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Battery Electric Bus Deployment Considering Cost and Environmental Equity

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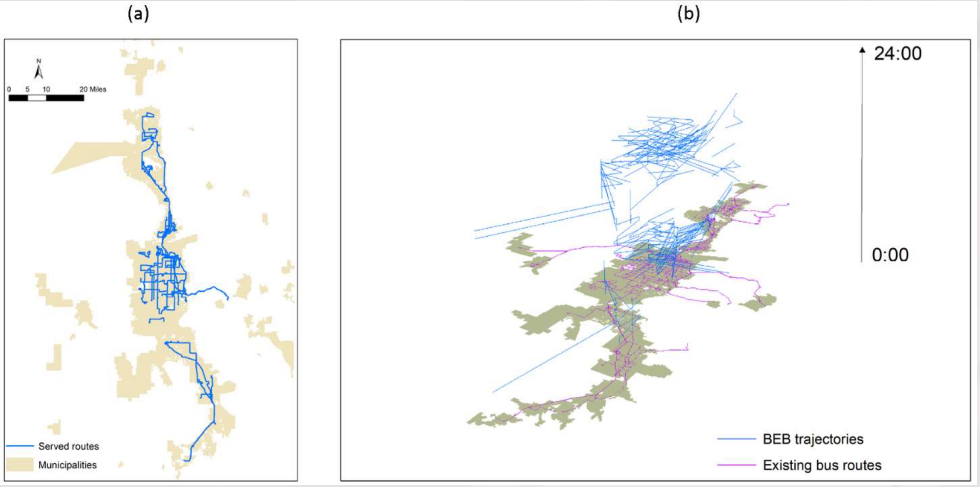
Previous Research

- *Research Question*: Optimizing the spatio-temporal deployment of battery electric bus system.

- *Problem Formulation:*.



  - Objective (0): Minimizing the total cost of:
    - In-depot and On-route Charging stations
    - Battery Electric Buses (BEB)
  - Input: Number of buses to be replaced with BEB.
  - Output:
    1. Locations and number of both in-depot and on-route charging stations.
    2. The exact buses that were to be replaced.

Latest Research

- *Research Question*: Optimizing BEB deployment considering cost and environmental equity for disadvantaged population.

- *Problem Formulation:*.

  - Objective (1): Maximize environmental equity.

  - Objective (2): Identical as Objective (0)

  - Input: Budget.

  - Output:

    1. Locations and number of both in-depot and on-route charging stations.

    2. Number of buses that were to be replaced.

    3. The exact buses that were to be replaced.

Formulation

$$\max \sum_i E_i Z_i$$

Objective (1)

$$min\ (\sum_i C^B Z_i + \sum_m C_m^O Y_m^O + \sum_m C_n^I Y_n^I)$$

Objective (2)

Constraints:

Subject to

$$D_{i,s-1} + l_{i,s-1,s} \leq R + (1 - Z_i)TD_i \quad (3)$$

$$D_{i,1} = 0, \forall\ i \quad (4)$$

$$D_{i,s} \leq D_{i,s-1} + l_{i,s-1,s}, \forall\ i, s \geq 2 \quad (5)$$

$$D_{i,s} \geq D_{i,s-1} + l_{i,s-1,s} - TD_i X_{is}, \forall\ i, s\ \geq 2 \quad (6)$$

$$D_{i,s} \leq (1 - X_{is})TD_i, \forall\ i, s \geq 1 \quad (7)$$

$$X_{is} \leq Y_m^O, \forall\ m, (i,s) \in \alpha_m \quad (8)$$

$$X_{is} \leq Z_i, \forall\ i, s \quad (9)$$

$$\sum_{(i,s)\in\beta_{mt}} X_{is} \leq\ p^O Y_m^O\ \forall\ m, t \quad (10)$$

$$\sum_{i\in\gamma_n} Z_i \leq\ p^I Y_n^I\ \forall\ n \quad (11)$$

$$X_{is} = 0\ or\ 1, \forall\ i, s \quad (12)$$

$$Z_i = 0\ or\ 1, \forall\ i$$

$$Y_m^O\ and\ Y_n^I\ are\ positive\ integers$$

$$D_{is} \geq 0, \forall\ i, s$$

Measure of environmental equity -- Ei

- *Motivation*: 1. Social functions depend highly upon the transit system.

  2. Disadvantaged populations are transit dependent and particularly vulnerable to air pollution.

- *Intention*: To benefit the disadvantaged population suffered most from air pollution when deploying BEB.

- *Measurement*: Maximize environmental equity ⟺ Maximize weighted population (Ei)

  - Weights: Pollutant (PM 2.5) concentration.
  - Population: low-income population.

