En route and home proximity in EV charging accessibility: a spatial equity analysis

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Motivation

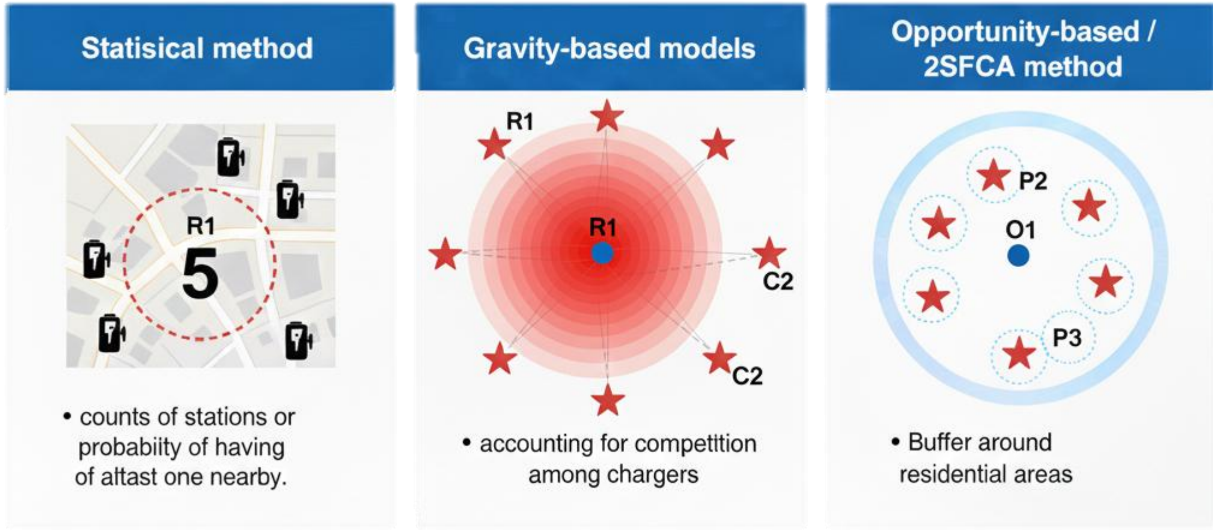
Importance of Public Charging

- Essential for EV users **without home charging** (renters, apartments).
- Reduces **range anxiety** and supports long-distance travel.
- Stimulates private/public investment and EV **market growth**.
- Rising **EV demand** creates pressure for faster infrastructure expansion.

Accessibility of Public Charging

Accessibility

- Measures ease of reaching activities/locations through land-use + transportation interactions.
- Key factors: demand, facility supply, travel impedance.
- Common methods:



Gaps (Accessibility of Public Charging)

- Developed for general amenities (e.g., hospitals, schools, parks)
- Realistic accessibility must include **both**:
  - **Destination charging** (hotels, gyms, supermarkets; not charge-level dependent).
  - **En route charging** (based on State of charge(SOC), range anxiety, travel routes).
- Ignoring en route charging misses competition effects and underestimates real demand

