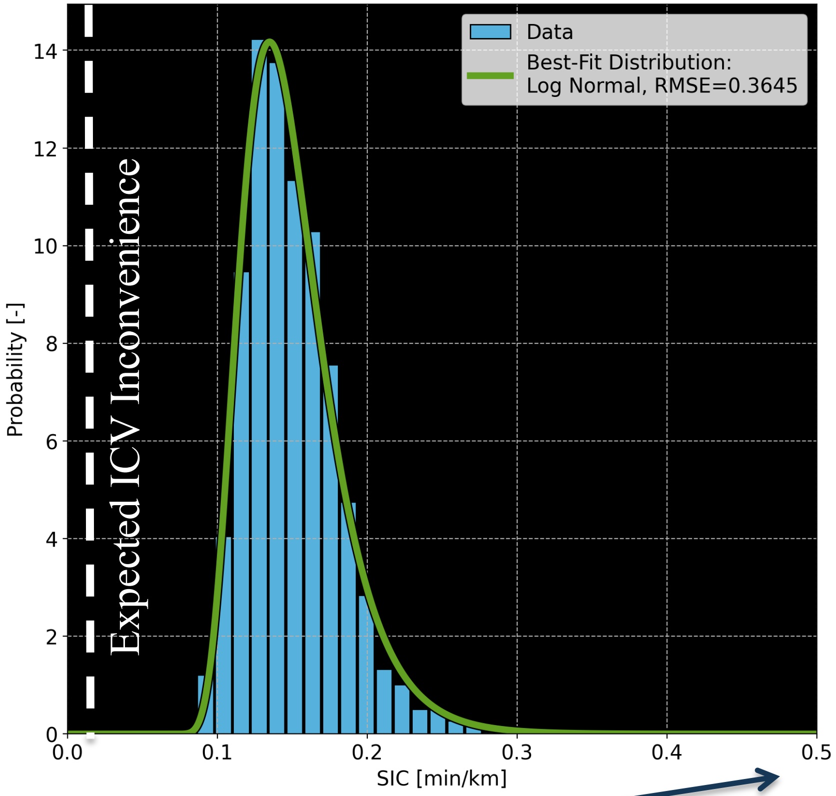


Bi-modal distribution - Vastly different experiences for those with and without home charging

Person-Wise Expected Inconvenience ***with*** Home Charging



Person-Wise Expected Inconvenience ***without*** Home Charging



Different Scales (0.05 vs 0.5)

Conclusions

1. Long-dwell charging is a major factor in determining BEV user experience
    1. Investments into charging in multi-unit dwellings, workplace chargers, and charger installation assistance can yield large returns in user experience
2. Public charging will need to reach near-ubiquity to meaningfully impact user experience
    1. Ubiquitous public slow charging is more beneficial for daily driving needs but fast charging infrastructure is necessary for long itineraries
    2. Subtractive relationship between diffrent types of EV charging infrastructure investments
3. Developed toolkit can evaluate inequities in user experience and specific investment returns in a graphical manner

Public Repository:

https://github.com/airabino/Vehicular_Operational_Inconvenience_Analysis

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Relevant Publications:

- Rabinowitz, A. I., Smart, J. G., Coburn, T. C., & Bradley, T. H. (2023). Assessment of factors in the reduction of BEV Operational Inconvenience. IEEE Access, 11, 30486–30497. https://doi.org/10.1109/access.2023.3255103
- Rabinowitz, A. I., Smart, J.,G., Coburn, T. C., & Bradley, T. H. (2023). A Geo-Spatial Method for Calculating BEV Charging Inconvenience using Publicly Available Data. INCOSE IS23. (To Appear)