UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

UTTRI

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

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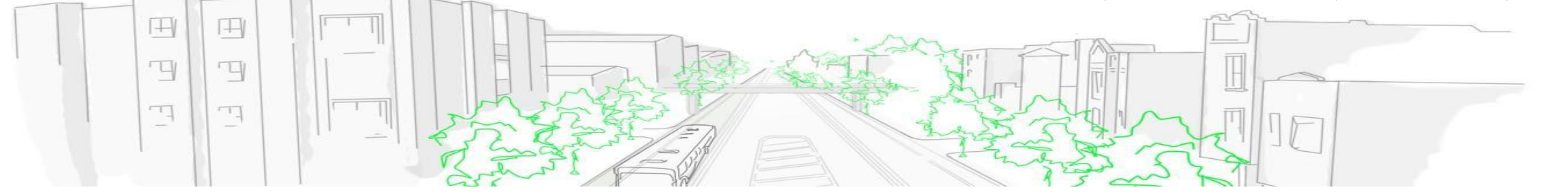
Transformative Transportation '20, iCity-CATTS Research Day

June 3, 2020

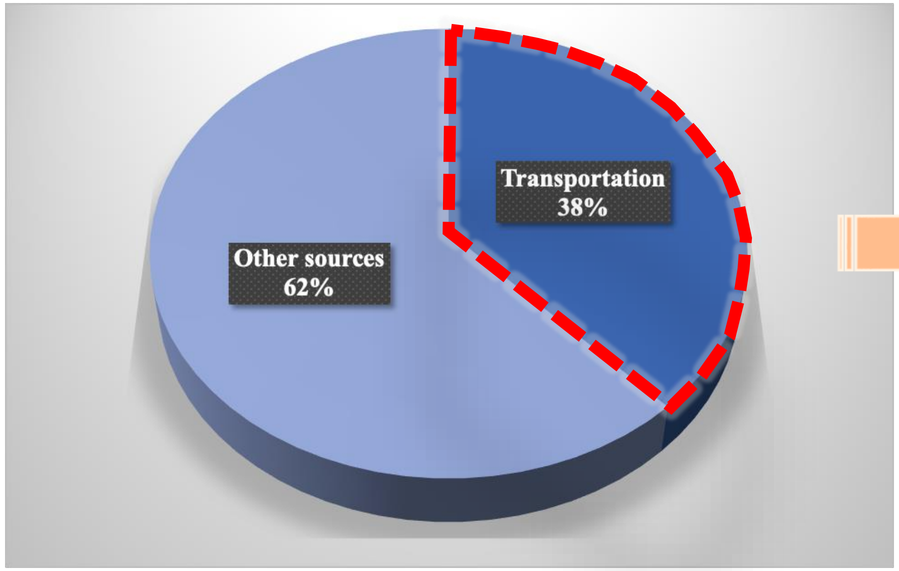
TRAQ

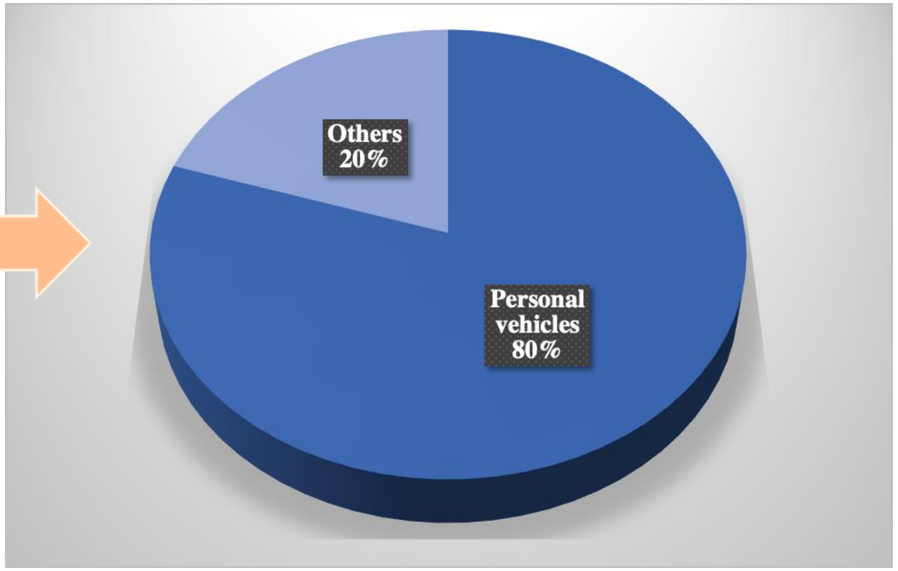
The Transportation & Air Quality Research Group



Transportation: a major source of greenhouse gas (GHG) emissions

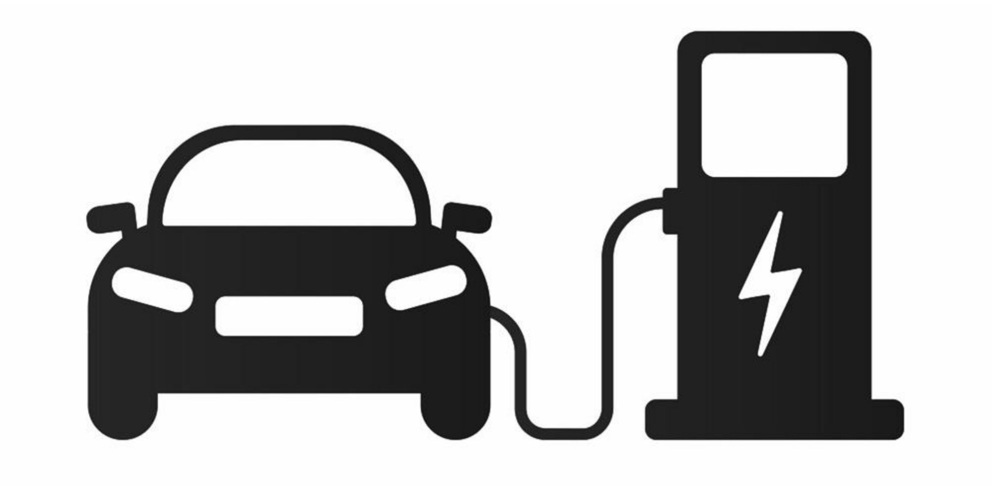
- **Transportation**: 2nd largest source of national total Greenhouse Gas (GHG) emissions; largest of Nitrogen Oxides (NOx) emissions
- Toronto emission inventory in 2017 shows:





A climate emergency has been declared in 2019

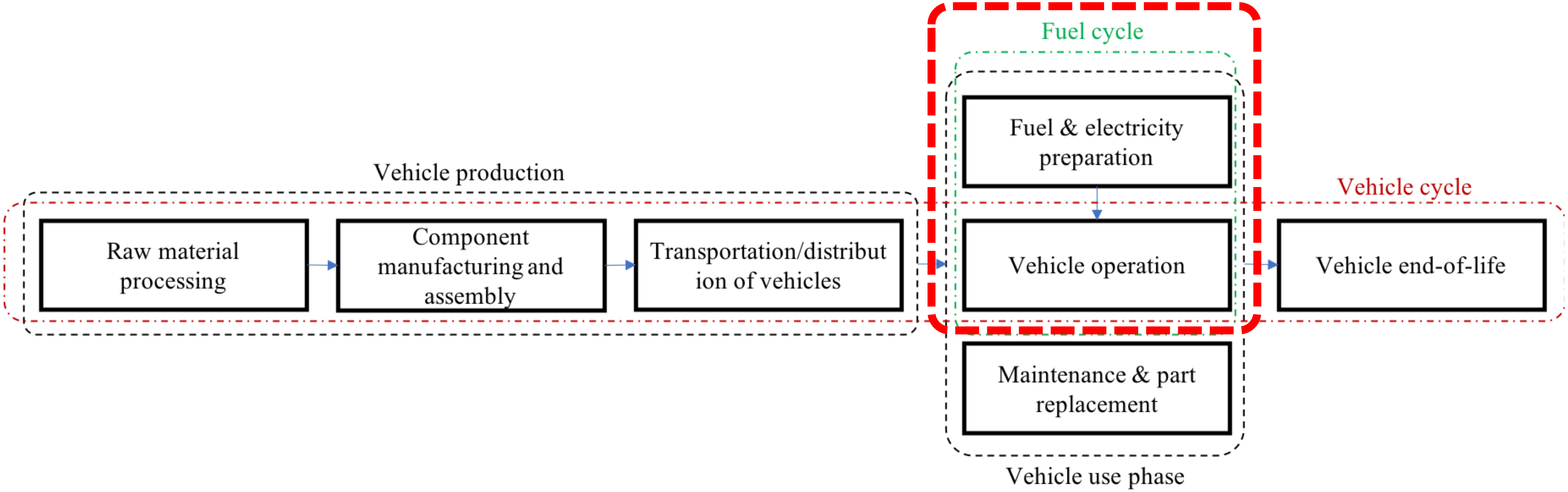
- TransformTO: Toronto's ambitious climate action strategy (2017)
- Automobile-related goals:
  - **45%** low- carbon vehicles by 2030;
  - **100%** low-carbon vehicles by 2050.



However, electric vehicle is not “zero-emissions”…

Emissions from electric vehicles

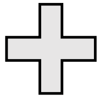
- Vehicle life-cycle emissions



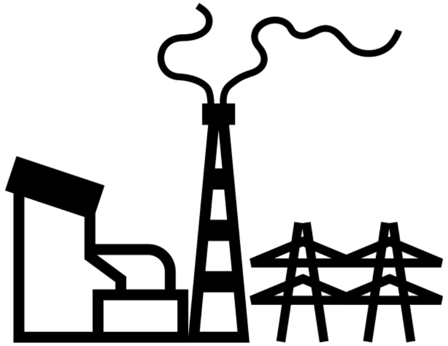
In this presentation:

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

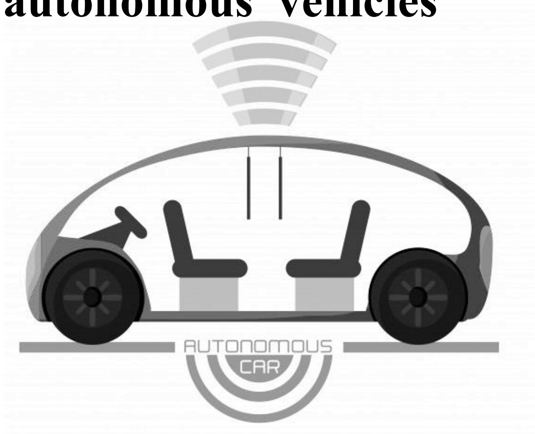
1) Electric vehicles



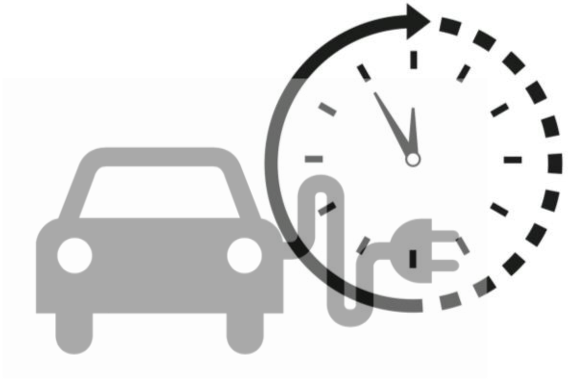
2) Electricity supply mix



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

Wang, An, Ran Tu, Yijun Gai, Lucas G. Pereira, J. Vaughan, I. Daniel Posen, Eric J. Miller, and Marianne Hatzopoulou. "Capturing uncertainty in emission estimates related to vehicle electrification and implications for metropolitan greenhouse gas emission inventories." Applied Energy 265 (2020): 114798.