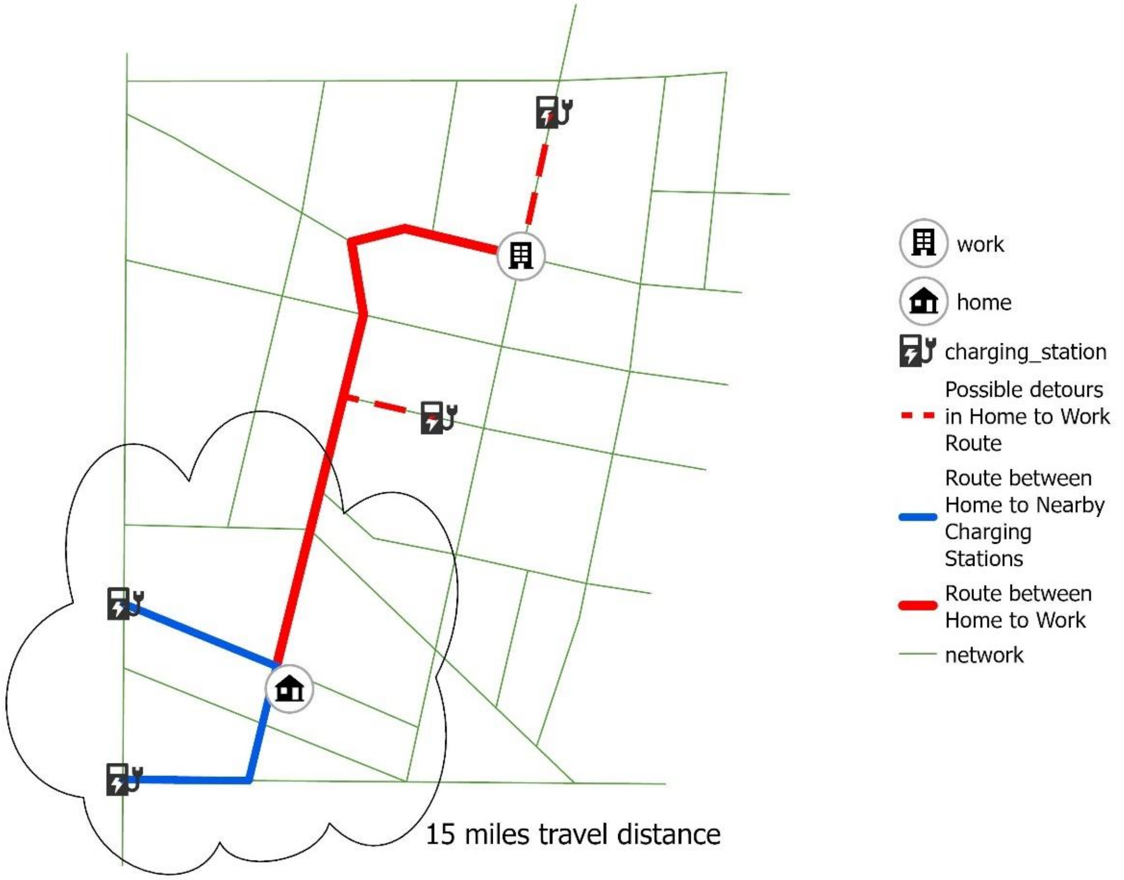
Methodology

1. Traditional Opportunity-Based Method

- Considers stations within 15 miles of home.
- Ignores daily mobility and route-based access.

2. Integrated Accessibility Method (proposed)

- Destination charging: Level 2 & DC fast stations within 15 miles of home.
- En route charging: DC fast chargers accessible with ≤1-mile detour along travel routes.
- Accessibility = Destination Access + En Route Access
- Accounts for competition among users and station capacity.