Ensure that the places where low-income population suffering the most from unhealthy air quality could receive priority in environmental benefits

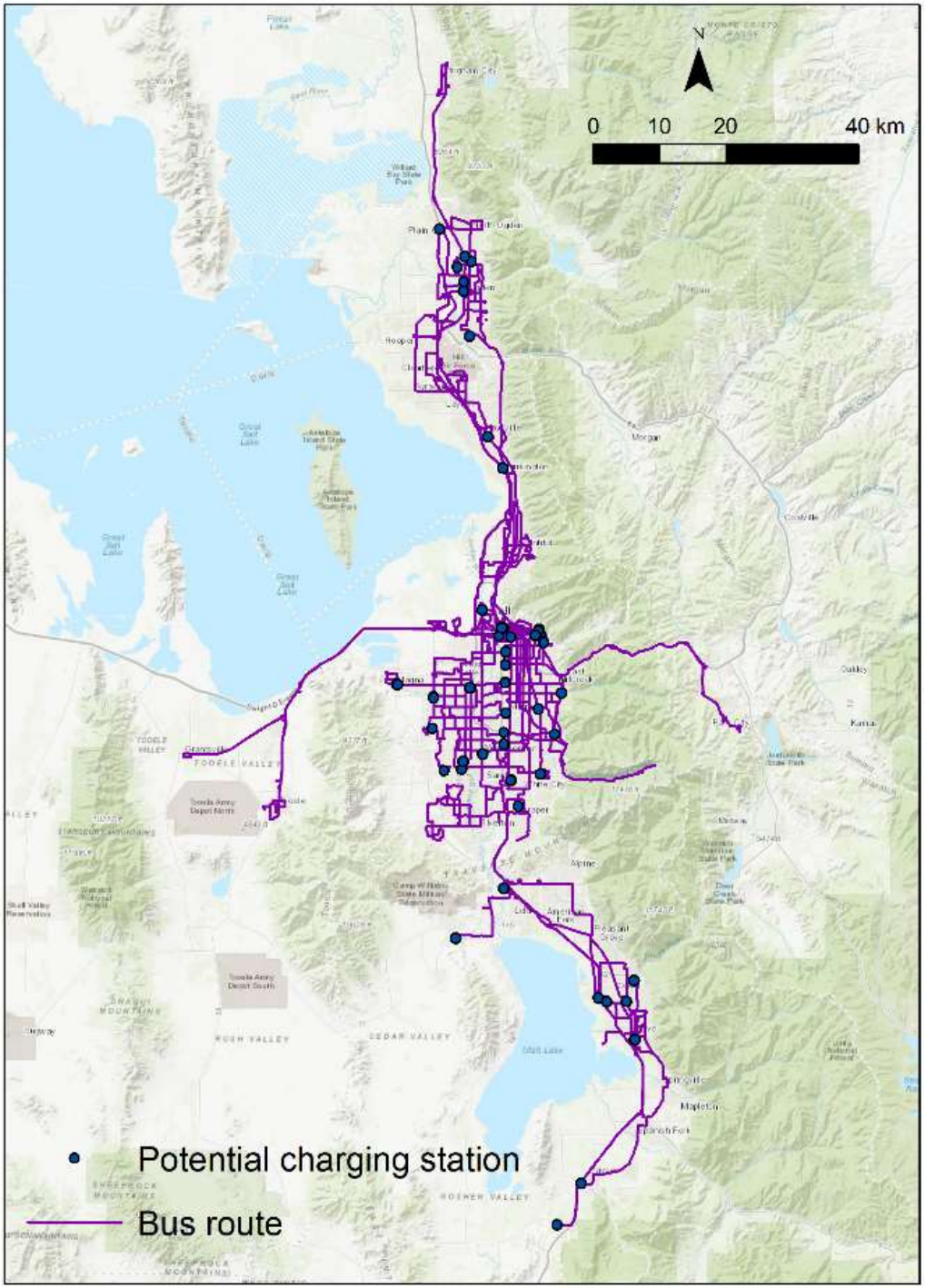
Application

Study Area

- UTA runs 467 diesel or GNC buses serving 121 routes on weekdays.

New Flyer's XE40

- Range: 62-200 miles depending on intensity of battery usage
- On-route charging 10 minutes



Low-income Population

- Data is retrieved from Metropolitan Planning Organizations (MPOs) in Utah for year 2019.
- Low-income group is classified according to 2010 Census income groupings ($0 – $34,999).
- The data is produced at TAZ level.

