Electrification of the Canadian Road Transportation Sector: A 2050 Outlook with TIMES-Canada

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- NSERC of Canada
- MDEI E of Quebec (link with REACCESS 7th FP-EU)

Partners:

- Resources Natural Canada
- Environment Canada
- Hydro-Quebec
We will present:

- TIMES-Canada and transportation sector
- Road electric vehicles database
- Charging stations infrastructure modelling
- Analysis of climate and energy policies
- Conclusion
The Integrated MARKAL-EFOM System (TIMES) model

- Combine advanced versions of MARKAL models (ETSAP, IEA)
- Linear programming bottom-up energy models
- Integrated modeling of the entire energy system
- Prospective analysis on a long term horizon (50-100 yrs)
  - Demand driven (exogenous) in physical units
  - Price-elasticities for end-use demands
- Partial and dynamic equilibrium (perfect market)
- Optimal technology selection
- Objective-function: Maximizes net social surplus
- Environmental constraints (GHG emission limits)
- Energy and emission permits trading
TIMES models in summary

**Economic**
- End-use demands
- Demand elasticities
- Crude oil price
- Reserve supply curves
- Other parameters
  - Discount rate
  - Time period
  - Time slices

**Technology database**
- Techno-economic attributes

**Environmental**
- Bounds
- Taxes, subsidies
- Sectors’ measures

**Equilibrium**
- Technology investments and annual activities
- Emission trajectories
- Adjusted demands for energy services
- Marginal prices of energy forms
- Imports/exports of energy and emission permits
- Total discounted system cost

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TIMES
TIMES-Canada

Regions: 13 provinces and territories

Base year: 2007
Horizon: 2050 (energy)
Horizon: 2100 (climate)

<table>
<thead>
<tr>
<th>Start</th>
<th>Mid</th>
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<th>Length</th>
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</tr>
<tr>
<td>10</td>
<td>2048</td>
<td>2050</td>
<td>2052</td>
</tr>
</tbody>
</table>

Time slices
- 4 seasons: Spring, Summer, Fall, Winter
- 3 day periods: Day, Night, Peak
Transportation sector RES

- **Road**
  - Gasoline
  - Diesel
  - Natural Gas Liquids
  - Natural Gas
  - Electricity (battery)
  - Ethanol
  - Biodiesel
  - Methanol
  - Biodimethyleter
  - Aviation Gasoline
  - Aviation Turbo Fuel
  - Heavy Fuel Oil
  - Gasoline
  - Diesel
  - Natural Gas
  - Electricity (battery)
  - Ethanol
  - Biodiesel
  - Methanol
  - Biodimethyleter
  - Aviation Gasoline
  - Aviation Turbo Fuel
  - Heavy Fuel Oil

- **Rail**
  - Passenger, Small cars
  - Passenger, Large cars
  - Passenger, Light trucks
  - Freight, Light trucks
  - Passenger, Urban buses
  - Passenger, Intercity buses
  - Passenger, School buses
  - Passenger, Motos
  - Passenger, Off road
  - Passenger, Trains
  - Freight, Trains
  - Passenger, Airplanes
  - Freight, Airplanes
  - All, Ships

- **Air**
  - Passenger, Small cars
  - Passenger, Large cars
  - Passenger, Light trucks
  - Freight, Light trucks
  - Passenger, Urban buses
  - Passenger, Intercity buses
  - Passenger, School buses
  - Passenger, Motos
  - Passenger, Off road
  - Passenger, Trains
  - Freight, Trains
  - Passenger, Airplanes
  - Freight, Airplanes
  - All, Ships

- **Marine**
  - Passenger, Small cars
  - Passenger, Large cars
  - Passenger, Light trucks
  - Freight, Light trucks
  - Passenger, Urban buses
  - Passenger, Intercity buses
  - Passenger, School buses
  - Passenger, Motos
  - Passenger, Off road
  - Passenger, Trains
  - Freight, Trains
  - Passenger, Airplanes
  - Freight, Airplanes
  - All, Ships
Transportation sector RES

Passenger, Small cars, ICE, Gasoline, CAFÉ Std.
Passenger, Small cars, ICE, Gasoline, CAFÉ 3.5 MPG.
Passenger, Small cars, ICE, Gasoline, CAFÉ 7.0 MPG.
Passenger, Small cars, ICE, Diesel, CAFÉ Std.
Passenger, Small cars, ICE, Diesel, CAFÉ 3.5 MPG.
Passenger, Small cars, ICE, Diesel, CAFÉ 7.0 MPG.
Passenger, Small cars, ICE, Natural gas liquids, Std.
Passenger, Small cars, ICE, Natural gas, Std.
Passenger, Small cars, HEV, Gasoline Hybrid, Std.
Passenger, Small cars, HEV, Diesel Hybrid, Std.
Passenger, Small cars, Fuel Cell, H2 Gas.
Passenger, Small cars, Fuel Cell, H2 Liquid.
Passenger, Small cars, ICE, H2 Gas.
Passenger, Small cars, ICE, H2 Liquid.