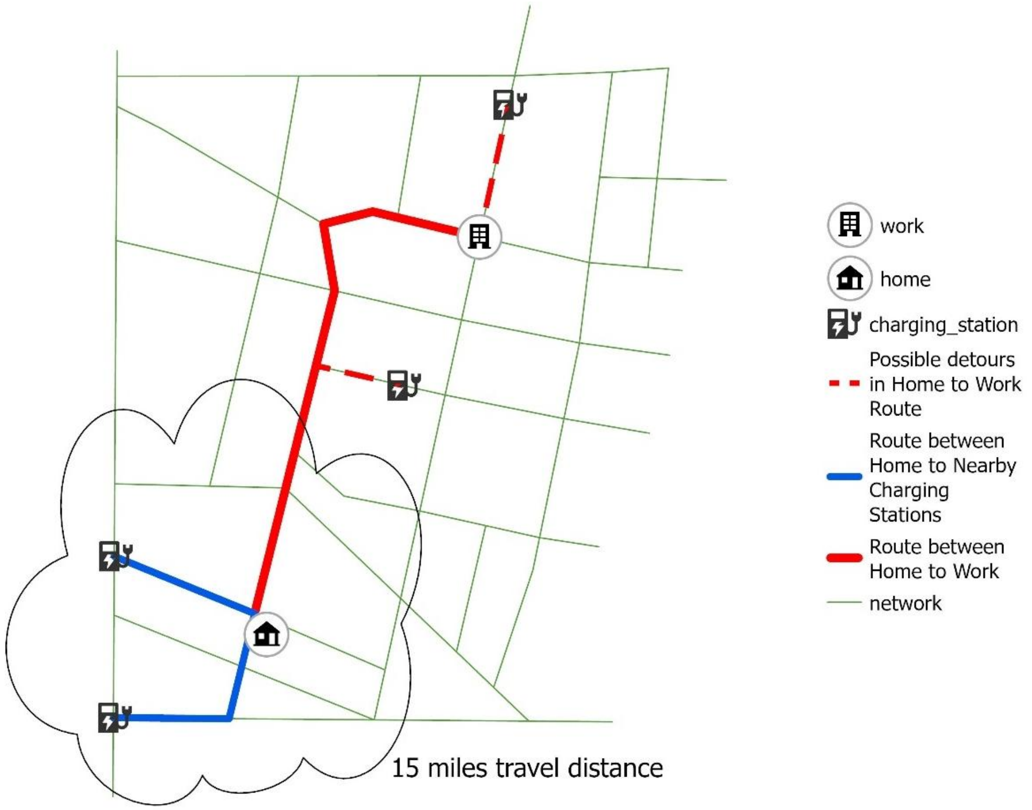


Methodology

$$A1_i = \sum_{k \in d_{ik} < d1_0} \frac{R_{k(Integrated)}}{d_{ik}^{\beta}}$$

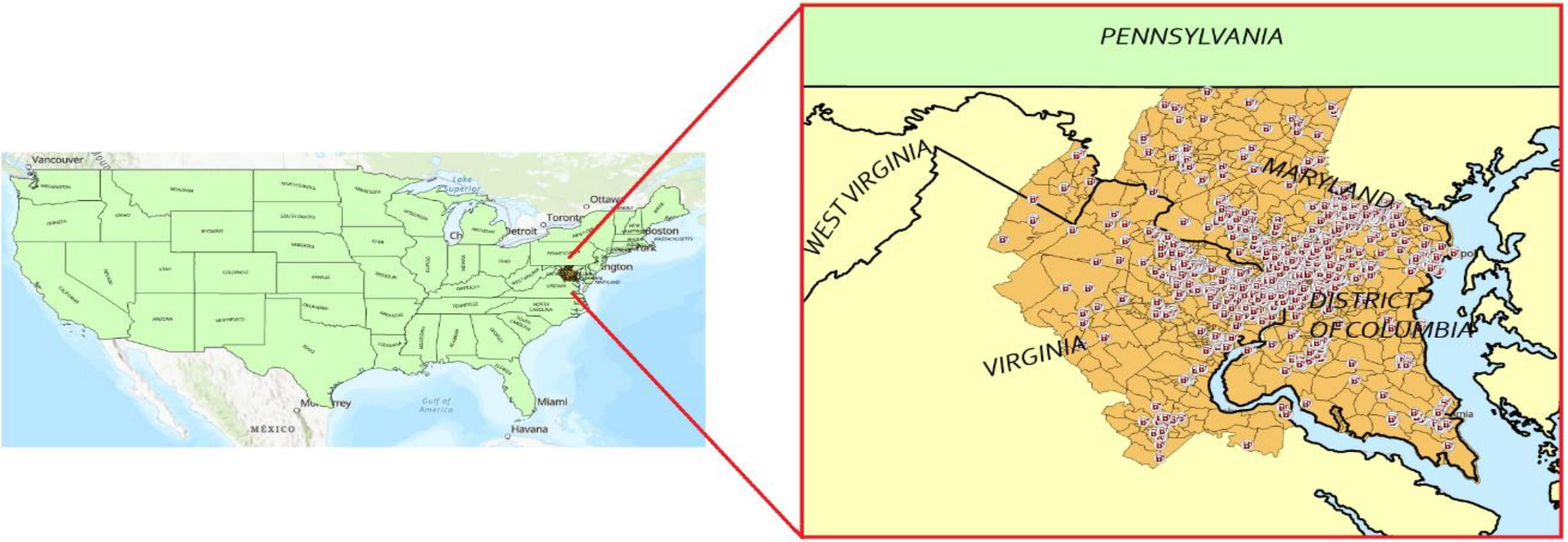
$$A2_i = \sum_{j \in J} \alpha_{ij} \sum_{k \in d_{ikj} < d2_0} \frac{R_{k(Integrated)}}{d_{ikj}^{\beta}}$$

$$R_{k(Integrated)} = \frac{\gamma N_{DC\_fast}}{\sum_{i \in \{d_{ik} < d1_0\}} \frac{D1_k}{d_{ik}^{\beta}} + \sum_{ij \in \{d_{ikj} < d2_0\}} \frac{D2_k}{d_{ikj}^{\beta}}} + \frac{N_{level2}}{\sum_{i \in d_{ik} < d1_0} \frac{D1_k}{d_{ik}^{\beta}}}$$



Data Source

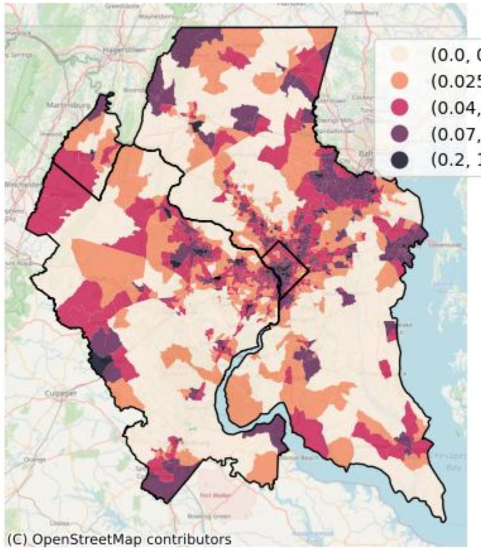
- **Regional Household Travel Survey (2017–2018)**
  ~126,000 trips.
- **DOE Alternative Fuels Data Center**
  1,576 public stations (Level 2 + DC fast).
- **American Community Survey (2018)**
  demographics, income, housing.
- **Study area:**
  DC–MD–VA–WV metropolitan region.



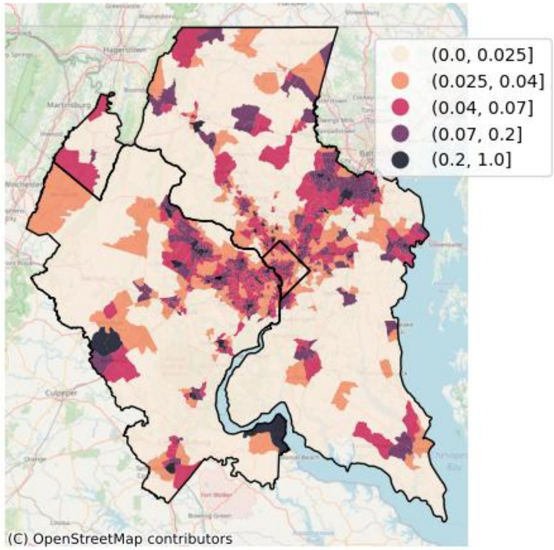
Key Findings

- Opportunity-based **overestimates** access in urban cores, underestimates in commuting zones
- These overestimated areas are **high-VMT**, **high-employment zones** with intense **demand and more DC fast charger.**
- Our Integrated Method is more balanced and realistic. It's less biased by station counts (correlation drops from 0.61→0.54).