MPO Boundaries

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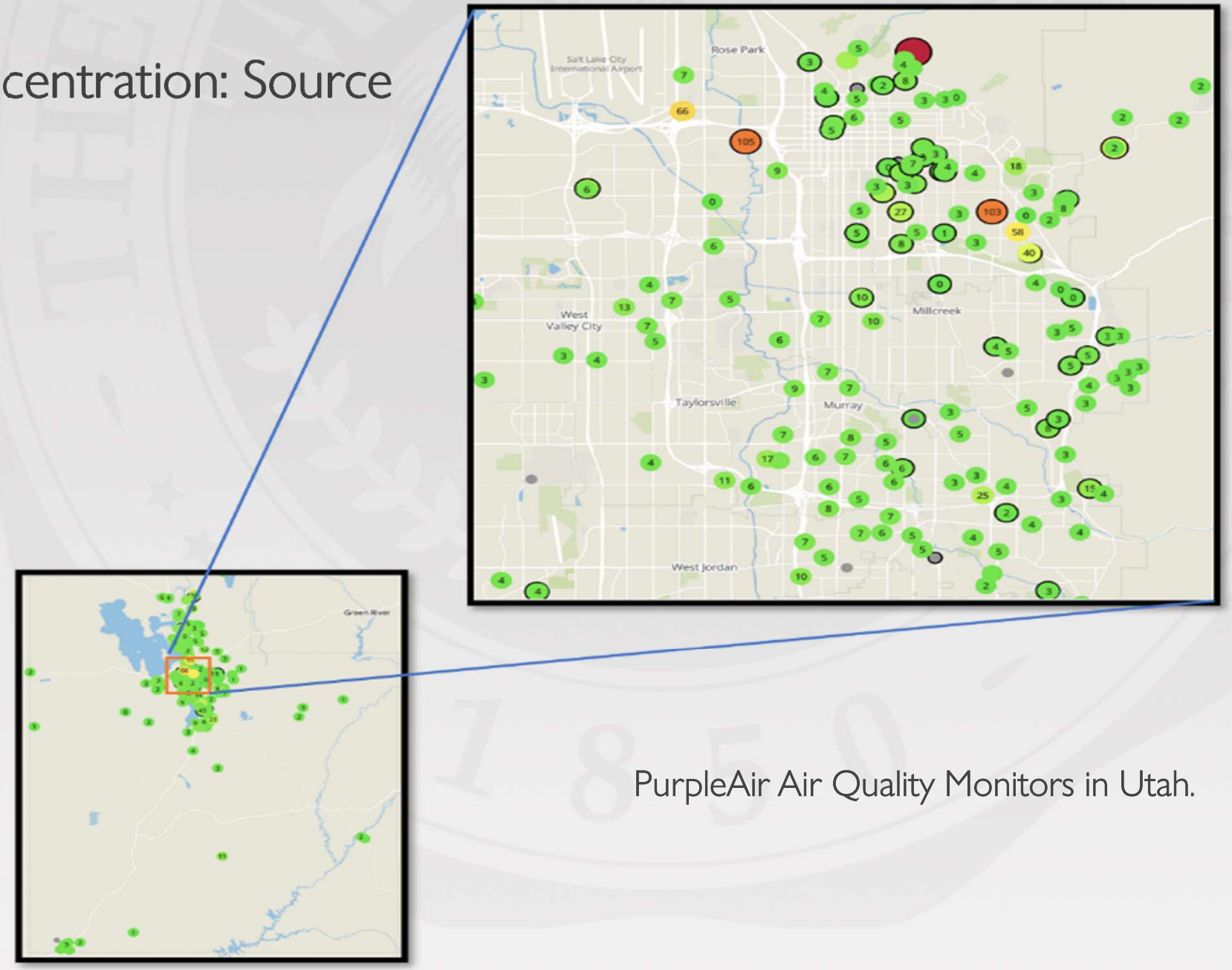
PM 2.5 Concentration: Source



PurpleAir Air Quality Monitors in Utah.

