26. “Challenges and Opportunities for Electric Vehicles in Indiana”

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Electric & Connected Vehicles

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SPR 4509:
A Strategic Assessment of Needs and Opportunities for Wider Adoption of Electric Vehicles in Indiana

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Overview

State-of the-art of electric vehicle (EV) charging technologies

Strategic deployment of EV charging stations

Impact on highway revenue and strategic partnerships
Strategic deployment of EV charging stations
Modeling and identification of EV infrastructure deficit areas

- The research team developed a framework to identify the EV infrastructure deficit areas and analyze potential EV charging station deployment.

- The simulation and GIS analysis also identified areas that could demand significant EV charging energy.

- Marion and Hendricks counties were identified as the top two counties where many EV long-distance trips may be interrupted due to running out of energy.

- Those of the counties include Morgan, Johnson, Madison, Bartholomew, Hamilton, Marshall, Boone, Grant, LaPorte, Cass, White, Shelby, Huntington, Putnam, Decatur, and Owen as potentially charging deserts in the future.

- The future EV infrastructure investment plan shall consider those counties to minimize the impact of energy deficient areas for the EV charging station deployment.

- The study outcomes also provide the geographical magnitude of the EV energy demand defined by the ISTDM regions.

- In addition, the study confirms that the Greater Indy area is potentially the most EV energy required region, followed by SR-46 Corridor, SIDC, and NCIRPC among the 17 ISTDM regions.
Introduction

• The simulation model is:
  - Suitable for the aggregated ISTDM-v8 trip data (total daily trip per day)
  - Capable of the statewide EV charging demand-based analysis
  - Built for the long-distance (inter-region) trip simulation
  - An open platform that allows users to determine various input parameters

• The simulation model is limited:
  - To design an individual trip
  - To separate vehicle types
  - To include existing EV charging stations

https://www.tesla.com/supercharger
Introduction

- Summary of previous work
  - An agent-based model for trips/day
  - Use 17 regions from ISTDM v.8
  - Use INDOT daily trip simulated data projected for 2015

- Summary of current model updates
  - Convert single independent trips $\rightarrow$ round-trips (matching origin and destination) $\rightarrow$ aggregate data for state-wide simulations
  - Creating scenarios
    - The user-defined minimum/maximum threshold determines initial charging level.
    - The energy consumption rate is simulated by user-defined factors.
    - A user-defined adoption rate is applied to determine the number of round-trips to be simulated.
    - The model provides user-friendly interface to allow users to customize the simulation.
  - Support GIS modeling by exporting geospatial data
Overall flow of EV trip failure identification simulation model

Model to Identify Potential Failures of Long-Distance EV Trips

EV Travel Demand Data

- EV conditions
- Driving behaviors
- Travel speed
- Travel distance
- EV energy capacity
- Discount factors
- GIS map environment

Agent-based Simulation Model

- Trip Dispatcher Agent
  - Assign Tasks
  - Report Completion
- EV Trip Agent
  - Record Stop Markers
- Data Collector Agent

Outcomes from Simulation Model

- Numerical Summary
  - Number of failed trips
  - Total energy consumption
  - Total energy demand
  - Average trip completion ratio

GIS-Related Analysis
Internal state charts of the agents in the model

(a) Trip Dispatcher Agent
(b) EV Trip Agent
(c) Data Collector Agent
Model details – step 1: data preparation

Daily vehicle trip data between 17 regions
- Transform the individual trips into round trips
- Consider long-distance trips between two different regions
- Randomly select origins vs. destinations for each round trip

Referencing from ISTD-M8 (Indiana Statewide Travel Demand Model V.8)
Model details – step 2: set simulation input parameters

Average EV speed
- According to some references, 60 miles/hour is an appropriate speed to cover different vehicles and road types

User-defined discount factors
- The user-defined discount factors are defined to capture more complexity of the real situation
- The factors can reflect any conditions, such as traffic delay, construction delay, battery degradation, charging deficiency, etc.
- The factors will directly reduce the effectiveness of electricity energy
- In the nine finished scenarios, all three factors are set 100% as a baseline (optimal case)