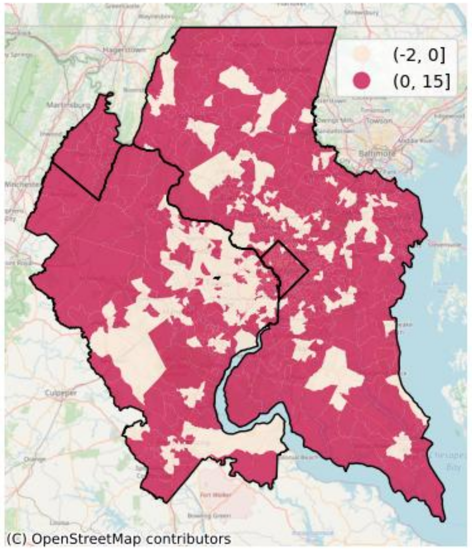
Integrated Accessibility Method



Opportunity-Based Method Accessibility



Relative Change of Two Methods of Accessibility



Key Findings

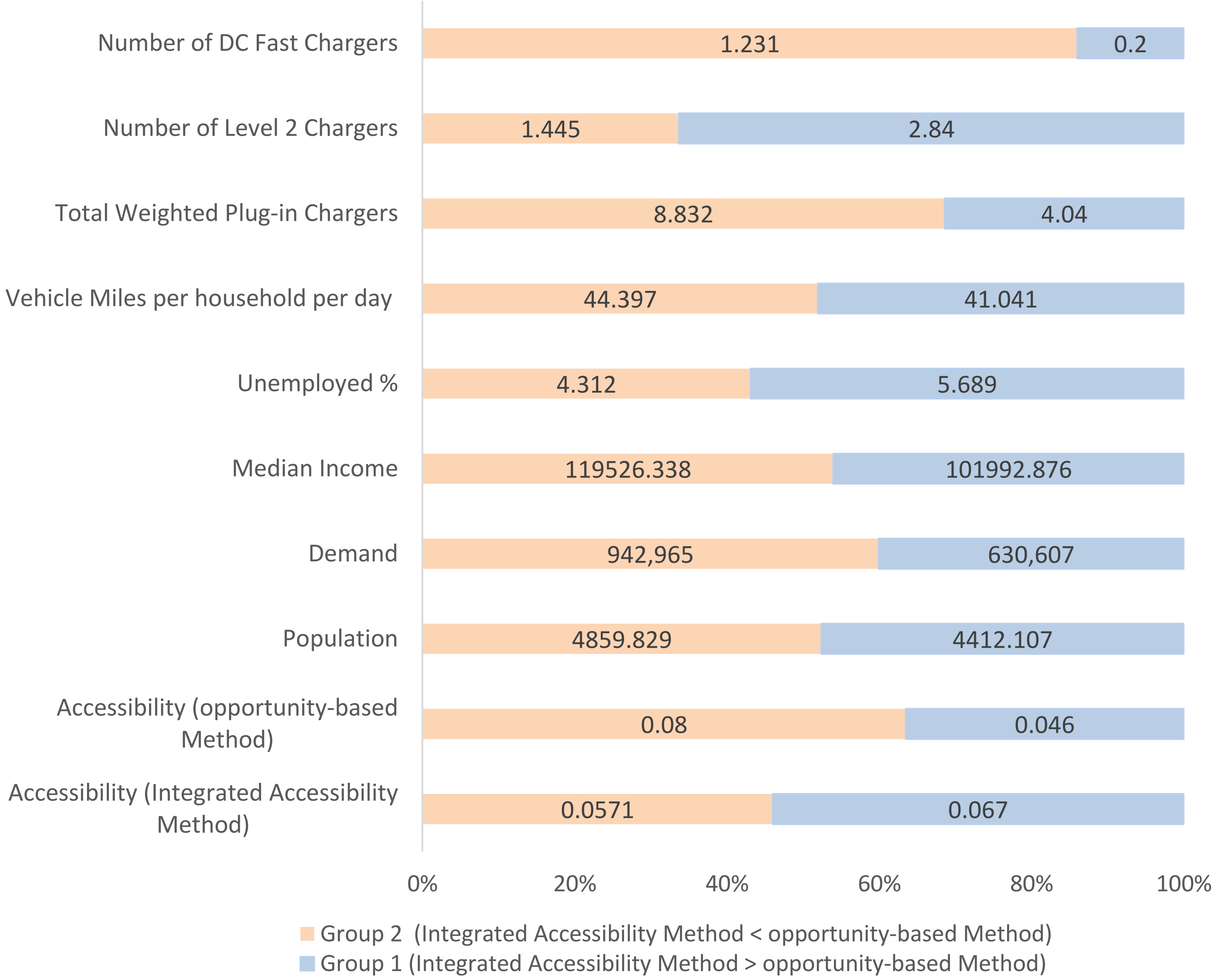
Group 1 (Red)

Dense **residential areas** with shorter trips, and more **Level 2 chargers**.

Fewer chargers within the tract, but **more charging opportunities on surrounding routes**.

Integrated method captures these external opportunities → higher accessibility.

Opportunity-based method **misses route-based charging**, risking **misallocation of resources**.