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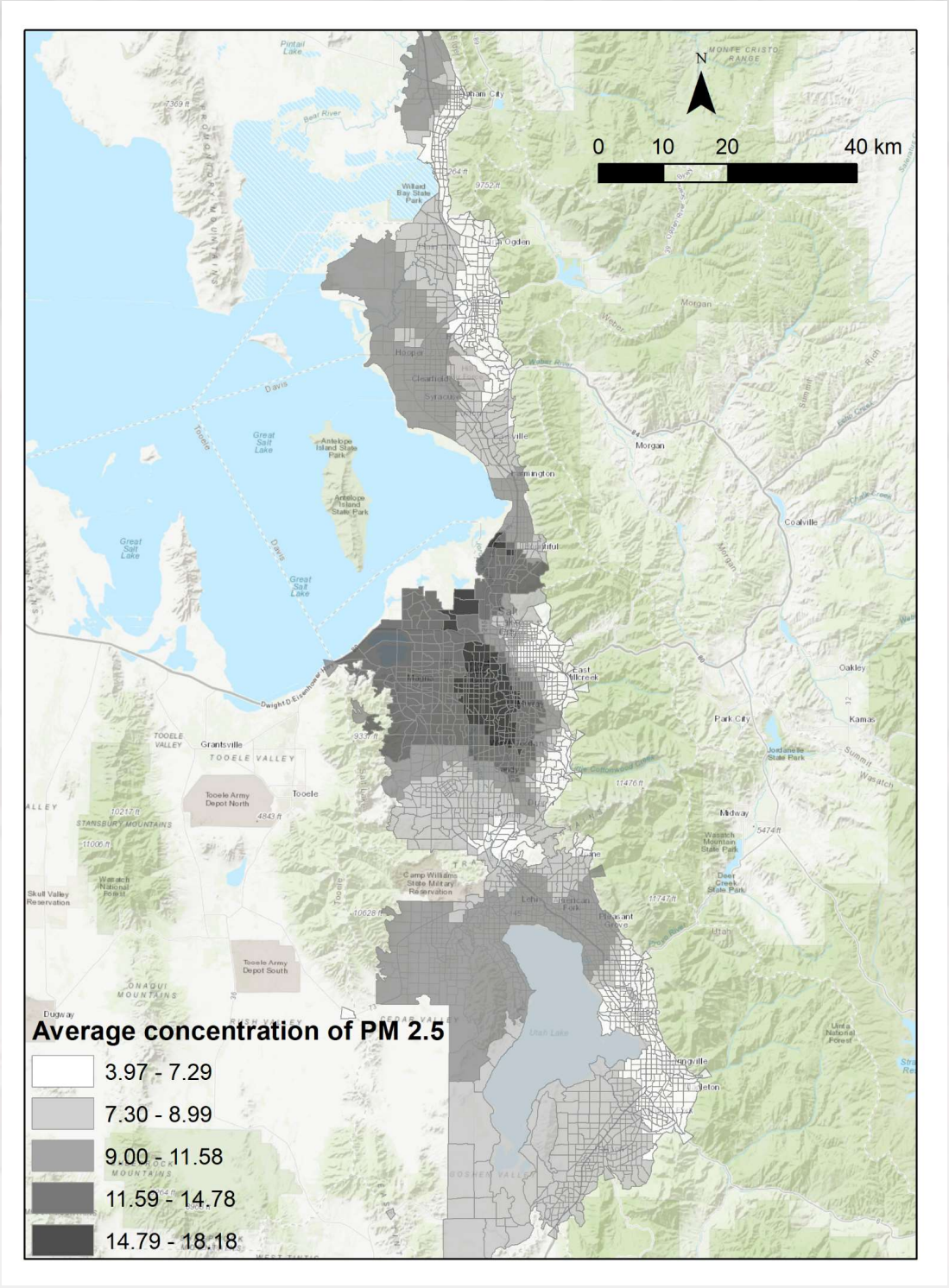
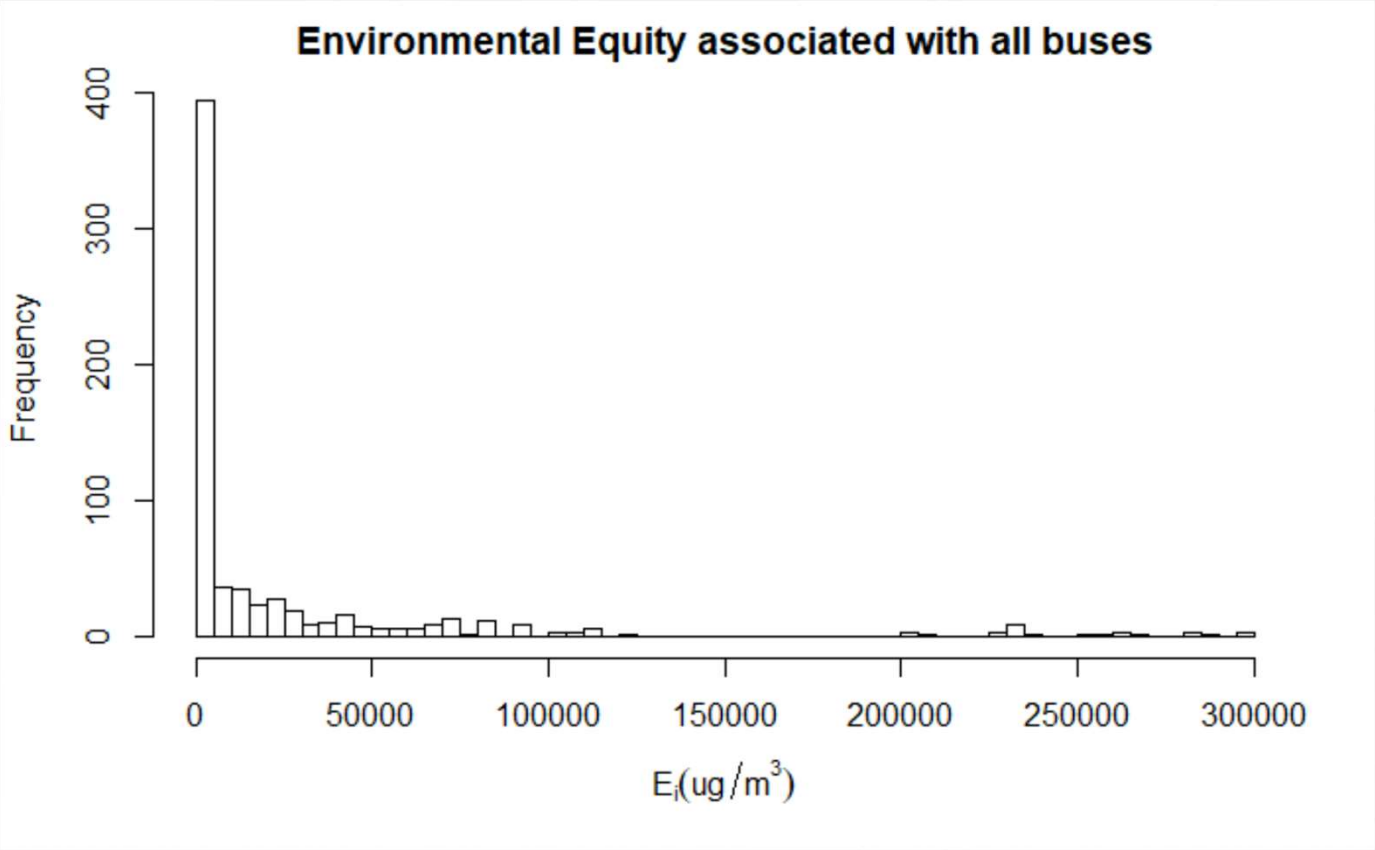
PM 2.5 Concentration: Result