Electric vehicles

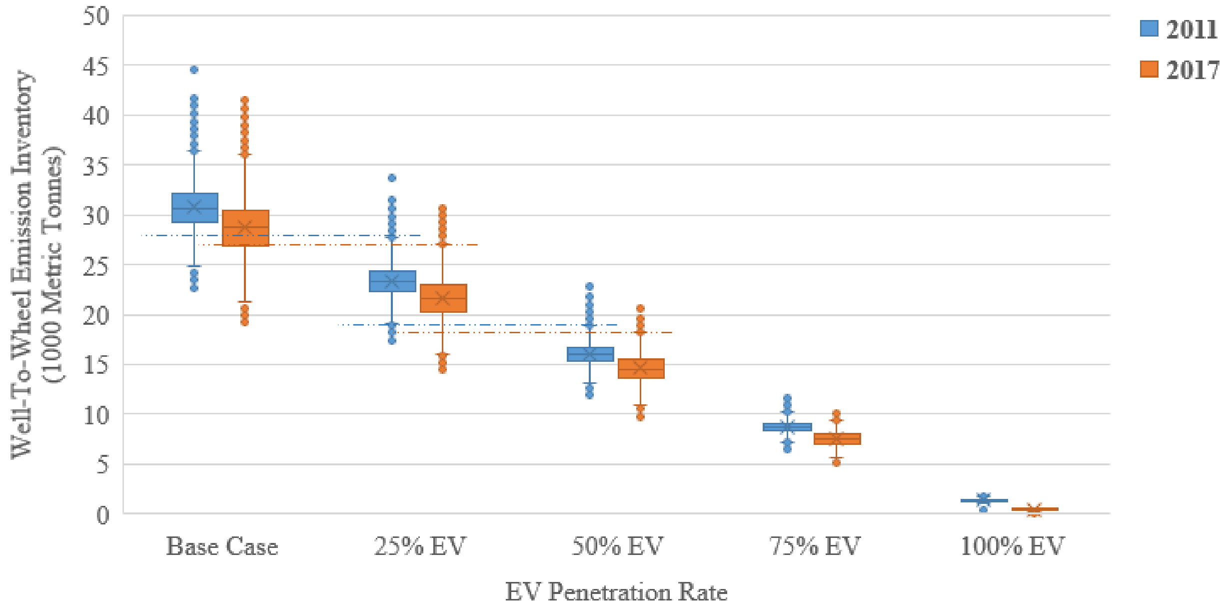
Methodology

- 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

Tu, Ran, Alfaseeh, L., Djavadian, S., Farooq, B., Hatzopoulou, M. "Quantifying the impacts of dynamic control in connected and automated vehicles on greenhouse gas emissions and urban NO2 concentrations." Transp. Res. Part D Transp. Environ (2019). 73, 142–151. doi:10.1016/j.trd.2019.06.008

Electric vehicles (EV)

+

Connected autonomous vehicles (CAV)