Key Findings

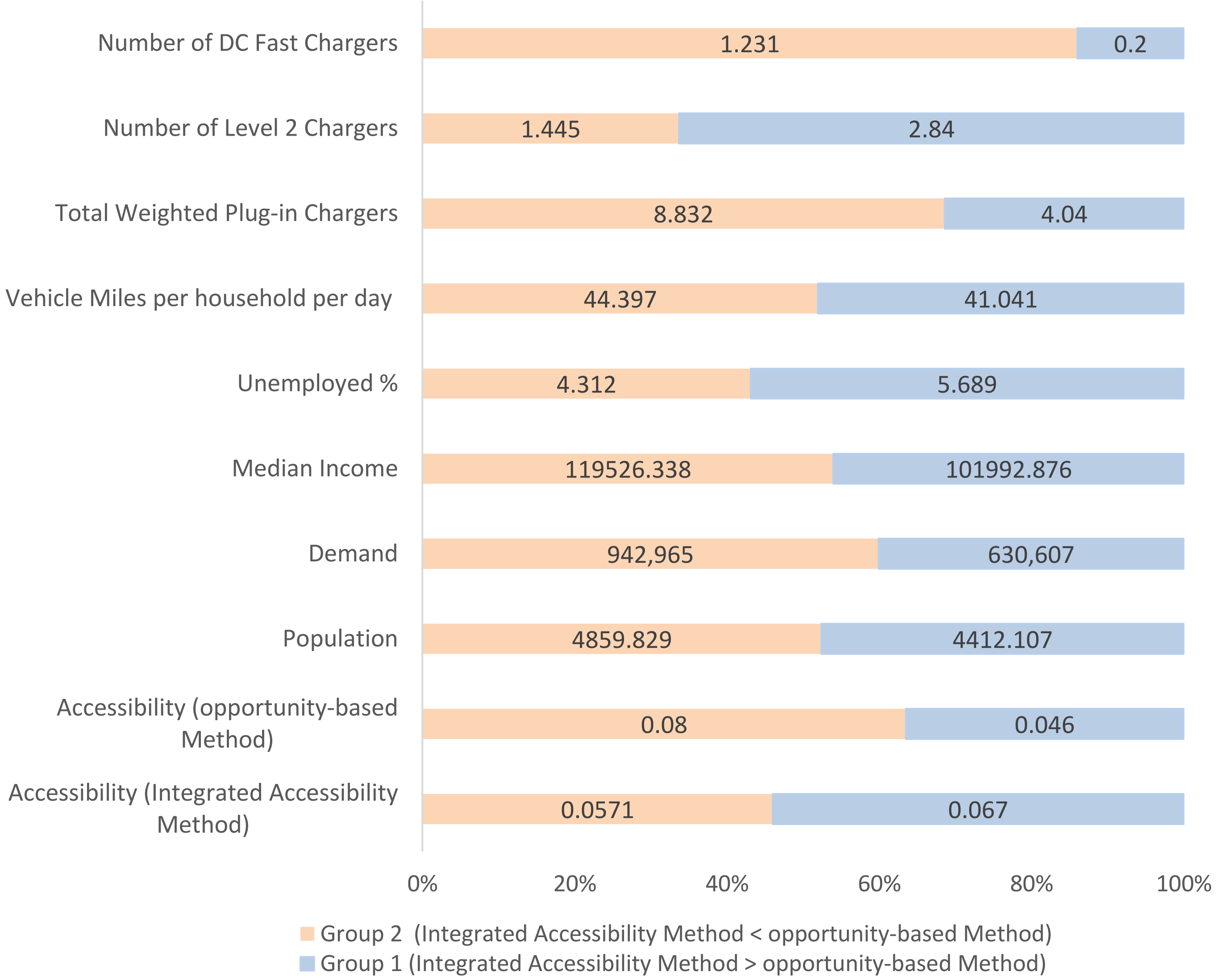
Group 2 (White)

Higher **weighted number of chargers**, **higher demand**, and **more DC fast chargers**.

Located in **employment corridors** with higher **VMT**, **higher median income**, and **lower unemployment**.

Opportunity-based method inflates accessibility because many chargers fall within the 15-mile buffer.

Integrated method shows **true competition is higher**—DC fast chargers serve both local and **en-route** demand → **lower actual accessibility**.



Spatial Equity

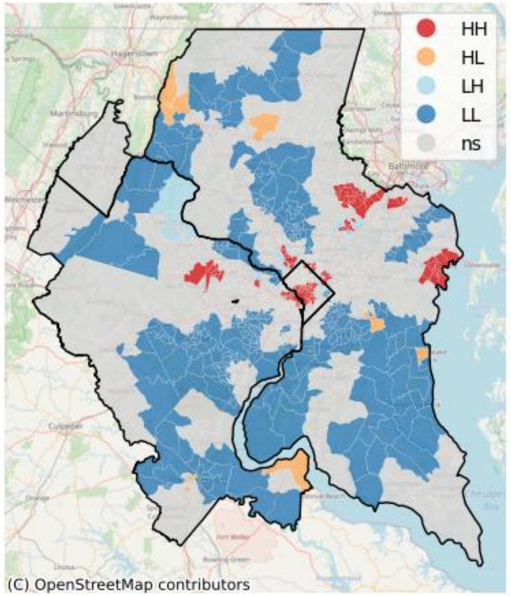
Global patterns

- Accessibility is not random → strong spatial clustering.
- High-access and Low-access zones group together → inequity.
- Integrated Method reveals stronger clustering (Moran's I = 0.30 vs. 0.21)