Averaged at TAZ level



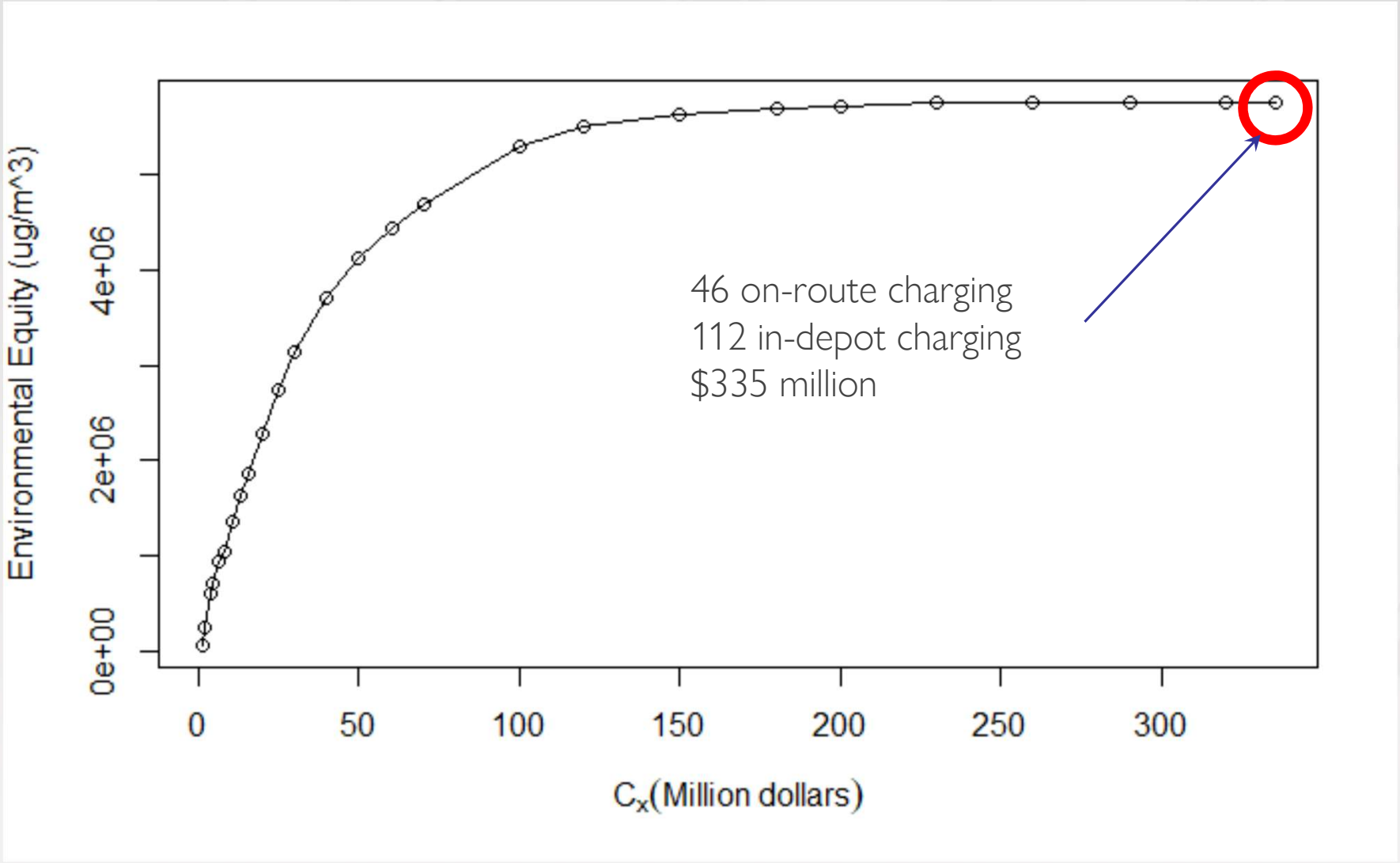
Distribution of Ei



Environmental equity associated with 90% of buses are below 25,000 ug/m^3

- Highly Imbalanced.