Initial charging level for each trip
- When EVs initiate a trip, an initial battery charging level can vary
- The team decided to choose a random value between two pre-determined thresholds as the initial charging level
- The pre-determined thresholds are set as 50% ~ 80%

https://www.nrdc.org/experts/patricia-valderrama/electric-vehicle-charging-101
<table>
<thead>
<tr>
<th>ID</th>
<th>Year</th>
<th>EV Adoption Rate</th>
<th>EV Battery Capacity (kWh)</th>
<th>EV Energy Consumption Rate (kWh/100 miles)</th>
<th>EV Speed (mph)</th>
<th>User-defined Discount Factors</th>
<th>Thresholds of Initial Charging Level</th>
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<tbody>
<tr>
<td>1</td>
<td>2025</td>
<td>5%</td>
<td>78.0</td>
<td>34.6</td>
<td>60</td>
<td>100% for all three factors</td>
<td>[50%, 80%]</td>
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<td>10%</td>
<td></td>
<td></td>
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</tr>
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<td>3</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>2030</td>
<td>21.25%</td>
<td>78.0</td>
<td>34.6</td>
<td>60</td>
<td>100% for all three factors</td>
<td>[50%, 80%]</td>
</tr>
<tr>
<td>6</td>
<td>2030</td>
<td>32.5%</td>
<td></td>
<td></td>
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<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>8</td>
<td>2035</td>
<td>32.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2035</td>
<td>50%</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>10</td>
<td>2035</td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80%, 85%, 95%</td>
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</table>
## Results from 10 simulation scenarios

<table>
<thead>
<tr>
<th>ID</th>
<th>Year</th>
<th>Adoption Rate</th>
<th># of Trips</th>
<th># of Failed Trips</th>
<th>Failure Rate</th>
<th>Energy Consumption (kWh)</th>
<th>Energy Demand (kWh)</th>
<th>Energy Gap (kWh)</th>
<th>Average Energy Gap Per Failed Trip (kWh)</th>
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<tbody>
<tr>
<td>1</td>
<td>2025</td>
<td>5%</td>
<td>23962</td>
<td>509</td>
<td>2.12%</td>
<td>605680.2</td>
<td>609484.5</td>
<td>3804.3</td>
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<td>2025</td>
<td>10%</td>
<td>47924</td>
<td>1021</td>
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<td>1208136.1</td>
<td>1214764.1</td>
<td>6628</td>
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<td>3</td>
<td>2025</td>
<td>15%</td>
<td>71885</td>
<td>1550</td>
<td>2.16%</td>
<td>1818068.6</td>
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<td>6.76</td>
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<td>4</td>
<td>2030</td>
<td>10%</td>
<td>49370</td>
<td>1054</td>
<td>2.13%</td>
<td>1251742.5</td>
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<td>6655.2</td>
<td>6.31</td>
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<tr>
<td>5</td>
<td>2030</td>
<td>21.25%</td>
<td>104910</td>
<td>2252</td>
<td>2.15%</td>
<td>2653532.9</td>
<td>2667953.2</td>
<td>14420.3</td>
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<tr>
<td>6</td>
<td>2030</td>
<td>32.5%</td>
<td>160451</td>
<td>3461</td>
<td>2.16%</td>
<td>4054475.4</td>
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<td>15%</td>
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<td>1700</td>
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<td>1931192.7</td>
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<td>8</td>
<td>2035</td>
<td>32.5%</td>
<td>165152</td>
<td>3436</td>
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<td>4178206.3</td>
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<td>50%</td>
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<td>6425286.8</td>
<td>6458855.7</td>
<td>33568.9</td>
<td>6.16</td>
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<tr>
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<td>2035</td>
<td>50%</td>
<td>254080</td>
<td>65326</td>
<td>26.08%</td>
<td>9303433.0</td>
<td>9966386.6</td>
<td>662953.6</td>
<td>10.15</td>
</tr>
</tbody>
</table>

- **Energy demand**: a total amount of energy needed to finish all planned trips successfully
- **Energy consumption**: energy consumed in simulated trips driven before failure
- **Energy gap** = energy demand – energy consumption
- **Average energy gap per failed trip** = energy gap / # of failed trips
Results from 10 simulation scenarios (Cont.)

• The results of first nine scenarios share a very similar pattern except the energy part, which means the trip data and EV adoption rate only influences the magnitude of failed trips.

• The change of discount factors has a significant effect on the simulation.