Scenario settings

Three levels of demand

Low demand

Medium demand

High demand

×

Three levels of CAV penetration rate

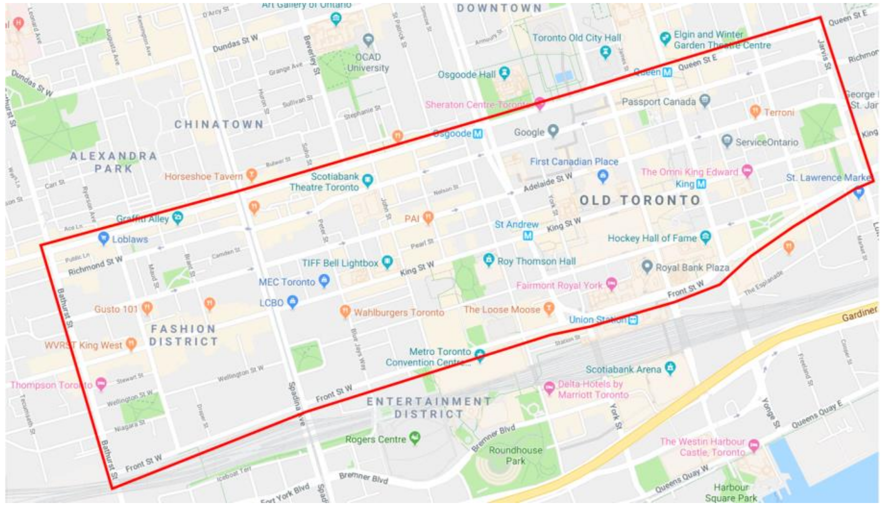
0%

5%

100%

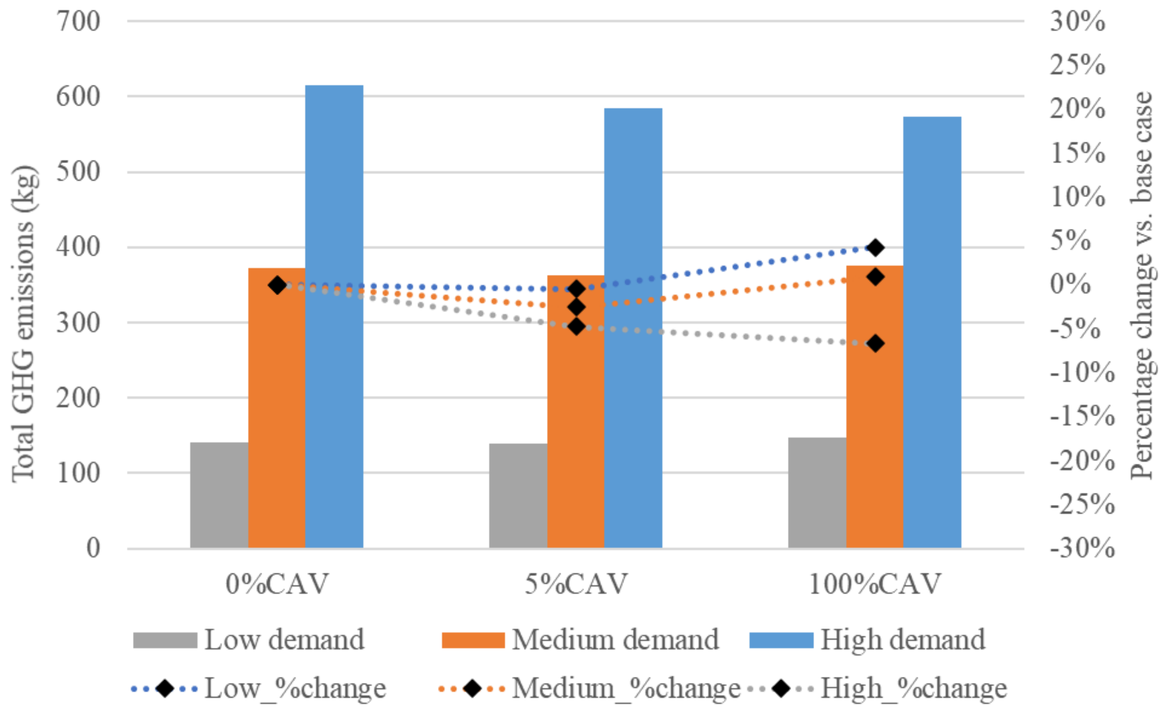
All EV

2016 Ontario energy mix



CAV algorithm: minimize total travel time

Total GHG emissions from the generation



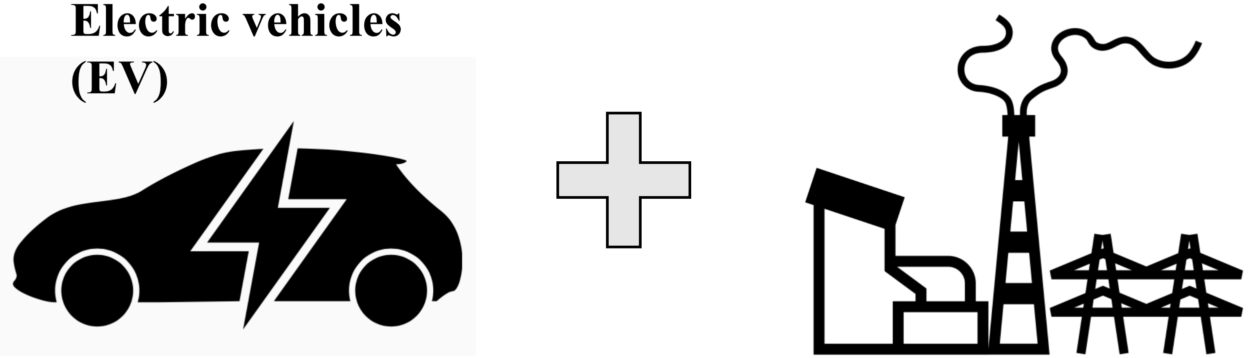
- *The GHG reduction can be enhanced by integrating AVs with EVs when traffic is congested;*
- *CAV application should be integrated with EV technology carefully to maximize the climate benefit.*

3. Electric vehicles and electricity supply mix

Wang, An, et al. "Automated, electric, or both? Investigating the effects of transportation and technology scenarios on metropolitan greenhouse gas emissions." Sustainable cities and society 40 (2018): 524-533.

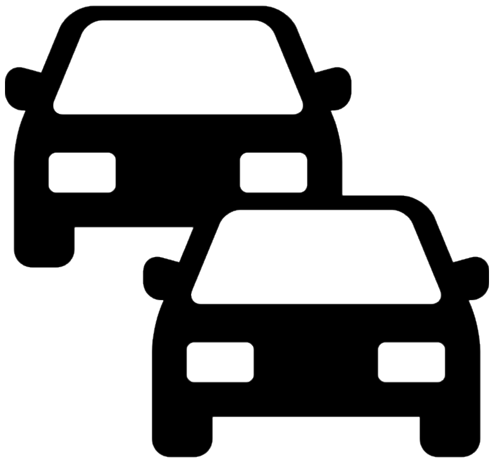
Electric vehicles (EV)