- Major contribution comes from a few buses.

Trade-off between Cost and Environmental Equity



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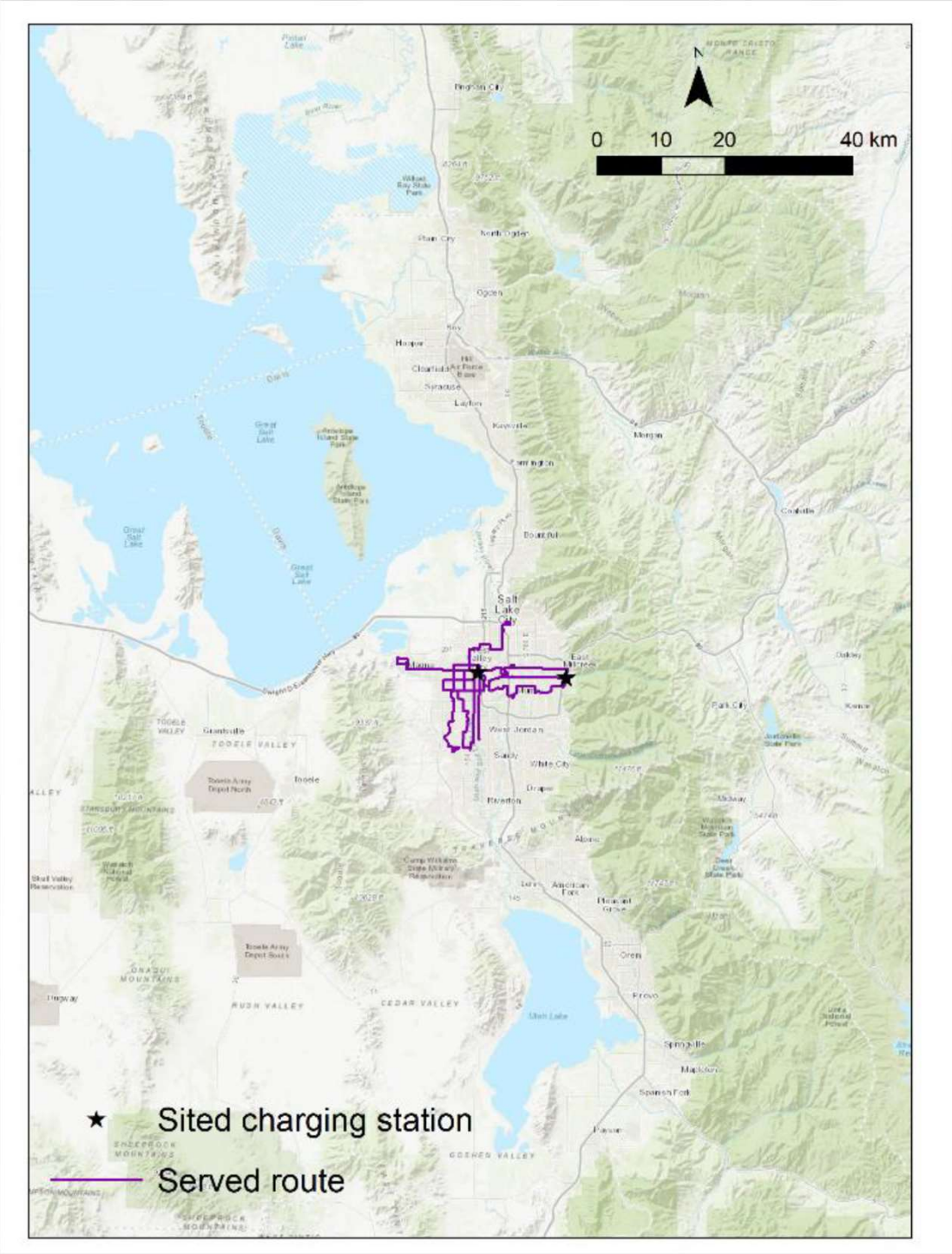
Example 1