• Result of scenario 10 demonstrates that the failure rate can reach 26% at a very realistic situation.
Spatial analysis and guidance for strategic deployment of EV charging infrastructure in Indiana

• Introduction
• GIS - aggregation analysis
• Summary
Introduction – data aggregation & analysis

- The main goal is to visualize the energy deficiency (gap) in the State of Indiana
- Conducted the geospatial aggregation analysis for the locations of failed trips over the Indiana GIS layer
- The aggregation analysis tool in ArcGIS summarizes statistics of points in terms of geospatial polygon features
- Requires a layer of point features and polygon features
  - Point layer: stop markers of failed trips in each simulation scenario
  - Polygon layer: divided areas within Indiana State
- Based on the point-in-polygon geospatial relationship, statistics about all points in the polygon are calculated and assigned
Introduction – boundary layers

• To provide different scales of results, the team applied two different levels of area divisions
  • 92 county layer
  • 17 ISTDM region layer

• For the statistics computed in the aggregation analysis, the team mainly focused on two parts
  • # of stop markers in each area
  • Total energy gap in each area

• To simplify the presentation, four scenarios are chosen to perform the GIS analysis
  • Scenarios 1, 5, 9, 10
GIS - stop markers (failed trips)

Scenario 1
2025 @ 5%

Scenario 5
2030 @ 21.25%

Scenario 9
2035 @ 50%

Scenario 10
2035 @ 50% w/ 80, 85, 95% factors
GIS - aggregation analysis results for scenario 1

2025 @ 5%

- County level results for # of stop markers
- County level results for total energy gap
- Region level results for # of stop markers
- Region level results for total energy gap
GIS - aggregation analysis results for scenario 5

2030 @ 21.25%

- County level results for # of stop markers
- County level results for total energy gap
- Region level results for # of stop markers
- Region level results for total energy gap
GIS - aggregation analysis results for scenario 9

2035 @ 50%

County level results for # of stop markers

County level results for total energy gap

Region level results for # of stop markers

Region level results for total energy gap
GIS - aggregation analysis results for scenario 10

2035 @ 50% w/ 80, 85, 95% factors

County level results for # of stop markers
County level results for total energy gap
Region level results for # of stop markers
Region level results for total energy gap
Summary

• The ArcGIS layers of first 3 scenarios share very similar patterns, which is consistent with the simulation results.

• In terms of county level division, the dense areas for failed trips as well as the energy gap are mainly along the interstate highway.

• In terms of ISTDM region level division, the Greater Indy region is much denser than other areas.
Simulation model and GIS analysis

• The agent-based simulation model of the study is developed for future long distance EV trip scenarios in the State of Indiana and uses unique geographical information and model parameters for Indiana.

• This model enables INDOT to identify EV energy deficient areas for current and future energy charging demand scenarios and can support the state’s strategic planning for the EV charging infrastructure development.

• *Recommendation:* Although the results are meaningful, the current simulation model cannot assess the operational capacities of the future EV charging infrastructure that INDOT may invest in. Therefore, the current simulation model needs to be enhanced to analyze the required capacities of future charging stations in major interstate corridors.
Future research – model steps

Model for EV Energy Demand Assessment of Charging Stations

1. Determine model parameters
   • O-D (#14 & #7) and corridors
   • # of charging stations and their locations

2. Run the model

3. Display results
   • energy demands of each charging station
   • service patterns
Future research – implementation

Model for EV Energy Demand Assessment of Charging Stations

• Analyzing how individual charging station performs for current EV demands
• Can be used to design capacity of charging stations once locations are determined
Impact on highway revenue
Introduction

- EVs bring challenges to the transportation funding scheme
- Revenue impacts of EV adoption have been examined either qualitatively or under scenarios for light-duty vehicles mostly

What is the impact of EVs on highway revenue? What is the optimal fee of EVs to break-even the revenue loss?
Data and methods

Annual fee per EV to break-even the fuel tax revenue loss (“recovery EV fee”)

EV registrations

*EV market penetration x vehicle registrations*

Annual Vehicle Miles Travelled (VMT) of EVs

*Annual VMT per vehicle x EV registrations*

Fuel gallons lost

*VMT of EVs / fuel efficiency*

Revenue loss

*(gallons lost x % gas consumed x taxes associated with gas) + (gallons lost x % diesel consumed x taxes associated with diesel)*

Recovery EV fee

*For each vehicle class*

*From 2021 to 2035*

*Revenue loss / EV registrations*
Data and methods

Impact of EVs on INDOT revenue

- It is anticipated that the revenues from the recovery EV fee will be split between the state and the local governments.
- If the number of EVs increases, a portion or all revenue can be distributed to State Highway Fund/INDOT.
- Uncertainty: (a) when/at what conditions INDOT will start to fully or partially collect revenue from EV fees
(b) percentage of revenue collected by INDOT.