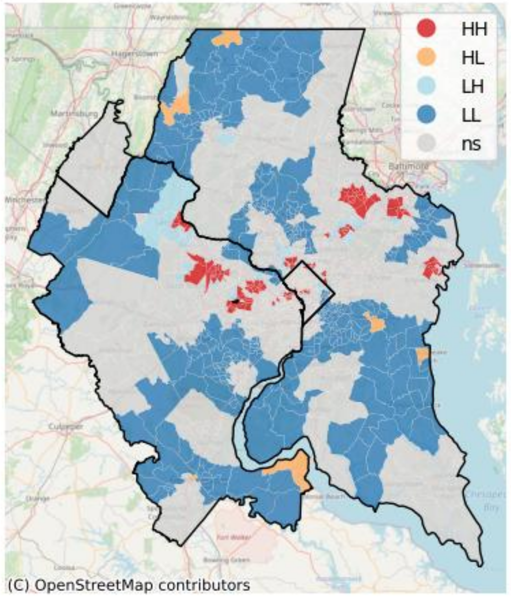
Local Patterns

- HH: Well-served "hot spots"
- LL: "Charging deserts"
- Well-served areas are surrounded by other well-served areas. Underserved zones are isolate

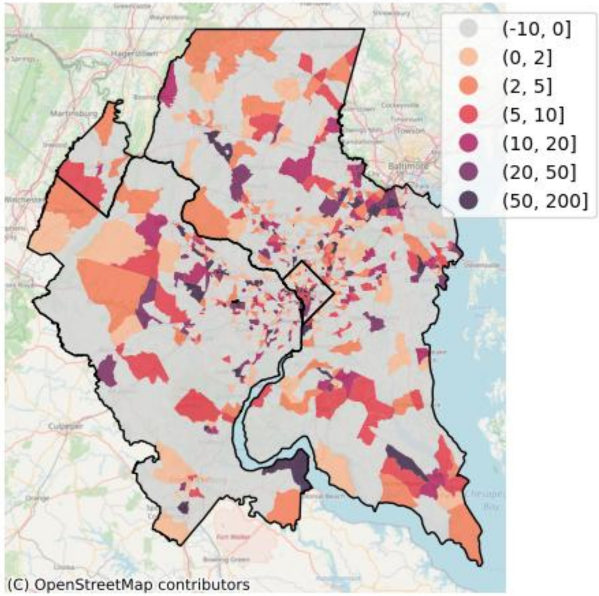
Integrated Accessibility Method



Opportunity-based Method Accessibility



Total Weighted Plug-in Chargers



Urban-Suburban Disparity

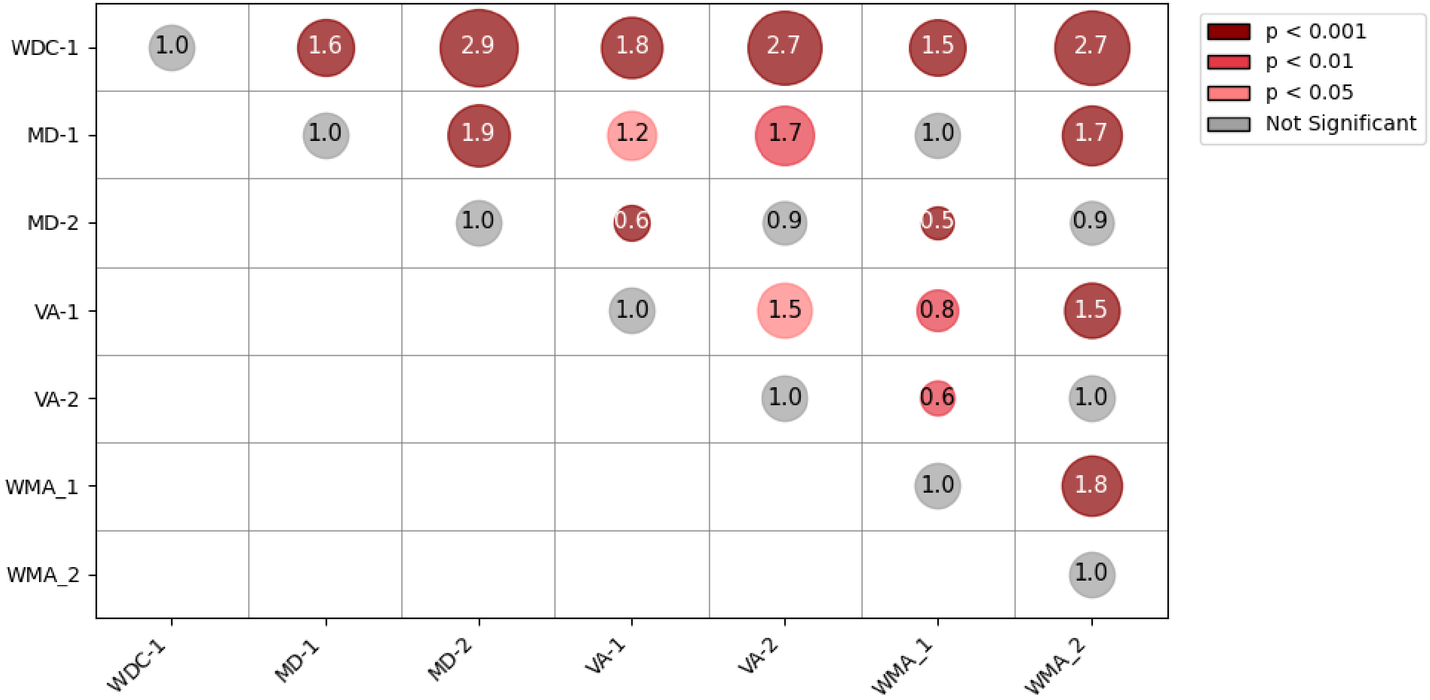
Big differences between urban cores vs. high-commuting areas

DC core → highest accessibility (≈1.5× higher than others)

Urban cores benefit from population density + policy support

High-commuting areas (MD & VA) → lowest accessibility

Causes: fewer chargers, passing through poorly served regions, Heavy reliance on personal vehicles, higher demand/competition



T-test Results Comparing Accessibility in Core and High-Commuting Areas. RUCA Code: 1 = core areas, 2 = high-commuting areas.