BEB Deployment Plan when Budget is set at $25 million

26 BEB
2 on-route charging
9 in-depot charging

West Valley Central Station and Millcreek

The daily mileage of the buses ranges from 161.89 miles to 263.33 miles with an average of 202.98 miles



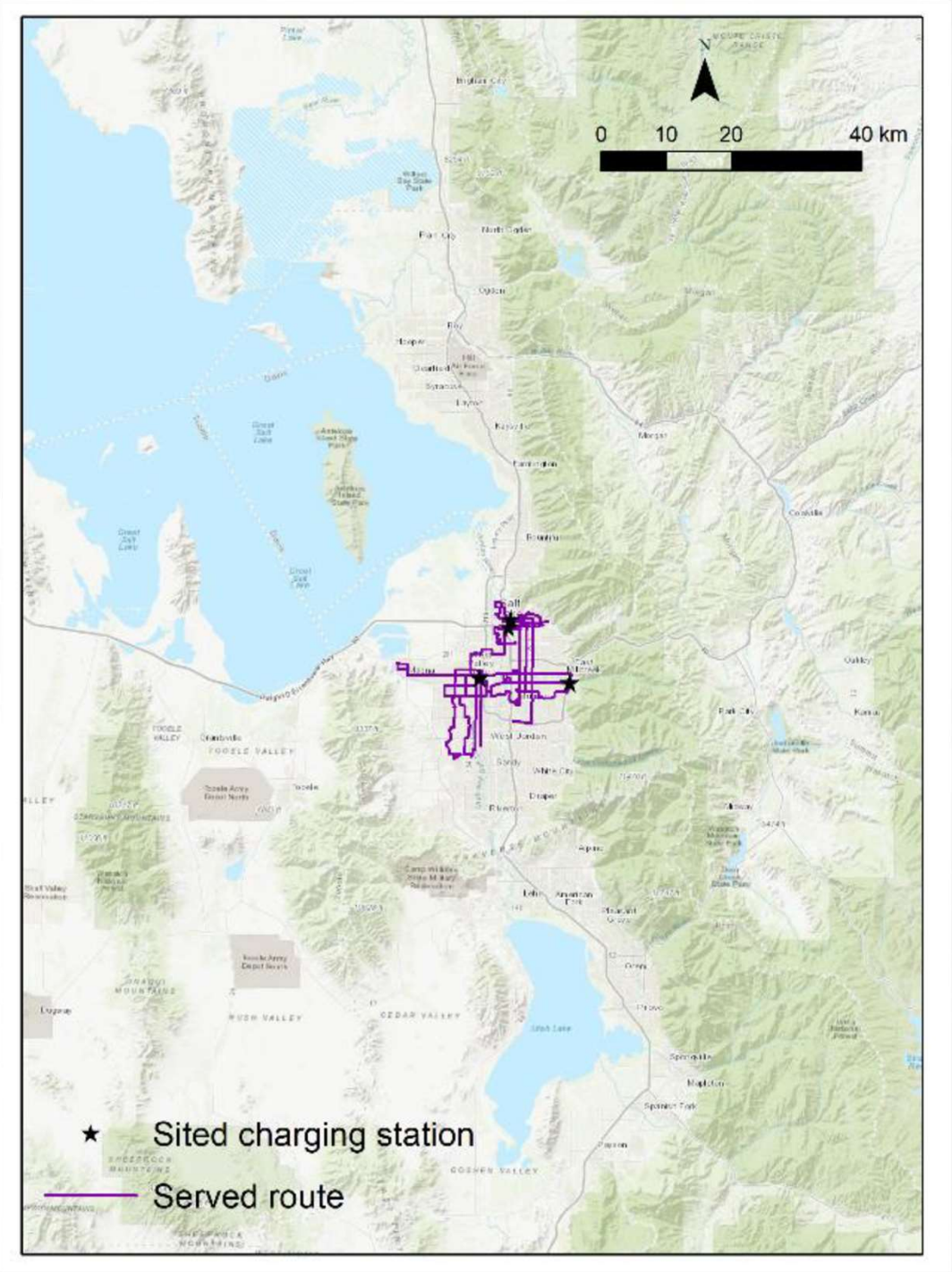
Example 2

BEB Deployment Plan when Budget is set at $60 million.