Electricity supply mix

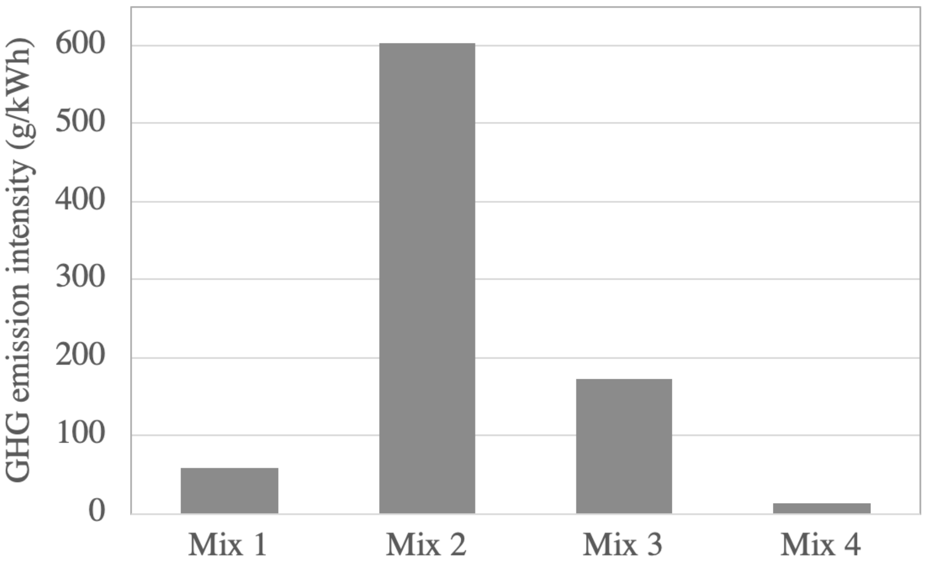


Energy sources of vehicles

Light duty vehicles

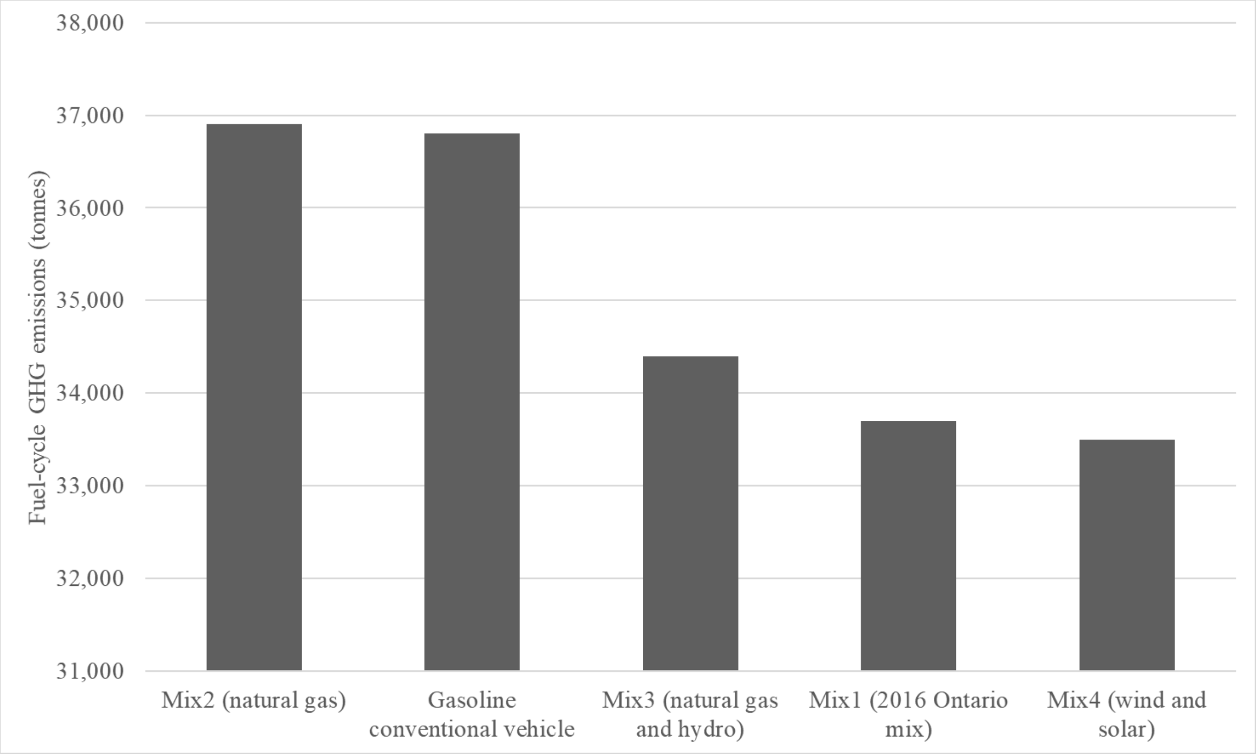


Gasoline or electricity



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*

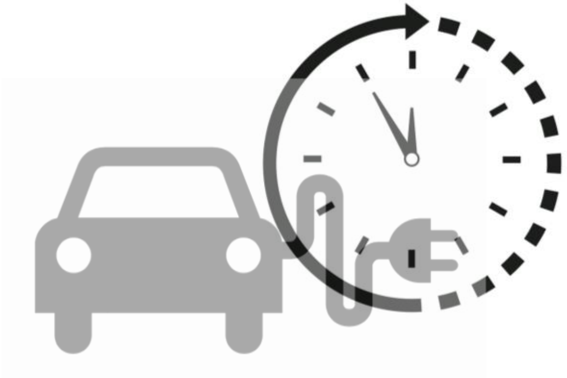
4. Electric vehicles and different charging schedules

Gai, Yijun, et al. "Marginal Greenhouse Gas Emissions of Ontario's Electricity System and the Implications of Electric Vehicle Charging." Environmental science & technology 53.13 (2019): 7903-7912.

Tu, Ran, Yijun Gai, Bilal Farooq, Daniel Posen, Marianne Hatzopoulou. "Electric Vehicle Charging Optimization to Minimize Marginal Greenhouse Gas Emissions". The 99th Transportation Research Board Annual Meeting. January 2020. Washington DC, USA

Electric vehicles

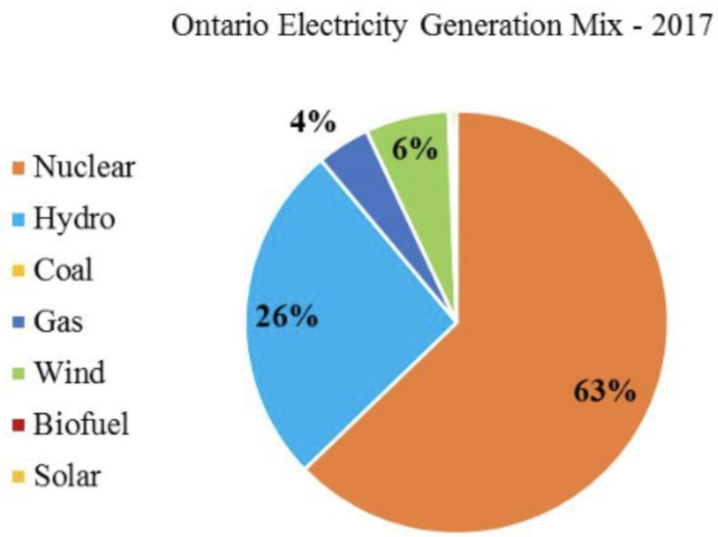
Different charging schedules



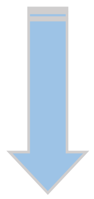
Introducing marginal emission factors

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

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

Where:

Gi is network electricity load at time *i;*

ΔG_i is the change of electricity demand;

D_{month} is the dummy variable indicating the specific month;

β0, *β1*, *β2*, and *β3* 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

→ EV charging schedules can influence the total emissions

Optimizing EV charging schedule

- Objective: minimize GHG emissions from the generation

$$\text{Objective: } \min Z = \frac{\sum_i MEF_i \times \sum_j x_{i,j}}{\delta \times (1-\gamma)}$$