Urban-Suburban Disparity

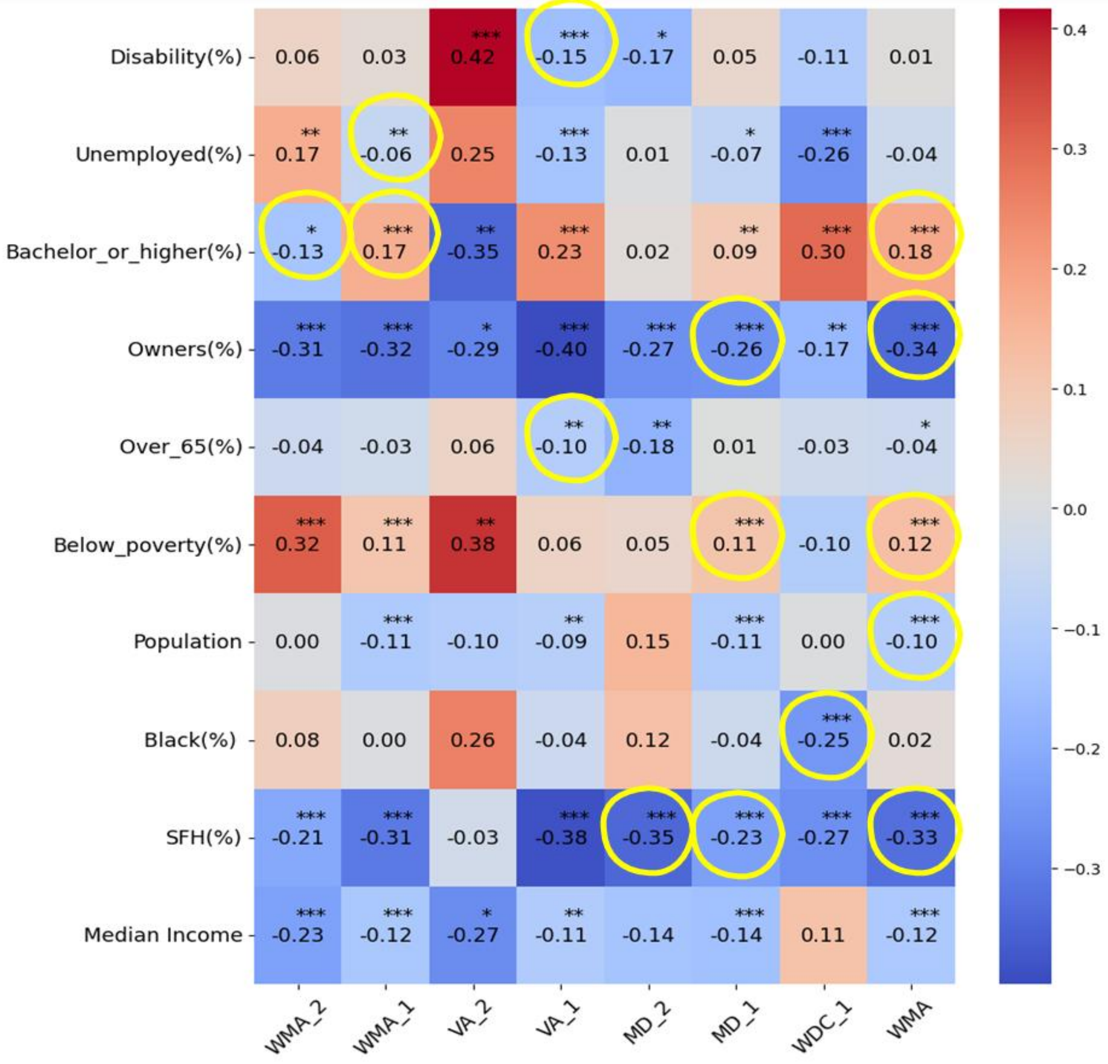
- Accessibility gap may limit EV adoption in suburban areas
- High-commuting zones = underserved, higher range anxiety
- New $3.9M investment focuses on already well-served core areas
- Risk: funding may widen existing accessibility gaps

Social Equity

- **Horizontal equity = equal access** to public infrastructure regardless of location or socioeconomic status.

- **Negative correlation** between accessibility and population ($r = -0.10$, $p < 0.01$):
  → **More populated areas have *lower* access** to charging stations.

- This inequity is strongest in **urban cores** → high land costs, permitting barriers, and competing land uses.