63 BEB
5 on-route charging
21 in-depot charging

West Valley Central
Millcreek, and North
Temple, SL Central

The daily mileage of the buses ranges from 62.78 miles to 263.33 miles with an average of 176.2 miles



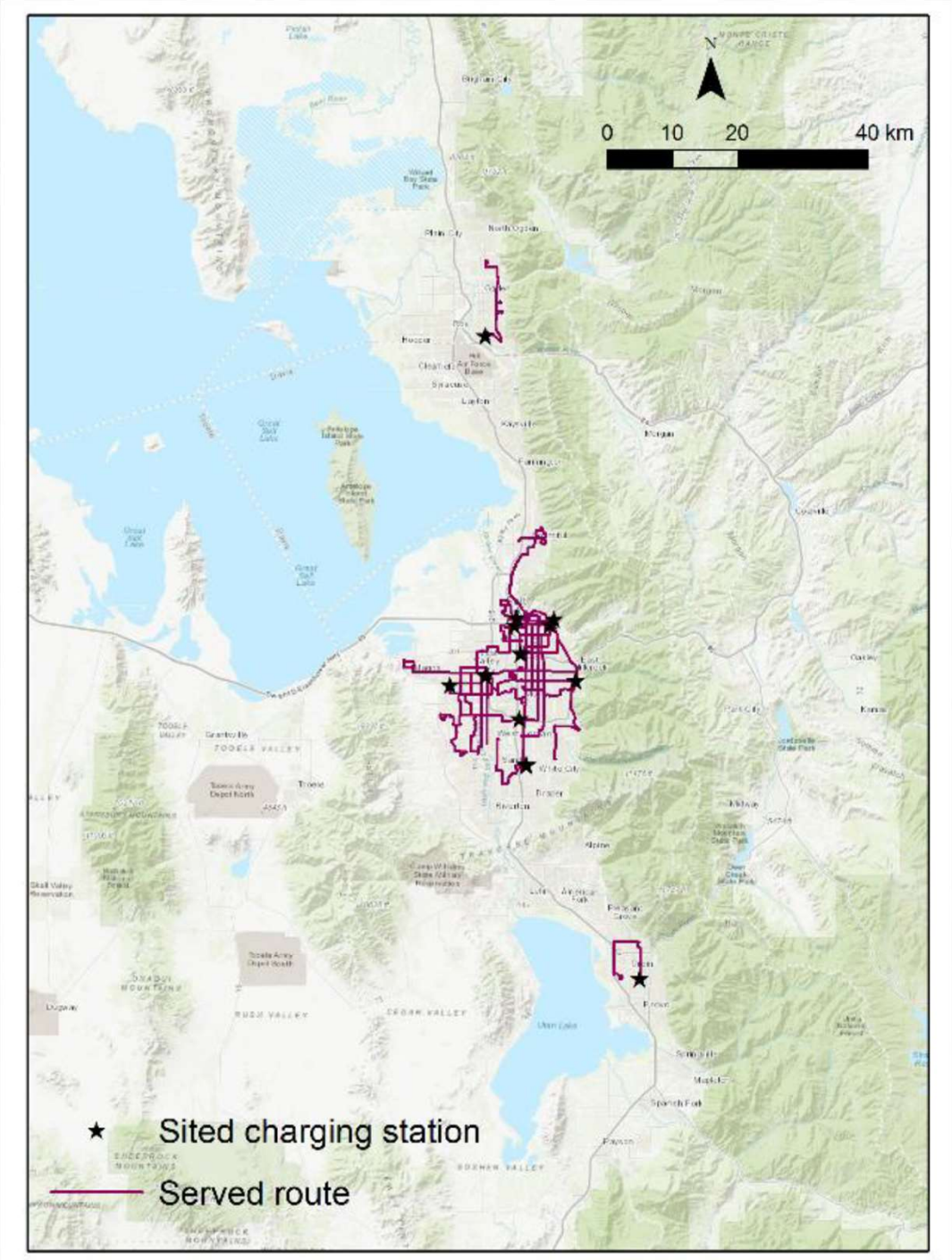
Example 3

BEB Deployment Plan when Budget is set at $120 million

122 BEB
14 on-route charging
41 in-depot charging

West Valley Central Millcreek, and North Temple, SL Central, Murry, Ogden, Orem

The daily mileage of the buses ranges from 62.78 miles to 263.33 miles with an average of 170.52 miles



Major Findings

- The model almost always favor the buses on the densely populated routes. When Cx =$25 million, all of the 26 buses chosen require both on-route and in-depot charging, because they tend to operate longer routes and hours than those (114 buses) requiring only in-depot charging.

- The model can be extended to incorporate additional goals other than budget and environmental equity achieved such as maximizing service area, fuel efficiency, robustness of the system, etc.

Q&A