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GERAD
Transportation sector RES for transportation sector

Focus on electric road transport

Charging stations infrastructure

Electricity (battery)

Passenger, Small cars, BEV70, Lead Acid
Passenger, Small cars, BEV70, Li-Ion
Passenger, Small cars, BEV70, NiMH
Passenger, Small cars, BEV150, Li-Ion
Passenger, Small cars, BEV200, Li-Ion
Passenger, Small cars, BEV300, Li-Ion
Passenger, Small cars, PHEV20, NiMH
Passenger, Small cars, PHEV20, Li-Ion
Passenger, Small cars, PHEV50, NiMH
Passenger, Small cars, PHEV50, Li-Ion
Passenger, Small cars, PHEV100, Li-Ion
Passenger, Small cars, PHEV200, Li-Ion

Plug-in hybrid

Passenger, Small cars, PHEV20, NiMH
Passenger, Small cars, PHEV20, Li-Ion
Passenger, Small cars, PHEV50, NiMH
Passenger, Small cars, PHEV50, Li-Ion
Passenger, Small cars, PHEV100, Li-Ion
Passenger, Small cars, PHEV200, Li-Ion

Gasoline

Passenger, Small cars, BEV70, Lead Acid
Passenger, Small cars, BEV70, Li-Ion
Passenger, Small cars, BEV70, NiMH
Passenger, Small cars, BEV150, Li-Ion
Passenger, Small cars, BEV200, Li-Ion
Passenger, Small cars, BEV300, Li-Ion
Passenger, Small cars, PHEV20, NiMH
Passenger, Small cars, PHEV20, Li-Ion
Passenger, Small cars, PHEV50, NiMH
Passenger, Small cars, PHEV50, Li-Ion
Passenger, Small cars, PHEV100, Li-Ion
Passenger, Small cars, PHEV200, Li-Ion

Diesel

Passenger, Small cars, BEV70, Lead Acid
Passenger, Small cars, BEV70, Li-Ion
Passenger, Small cars, BEV70, NiMH
Passenger, Small cars, BEV150, Li-Ion
Passenger, Small cars, BEV200, Li-Ion
Passenger, Small cars, BEV300, Li-Ion
Passenger, Small cars, PHEV20, NiMH
Passenger, Small cars, PHEV20, Li-Ion
Passenger, Small cars, PHEV50, NiMH
Passenger, Small cars, PHEV50, Li-Ion
Passenger, Small cars, PHEV100, Li-Ion
Passenger, Small cars, PHEV200, Li-Ion

Electric

Plug-in hybrid

Gasoline

Diesel
Electric vehicles characteristics

- BEVs & PHEVs
- End-use demand
- Electric range (km)
- Battery (Lead-Acid, NiMH, Li-Ion)
Small passenger cars

Small BEV – 50 (Li-ion)
Capital costs
2012: 36,558 $
2050: 12,328 $
Battery capacity:
2012: 25.17 kWh
2050: 13.43 kWh

