Advancing the climate benefits of electric vehicles to reduce greenhouse gas emissions

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TRAQ
The Transportation & Air Quality Research Group
Transportation: a major source of greenhouse gas (GHG) emissions

- **Transportation**: 2nd largest source of national total Greenhouse Gas (GHG) emissions; largest of Nitrogen Oxides (NOx) emissions

- Toronto emission inventory in 2017 shows:
A climate emergency has been declared in 2019

- TransformTO: Toronto’s ambitious climate action strategy (2017)
- Automobile-related goals:
  - 45% low-carbon vehicles by 2030;
  - 100% low-carbon vehicles by 2050.
However, electric vehicle is not “zero-emissions”...
Emissions from electric vehicles

• Vehicle life-cycle emissions
In this presentation:

• Reduction of GHG emissions in the following electric vehicle scenarios:

1) Electric vehicles

2) Electricity supply mix

3) Connected autonomous vehicles

4) Different charging schedules
Study domain and data source

- Greater Toronto and Hamilton Area (GTHA)
- Demand data: Transportation Tomorrow Survey (TTS) data
- Travel distance and time: GTAModel
1. Electric vehicles with different penetration rates

Methodology

• Road link-based emission factors (gram/km) and energy consumption factors (kJ/km) are applied;

• **Fuel cycle GHG emissions** in 2011 and 2017 are calculated for conventional gasoline vehicles and electric vehicles;

• **25%, 50%, 75%, 100%** EV penetration rates are implemented;

• Emission uncertainties from **vehicle on-road operation, electricity generation, and gasoline supply** are considered with the Monte-Carlo random process.
Sources of uncertainties

• Vehicle operation: variation of microscopic driving operations;

• Gasoline supply: monthly difference of supply share and emission intensity of different supply sources;

• Electricity generation: monthly difference of electricity generation mix.
Fuel-cycle emission comparison

From a probabilistic perspective, having more EVs does not ensure the emission reduction;

Besides having more EVs, keeping a good traffic condition and a cleaner energy source can enhance the climate benefit of EVs.
2. Electric vehicles and connected autonomous vehicles

### Scenario settings

<table>
<thead>
<tr>
<th>Three levels of demand</th>
<th>Three levels of CAV penetration rate</th>
<th>All EV</th>
<th>2016 Ontario energy mix</th>
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</thead>
<tbody>
<tr>
<td>Low demand</td>
<td>0%</td>
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<tr>
<td>Medium demand</td>
<td>5%</td>
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<td>High demand</td>
<td>100%</td>
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CAV algorithm: minimize total travel time
Total GHG emissions from the generation

- The GHG reduction can be enhanced by integrating AVs with EVs when traffic is congested;
- CAV application should be integrated with EV technology carefully to maximize the climate benefit.
3. Electric vehicles and electricity supply mix

Energy sources of vehicles

Light duty vehicles

- Gasoline or electricity

Mix 1: 2016 Ontario electricity generation mix
Mix 2: 100% natural gas
Mix 3: Hydro and natural gas
Mix 4: Wind and solar
Total GHG emissions

• **EVs do not necessarily reduce emissions (Mix 2 EV vs. gasoline conventional vehicles)**

• **Clean energy sources of the electricity generation enhance the climate benefit of EVs**
4. Electric vehicles and different charging schedules


Introducing marginal emission factors

Average emission factor:

$$\sum Share_{energy\ source\ i} \times Emission\ intensity_{energy\ source\ i}$$

However, only some specific generators (usually they are dispatchable) respond to the near-term increase of the electricity demand.

The marginal emission factor (MEF): capture the marginal change of the generator and the corresponding change on the emission intensity.
Marginal emission factor model

(a). \[ MEF_i = (\beta_0^+ + \beta_1^+ \times G_i + \beta_2^+ \times \Delta G_i) \times D_{month}, \] if \( \Delta G_i \geq 0; \)

(b). \[ MEF_i = (\beta_0^- + \beta_1^- \times G_i + \beta_2^- \times \Delta G_i) \times D_{month}, \] if \( \Delta G_i < 0; \)

Where:

\( G_i \) is network electricity load at time \( i; \)
\( \Delta G_i \) is the change of electricity demand;
\( D_{month} \) is the dummy variable indicating the specific month;
\( \beta_0, \beta_1, \beta_2, \) and \( \beta_3 \) are constant coefficients in the MEF model;

This set of MEF formula is for August 2017.

MEF is related to:

- year, month;
- electricity demand at the current hour;
- Marginal change of the electricity demand

The MEF varies in different hours of a day

\( \rightarrow \) EV charging schedules can influence the total emissions
Optimizing EV charging schedule

• Objective: minimize GHG emissions from the generation

Objective: \( \min Z = \frac{\Sigma_i \text{MFE}_i \times \Sigma_j x_{i,j}}{\delta \times (1-\gamma)} \)

S.t.
(I). Vehicle cannot be charged during driving;
(II). Total energy consumption cannot exceed total charged energy plus battery capacity;
(III). At the end of the day, total energy consumed should be approximately same as total energy charged;
(IV). Total charging demand of the network cannot exceed the generation spare capacity.

\( x_{i,j} \): charging levels (0, level1, level2, level3) of vehicle \( j \) in timeslot \( i \).
Scenario settings

• 5% random samples out of all drivers in the TTS data

• Scenarios:
  • Optimized plan: minimizing GHG emissions as the objective;
  • Home charging: only charge at home;
  • Out-of-home charging: cannot charge at home;
  • After-trip charging: charging is available after each trip;
  • After 3am charging: charging is available after 3am.
Scenario comparison

Total emissions from the generation
Scenario comparison

**Total emissions from the generation**

<table>
<thead>
<tr>
<th></th>
<th>Optimized</th>
<th>Home</th>
<th>Out of home</th>
<th>After trip</th>
<th>After 3am</th>
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<tbody>
<tr>
<td>GHG emissions (kg)</td>
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**Charging schedules**

An optimized charging schedule with a proper charging level management can maximize the GHG reduction from EVs.

After-3am

Optimized

After-trip

Hour of a day

Charging schedules

Total emissions from the generation

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Distribution of charging durations

Level 1

Home location is the most popular option

Level 2 and Level 3 charging events follow the similar distribution, but different numbers of event.
The availability of charging facilities ensures the possibility of the optimized charging schedule;

Optimized plan and after-3am plan request the most public charging ports;

Level 1 is the highest requested public charging level;

Conflicts exist between the climate benefit of EVs and the investment cost of the infrastructure.
A closing remark
The share of EVs is far from the goal

- TransformTO:
  - 45% low-carbon vehicles by 2030;
  - 100% low-carbon vehicles by 2050.
The share of EVs is far from the goal

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  • 45% low-carbon vehicles by 2030;
  • 100% low-carbon vehicles by 2050.

• Currently (in 2019):

  Technological improvements, incentives are needed to increase the EV share.

Figure 4: Current share of personal vehicles in Toronto that are EVs.
Pathway to enhance the climate benefit of electric vehicles

• A better traffic condition with less congestion saves electrical energy;
• A cleaner electricity generation mix reduces emission intensity per kWh of electrical energy;
• With the same energy consumption, a proper EV charging plan can reduce marginal emissions;
• An appropriate allocation of charging facilities is the prerequisite of the optimized EV charging plan.
Thank you!

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