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

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;

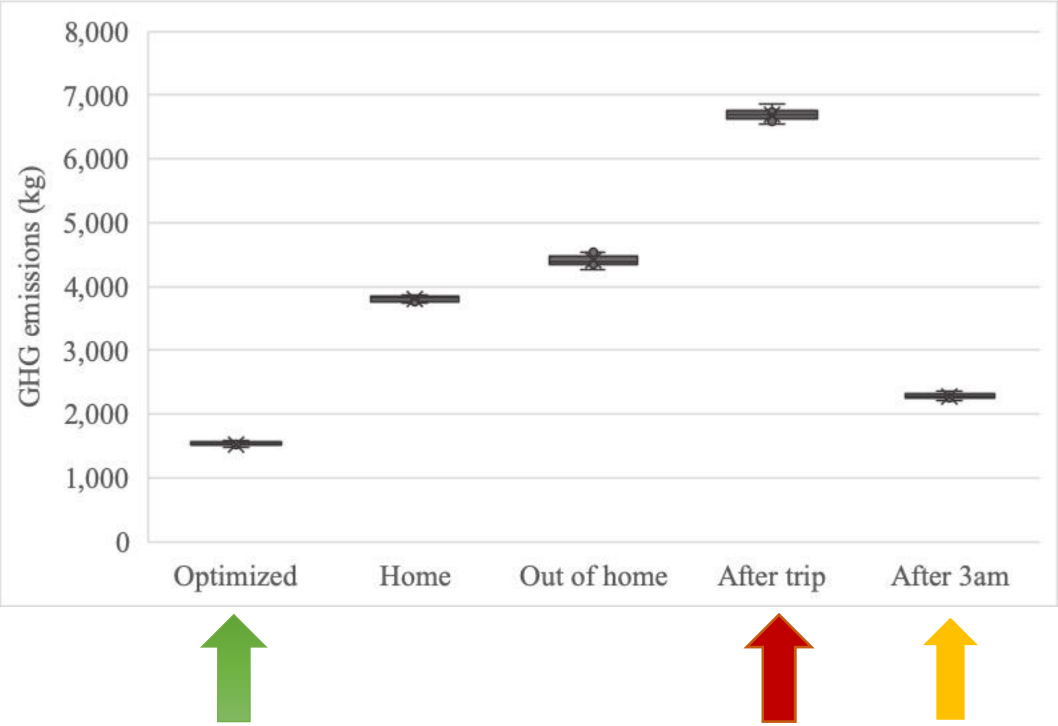
(IV). Total charging demand of the network cannot exceed the generation spare capacity.

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.