Example: Mitsubishi i-Miev
(range: 150 km, battery: 16 kWh, capital cost: 33,000$)
# Small passenger cars (18)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Battery (start year)</th>
<th>Fuel</th>
<th>Capital cost ($/technology)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Start year</td>
<td>2050</td>
</tr>
<tr>
<td><strong>BEV – 70</strong></td>
<td>Lead (2008)</td>
<td>ELC</td>
<td>14,730</td>
<td>8,749</td>
</tr>
<tr>
<td></td>
<td>NiMH (2008)</td>
<td></td>
<td>17,314</td>
<td>9,849</td>
</tr>
<tr>
<td></td>
<td>Li-Ion (2010)</td>
<td></td>
<td>22,834</td>
<td>7,000</td>
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<tr>
<td><strong>BEV – 150</strong></td>
<td>Li-Ion (2012)</td>
<td>ELC</td>
<td>36,558</td>
<td>12,328</td>
</tr>
<tr>
<td><strong>BEV – 200</strong></td>
<td>Li-Ion (2014)</td>
<td>ELC</td>
<td>45,136</td>
<td>17,784</td>
</tr>
<tr>
<td><strong>BEV – 300</strong></td>
<td>Li-Ion (2016)</td>
<td>ELC</td>
<td>62,290</td>
<td>26,394</td>
</tr>
<tr>
<td><strong>PHEV – 20</strong></td>
<td>NiMH (2008)</td>
<td>ELC &amp; GSL / ELC &amp; DST</td>
<td>19,105 / 20,355</td>
<td>9,713 / 10,022</td>
</tr>
<tr>
<td></td>
<td>Li-Ion (2010)</td>
<td>ELC &amp; GSL / ELC &amp; DST</td>
<td>19,731 / 20,981</td>
<td>9,068 / 9,377</td>
</tr>
<tr>
<td><strong>PHEV – 50</strong></td>
<td>NiMH (2010)</td>
<td>ELC &amp; GSL / ELC &amp; DST</td>
<td>36,608 / 37,788</td>
<td>18,979 / 19,560</td>
</tr>
<tr>
<td></td>
<td>Li-Ion (2012)</td>
<td>ELC &amp; GSL / ELC &amp; DST</td>
<td>38,378 / 39,558</td>
<td>17,446 / 18,040</td>
</tr>
<tr>
<td><strong>PHEV – 100</strong></td>
<td>Li-Ion (2014)</td>
<td>ELC &amp; GSL / ELC &amp; DST</td>
<td>68,415 / 70,518</td>
<td>32,524 / 33,603</td>
</tr>
<tr>
<td><strong>PHEV – 200</strong></td>
<td>Li-Ion (2016)</td>
<td>ELC &amp; GSL / ELC &amp; DST</td>
<td>128,489 / 132,439</td>
<td>63,205 / 65,273</td>
</tr>
</tbody>
</table>
Battery modelling

**Cost evolution**

**Energy efficiency evolution**

- Li-Ion ROPT
- Li-Ion OPT
- Li-Ion PESS
- Li-Ion really RPESS
- NiMH
- Lead-Acid
Charging stations locations

Residential

Commercial

Public station
Chargers level

**Level 1**
- Level 1.1
  - 1.2 KW
  - 50 min/kWh
- Level 1.2
  - 1.6 KW
  - 40 min/kWh

**Level 2**
- 6.5 KW
  - 10 min/kWh

**Level 3 – fast charger**
- Level 3.1
  - 30 KW
  - 2.5 min/kWh
- Level 3.2
  - 60 KW
  - 1 min/kWh
# Charging stations

<table>
<thead>
<tr>
<th>Location</th>
<th># of chargers</th>
<th>Level of chargers (kW)</th>
<th>Power of Stations (kW)</th>
<th>Start (yr)</th>
<th>Life (yr)</th>
<th>INVCOST ($/kw)</th>
<th>INVCOST ($ )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Residential</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2012</td>
<td>2025</td>
</tr>
<tr>
<td>Residential</td>
<td>1</td>
<td>1.1</td>
<td>1.2</td>
<td>2012</td>
<td>50</td>
<td>1,030 (1,236)</td>
<td>730 (876)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.2</td>
<td>1.6</td>
<td>2012</td>
<td>50</td>
<td>779 (1,246)</td>
<td>553 (885)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>6.5</td>
<td>2012</td>
<td>50</td>
<td>315 (2,047)</td>
<td>188 (1,222)</td>
</tr>
<tr>
<td><strong>Commercial</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2012</td>
<td>2025</td>
</tr>
<tr>
<td>Commercial</td>
<td>2</td>
<td>2</td>
<td>13</td>
<td>2012</td>
<td>50</td>
<td>441 (5,733)</td>
<td>279 (3,627)</td>
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<tr>
<td></td>
<td>2</td>
<td>3.1</td>
<td>60</td>
<td>2012</td>
<td>50</td>
<td>988 (59,280)</td>
<td>442 (26,520)</td>
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<td></td>
<td>2</td>
<td>3.2</td>
<td>120</td>
<td>2013</td>
<td>50</td>
<td>746 (89,520)</td>
<td>355 (42,600)</td>
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<tr>
<td><strong>Public station</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2010</td>
<td>2013</td>
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<tr>
<td>Public station</td>
<td>2</td>
<td>2</td>
<td>13</td>
<td>2010</td>
<td>50</td>
<td>625 (8,125)</td>
<td>396 (5,135)</td>
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<td></td>
<td>2</td>
<td>3.1</td>
<td>60</td>
<td>2012</td>
<td>50</td>
<td>1,593 (95,580)</td>
<td>713 (42,780)</td>
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<tr>
<td></td>
<td>2</td>
<td>3.2</td>
<td>120</td>
<td>2013</td>
<td>50</td>
<td>545 (65,400)</td>
<td>260 (31,200)</td>
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</tbody>
</table>
Charging time & availability of technologies