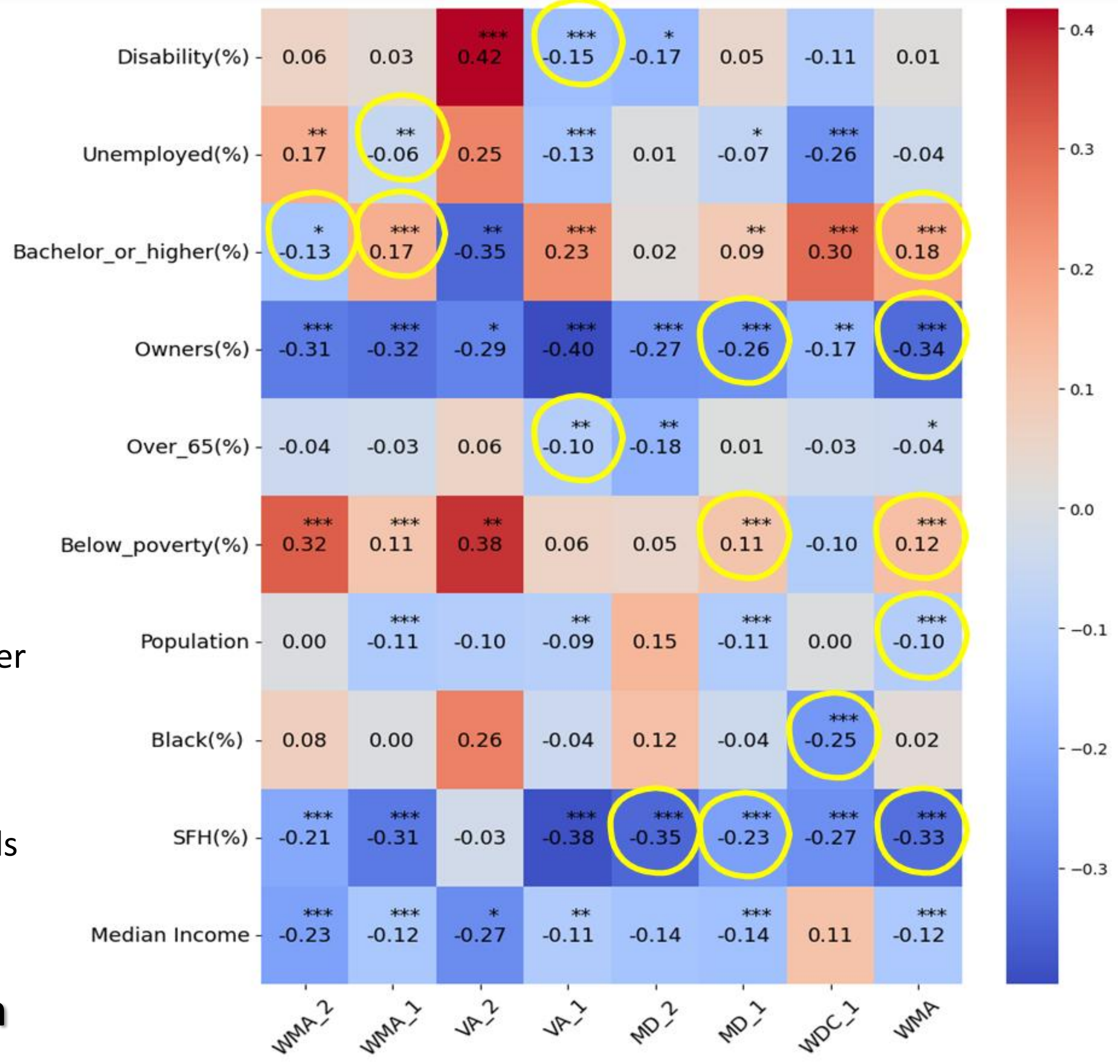
horizontal equity is violated

Social Equity

- **Vertical Equity =** Prioritize infrastructure for socioeconomically disadvantaged groups.

- **Overall Trends:**
  - Accessibility **higher in lower-income, renter, and high-poverty areas** → supports vertical equity.
  - Negative correlation with **income, homeownership, single-family homes**.
  - Positive correlation with **poverty rates**.
  - Younger, more educated populations tend to have higher accessibility.

- **Regional Nuances:**
  - **High-commuting areas:** Lower-income & disadvantaged groups have better access.
  - **Urban cores (DC & VA):** Higher accessibility often favors educated populations.
  - **D.C. racial disparities:** Lower access in predominantly Black neighborhoods → racial inequity.



Infrastructure policies partially support vertical equity, but urban cores & racial disparities need targeted interventions.

Conclusion

Key Findings

- Integrated method accounts for **local demand + en-route detours**, providing a **more balanced accessibility distribution**.
- High-commuting, higher-income areas show **lower public charging accessibility** despite potential demand.
- **Horizontal Equity:** Population-dense areas often have **lower access**, highlighting spatial inequity.
- **Vertical Equity:** Lower-income and renter populations have **better access to public chargers**, reflecting reliance on shared infrastructure.

Conclusion

Policy Implications

- Deploy charging stations **proportionally in high-density areas** for horizontal equity.
- Prioritize **lower-income, minority, and renter-heavy areas** for vertical equity.
- Consider **daily travel patterns** in planning, not just residential location.

Future Research

- Validate methodology in **other metropolitan areas** and for **different infrastructure types**
- Use **longitudinal or causal methods** to measure impacts of new stations or policy interventions.

Thank you!

Any Questions?

Scan for more information
Link to our paper

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