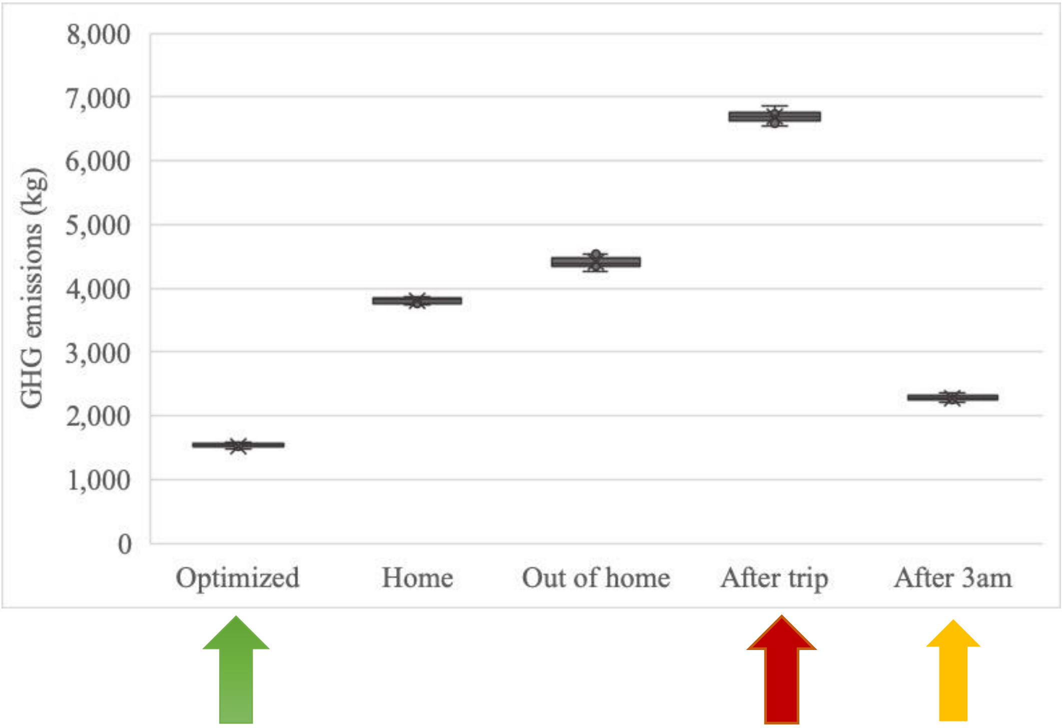
Scenario comparison

Total emissions from the generation

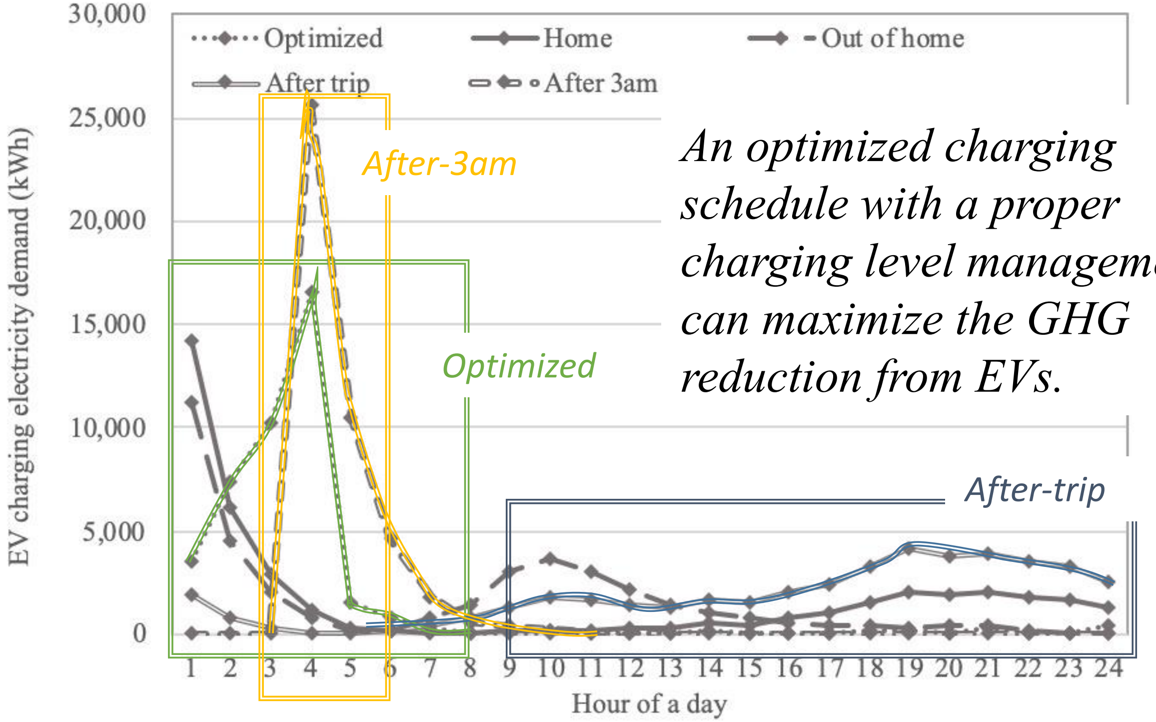


Scenario comparison

Total emissions from the generation

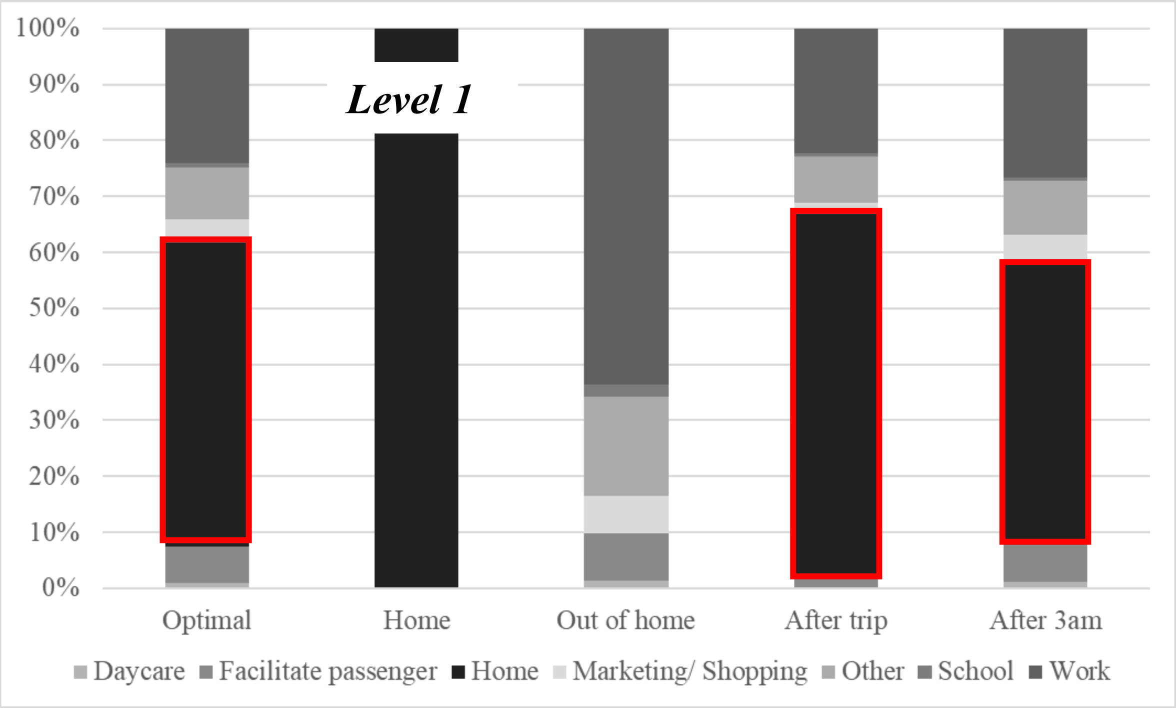


Charging schedules



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

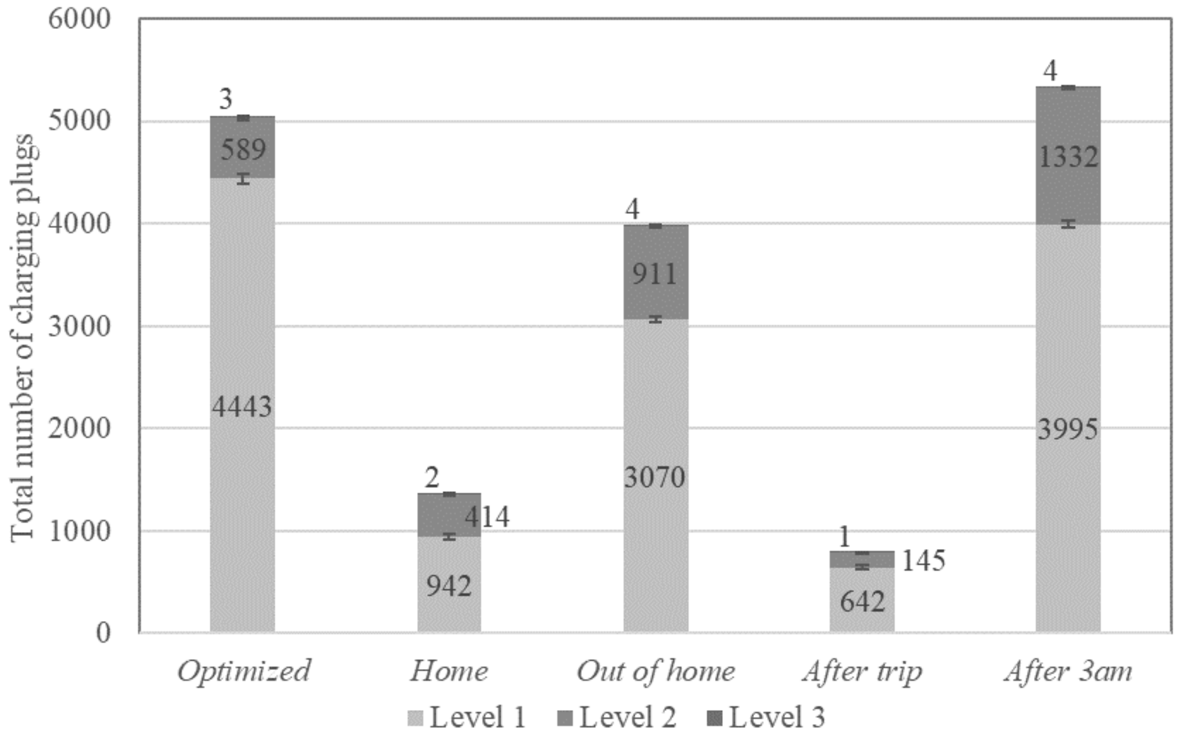
Distribution of charging durations



Home location is the most popular option

Level 2 and Level 3 charging events follow the similar distribution, but different numbers of event.

Total number of public charging ports