- 50 min/kWh: 30%
  - 1.2 KW level 1.1
- 37.5 min/kWh: 50%
  - 1.6 KW level 1.2
- 9.2 min/kWh: 85%
  - 6.5 KW level 2
- 2.4 min/kWh: 97%
  - 30 KW level 3.1
- 1 min/kWh: 99%
  - 60 KW level 3.2
Charging time & availability of technologies

<table>
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<tr>
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<th>SPRING</th>
<th>SUMMER</th>
<th>FALL</th>
<th>WINTER</th>
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<tr>
<td></td>
<td>day</td>
<td>night</td>
<td>peak</td>
<td>day</td>
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<tr>
<td>Commercial and Public</td>
<td>18%</td>
<td>3%</td>
<td>5%</td>
<td>18%</td>
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<tr>
<td>Residential</td>
<td>3%</td>
<td>18%</td>
<td>5%</td>
<td>3%</td>
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Investment in charging stations

Electricity demand TELCBAT1 → Electric vehicles

Charging stations ↔ Electricity production

Generation mix

Bahn, Marcy, Vaillancourt, Waaub

GERAD
Baseline scenario

End-use demands for passenger transportation, 2007-2050, per category
Baseline scenario

End-use demands for freight transportation, 2007-2050, per category
Climate policy scenario

<table>
<thead>
<tr>
<th>Province</th>
<th>Reference year</th>
<th>Target for 2020</th>
<th>Target for 2050</th>
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<tr>
<td>Alberta</td>
<td>2005</td>
<td>5%</td>
<td>14%</td>
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<tr>
<td>British Columbia</td>
<td>2007</td>
<td>33%</td>
<td>50%</td>
</tr>
<tr>
<td>Manitoba</td>
<td>2005</td>
<td>15%</td>
<td>45%</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>1990</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>Newfoundland</td>
<td>1990</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>1990</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>Northwest Territories</td>
<td>2005</td>
<td>17%</td>
<td>50%</td>
</tr>
<tr>
<td>Nunavut</td>
<td>2005</td>
<td>17%</td>
<td>50%</td>
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<tr>
<td>Ontario</td>
<td>1990</td>
<td>15%</td>
<td>30%</td>
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<tr>
<td>Prince Edward Island</td>
<td>1990</td>
<td>10%</td>
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<tr>
<td>Quebec</td>
<td>1990</td>
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<td>Saskatchewan</td>
<td>2006</td>
<td>20%</td>
<td>40%</td>
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<tr>
<td>Yukon</td>
<td>2005</td>
<td>17%</td>
<td>50%</td>
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## Energy policy scenario

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<th>Year</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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<td>EV’s penetration target</td>
<td>5%</td>
<td>18%</td>
<td>31%</td>
<td>44%</td>
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</table>
Final energy consumption

By sector, for the baseline scenario

By sector for the baseline, climate policy and energy policy scenarios
Final energy consumption

By source, for the baseline scenario

By source for the baseline, climate policy and energy policy scenarios
Final energy consumption for transportation

By source, for the baseline scenario

By source for the baseline, climate policy and energy policy scenarios
GHG emissions

Canadian GHG emissions in our three scenarios

![Graph showing GHG emissions over time for different scenarios (BAU, CLIM, EVP) with data points for years 2007 to 2050.](image-url)
GHG emissions

GHG reductions by province and sector in the climate policy scenario, 2050
Impacts on the road transportation sector

Penetration of passenger vehicles in the climate policy scenario
Impacts on the road transportation sector

Penetration of freight vehicles in the climate policy scenario

- Penetration of freight vehicles in the climate policy scenario


- M Tkm

- Penetration of freight vehicles in the climate policy scenario

ICV + fossils fuels
ICV + biofuels
HEV
PHEV
BEV
ICV & FCV + Hydrogen

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Impacts on the road transportation sector

Penetration of passenger vehicles in the energy policy scenario
Electricity generation

By type, for the baseline scenario

By type for the baseline, climate policy and energy policy scenarios
Sensitivity analysis

- Hydrogen
- Natural gas and NGL
- Gasoline
- Electricity
- Diesel
- Biofuels

Scenarios
- BAU scenarios 2050
- CLIM scenarios 2050
- EVP scenarios 2050
Conclusion

- TIMES-Canada has been used to analyze the impacts of climate and energy policies on the Canadian road transportation sector
- The energy policy yields results rather similar to the baseline
- Only the climate policy yields significantly different results, in particular in terms of GHG emission reduction
- The transportation sector contributes significantly to the GHG reduction effort imposed by the climate policy
- Within this sector, the use of biofuels can be seen as a transition phase before EVs become competitive (from 2030)