### Scenario analysis

<table>
<thead>
<tr>
<th>EV market penetration levels for each vehicle class</th>
<th>Year of EV revenue collection by INDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2025</td>
</tr>
<tr>
<td>Automobiles</td>
<td>5%, 10%, 20%, 25%</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>5%, 10%, 20%, 25%</td>
</tr>
<tr>
<td>Light trucks</td>
<td>5%, 10%, 20%, 25%</td>
</tr>
<tr>
<td>Buses</td>
<td>5%, 10%, 20%, 25%</td>
</tr>
<tr>
<td>Single unit trucks</td>
<td>5%, 10%, 20%, 25%</td>
</tr>
<tr>
<td>Combination trucks</td>
<td>5%, 10%, 20%, 25%</td>
</tr>
<tr>
<td>Percentage of revenue collected by INDOT</td>
<td>0%, 25%, 50%, 75%, 100%</td>
</tr>
</tbody>
</table>
Results

Recovery EV fee

Recovery EV fee automobiles, motorcycles, buses, light-duty and single-unit trucks

Periodic payments, vehicle miles traveled fee, pay-as-you-charge fee
Results

• EV market penetration (2030).
  Most likely scenario:
  
  5%  
  30%  

• In 2035, total fuel tax revenue ~$3B due to the revenue loss (~$2.1B)

• If no revenue loss total fuel tax revenue ~$5.1B

Note: Fuel tax revenue loss was also calculated per vehicle class. Multiple EV market penetration (% of registrations) scenarios were developed.
Results

- EV market penetration (2030).
  Most likely scenario:
  - 5%
  - 30%

- Fuel tax revenue loss in 2035: ~963 M

- Recovery EV fee: offers revenue surplus for 75%, 100% revenue takeover. Existing EV fee: offers revenue deficit for all % of revenue takeover

Note: Fuel tax revenue loss was also calculated per vehicle class. Multiple EV market penetration (% of registrations) scenarios were developed.
Funding mechanisms discussion

• Similar to the pay-at-the-pump nature of existing fuel taxes.

• Difficult to separate the EV electricity usage from the household usage.

• Pay-as-you-charge fee

• Similar to the pay-at-the-pump nature of existing fuel taxes.

Partnerships between utilities and INDOT are necessary.

• Can be adjusted to account for the actual cost caused to the transportation network (e.g., if combined with weight-based fees).

• EVs could be made to have lower VMT fees (user perspective).

• Concerns exist in terms of privacy, administrative costs and disparity between rural vs. urban EV users.

Vehicle miles traveled (VMT) fee
Practical implications & future work

• The results of this task can inform INDOT’s revenue model and assist decision making.

• Estimations of EV fees can be used in pilot programs to assess user acceptance.

• Implementing the recovery EV fee as an annual flat fee may generate opposition from the public and road users. Other alternatives include a VMT ($/mile) or pay-as-you-charge ($/kwh) fee. Extensive public outreach and education should be undertaken to inform users about cost savings of EV use.

• Future research: disaggregate results by weight class, develop metrics to consider equity of funding mechanisms, consider how transportation revenue sources can align with available funds and broader goals.
Strategic partnerships
Evaluation of strategic partnerships and recommendations based on stakeholders’ inputs

- Selection criteria for stakeholder sample: relevant experience and key position in their stakeholder group
- Data collection: semi-structured interviews and pre-survey
- Methods: content analysis to identify the main concepts arising in the interviews
- Sample size: 23 individuals from 19 organizations/agencies