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

- TransformTO:
  - 45% low- carbon vehicles by 20:
  - 100% low-carbon vehicles by 20
- Currently (in 2019):

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

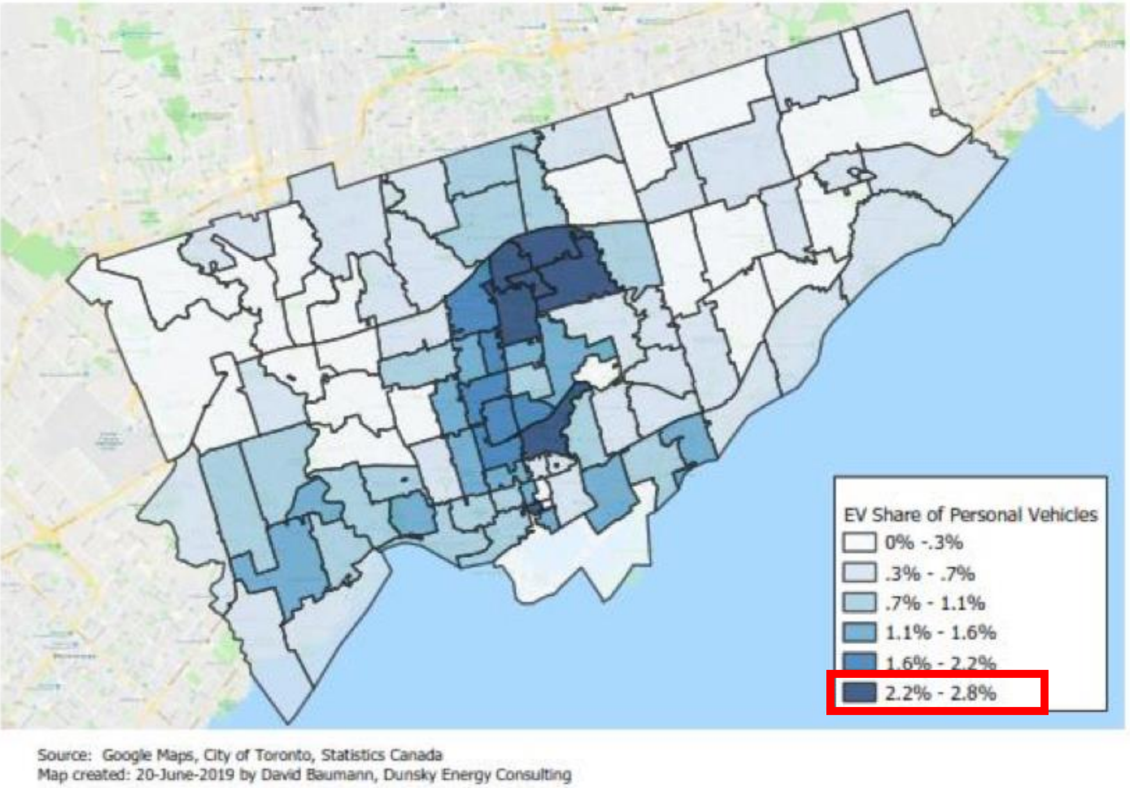


Figure 4: Current share of personal vehicles in Toronto that are EVs.

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.

TRAQ

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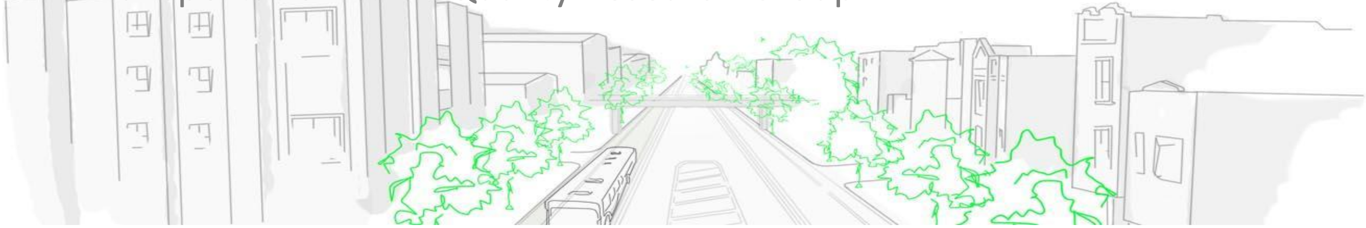

Thank you!

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