<table>
<thead>
<tr>
<th>Stakeholder group</th>
<th>Number of organizations/agencies</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive industry/manufacturers</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Utilities/energy providers</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Government/policy makers</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Charging equipment/infrastructure providers</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Non-profit/non-governmental organizations (Clean Cities)</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Other (engineering consulting firms, researchers, EV operators etc.)</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Stakeholder groups, number of organizations/agencies and participants
Stakeholder interrelationships

- Collaboration and knowledge exchange regarding EV charging and battery technology
- Support and knowledge exchange on the installation and maintenance of EV charging equipment
- Understanding of the demand, the location of charging infrastructure, and existing policies
- Better transparency of the pricing policy and payment systems
- Education and coordination for better communication of public policy frameworks, with relevant information for special electricity rates or incentives
Business models

Level 2 charging is the most common solution at the local level. Level 2 charging infrastructure is not necessarily owned by utilities, but operational data is needed to inform their plans and offer a reliable grid at an optimal cost.

Operation and deployment of charging infrastructure is not an industry that OEMs are willing to get involved.

Utilities, public sector and charging network providers are the main stakeholders involved in fast charging.

Private involvement is essential for the provision of charging infrastructure.

Public sector can offer direct or indirect incentives, especially for fast charging which may not be financially feasible at low utilization rates.

As the complexity of an appropriate business model for commercial fleets is high as they operate in a unique way, they mainly rely on private charging infrastructure.

Charging as a service with payments for the use of charging infrastructure is an alternative business model.
Transportation funding concerns

- Registration fee for EVs is too high and certain adjustments may be necessary to promote equity.
- Implementation of a motor fuel tax as a gasoline gallon equivalent that is based on a fee per kwh.
  - Taxation during charging is viable but the multiples ways of charging (home, work etc.) pose difficulties.
  - There are also privacy concerns and need for expensive equipment.
  - Concerns were expressed by interviewees regarding its fairness.

- VMT fee
  - It is viewed as a fair approach.
  - It requires new methods for measuring the VMT with privacy concerns again being a major barrier.

<table>
<thead>
<tr>
<th>Potential of different tax/fee revenue structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMT fee</td>
</tr>
<tr>
<td>Pay-as-you-charge fee (e.g., $/kwh/ similar to the fuel tax)</td>
</tr>
<tr>
<td>EV registration fee broken into periodic payments</td>
</tr>
<tr>
<td>EV annual registration fee</td>
</tr>
<tr>
<td>No potential</td>
</tr>
<tr>
<td>Low potential</td>
</tr>
<tr>
<td>Medium potential</td>
</tr>
<tr>
<td>High potential</td>
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</table>
Charging infrastructure, adoption & grid impact

Level of charging availability and accessibility

- Controversial stakeholders’ opinions exist concerning the level of charging availability and accessibility
- It highly depends on the location of the area under review
- There is sufficient coverage in urban environments
- Infrastructure in rural environments as well as along minor and principal arterials is scarce

Vehicle class or type with future high adoption rate

- The stakeholders identified transit buses as having the highest potential for electrification due to both operational and financial attributes
- School buses and terminal or port applications were also viewed with a high potential for electrification, followed by small freight vehicles or delivery vans

Grid impact and renewable energy integration

- With the current adoption rates, there is no need for major grid updates
- Close collaboration between utility companies and the public sector is crucial, especially in the near future with increased adoption rates
- Commercial fleet electrification was the main area for which stakeholders expressed concerns regarding future grid needs
- Grid management would be of high priority as EV adoption increases
- EVs should become a grid asset with technologies like vehicle-to-grid (V2G), on-site energy generation and on-site energy storage
- Renewable energy should be an integral part of the transportation electrification process
Practical implications & implementation plan

• The results can enhance preparedness for increasing EV adoption rates across vehicle classes and strengthen the engagement of different entities in the provision of charging infrastructure.

• Public agencies’ role focuses on planning the charging infrastructure, providing direct or indirect incentives, raising awareness and educating all stakeholders involved.

• Collaboration between utilities and policy makers is needed to plan for increasing EV demand (especially regarding commercial vehicles that have increased power requirements).

• Prioritizing planning (e.g., incentives, charging infrastructure) for the successful implementation of EV technology across transit/school buses and small freight vehicles or delivery vans is crucial to handle the potential increased EV demand.

• A robust dataset of charging infrastructure points is necessary for communication purposes and from a public policy standpoint.