Winter Performance of Electric Vehicles in Canada: A Life Cycle Assessment of GHG Emissions Under Canadian Climate Conditions

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Abstract. Although Battery Electric Vehicles (EVs) will be a part of the reduction plan for transport emissions in Canada, their cold-weather driving performance has raised questions about whether they are still more environmentally friendly than traditional gasoline and diesel cars in Canada's colder regions. A Life Cycle Assessment (LCA) of cumulative greenhouse gas (GHG) emissions for a representative mid-sized electric vehicle (EV) and a mid-sized gasoline internal combustion engine (ICE) vehicle is presented here, which considers both embodied manufacturing emissions and operational emissions under a winter efficiency penalty calibrated using real-world Canadian data. Three typical provinces have been selected for analysis to represent the full range of grid carbon intensity in Canada (Quebec, Ontario, and Alberta). The two seasonal scenarios are an all-winter worst-case and a four-season blended case. The ecological breakeven distances in Quebec and Ontario are about 46,100-51,900 km, and in Alberta, due to different emission factors of the provincial grids, they reach as high as 166,100-212,900 km. The EV's ecological advantage is available in all three provinces but is not yet realised in the high-carbon grid areas. A ±30% sensitivity analysis shows that the provincial electricity emission factor and battery carbon intensity are the main uncertainty drivers. The results support the deployment of electric vehicles as a national climate strategy and indicate that grid decarbonisation in high-carbon grid provinces, such as Alberta, is also required to complement this.

Keywords: Electric vehicle, Life Cycle Assessment, greenhouse gas emissions, cold-weather efficiency, Canada, grid decarbonisation.

1. Introduction

1.1. Transportation Emissions and the Role of Light Vehicles in Canada

Transport accounts for one of the highest proportions of greenhouse gas (GHG) emissions in Canada at 22% annually. This is the same as 156 megatonnes of CO_2-equivalent (CO_2-eq.) in 2022 [1]. Among light-duty vehicles (LDVs) in the transportation sector, passenger cars are by far the largest.

Electric vehicles (EVs) have been introduced in the decarbonisation of LDV transportation to address this problem by replacing internal combustion engines (ICEs) with electric drives. Electric vehicles do not have direct emissions and reduce GHG emissions significantly. According to the Government of Canada's Electric Vehicle Availability Standard, all new passenger car and light truck sales must be zero-emission vehicles by 2035, and they will take the lead in emission reductions [2].

Although they have the potential to be introduced in Canada, Li-ion battery performance is negatively affected by low-temperature conditions, leading to a higher electricity consumption per kilometre and a reduced driving range. The two reasons for this drop are as follows. First, at low temperatures, the ionic conductivity of the battery electrolyte is reduced, and the resistance to charge transfer at the electrode interface increases; thus, the rate of lithium-ion intercalation is limited, and the usable energy output of the battery under a certain power demand significantly drops [3, 4]. Secondly, as ICE vehicles can be used to warm the cabin by diverting engine waste heat without extra fuel consumption, EVs have to draw power directly from the traction battery to heat both the passenger compartment and the battery pack. At -7°C, this auxiliary heating demand will be relatively large, adding 10-20 kWh per 100km above warm-weather consumption [3].

The combined effect of these mechanisms increases electricity consumption by 30–53% at sub-zero temperatures relative to a 23°C baseline, and reduces driving range by 14–39% [3-6]. Conventional ICE vehicles are also affected by cold weather — denser cold air, higher lubricant viscosity, and longer engine warm-up times increase fuel consumption by approximately 12–28% in winter conditions compared to summer baselines [6]. Nonetheless, the magnitude of the cold-weather penalty is generally larger for EVs than for ICE vehicles.

Although the ecological advantages of electric vehicles over internal-combustion engines are well-known in mild operating conditions, it has not been determined whether these advantages will be maintained under the cold climate in Canada across all ranges of Canadian provincial electricity grids. The gap in the above study will be addressed by an LCA. Existing LCA research has shown that EVs generally have lower life-cycle emissions than ICE vehicles in mild climates [7-9]; this paper extends this work by adding Canadian winter conditions.

1.2. Hypothesis and Research Approach Overview

It is assumed that although battery electric vehicles have a higher electricity consumption in winter, they still have a net environmental advantage over conventional internal combustion engine vehicles in Canada in terms of reduced cumulative lifetime CO_2-eq. emissions across a representative set of provincial electricity grids.

The following is the research content. Section 2 sets up the LCA framework and system boundaries. Section 3 documents the input data and assumptions. Section 4 shows the emissions calculations. Section 5 reports the break-even point and graph. Section 6 presents the results of the provinces. Section 7 presents the sensitivity analysis. Section 8 concludes.

2. Background Information

2.1. Life Cycle Assessment Framework

All Greenhouse Gas (GHG) emissions at different times in the life cycle of a product, such as production and use, will be quantified by means of a Life Cycle Assessment (LCA) in this study. Typically, the two main stages of the life cycle assessment for vehicles are as follows:

Phase 1: Embodied carbon (manufacturing phase) — CO_2eq. emissions associated with producing the vehicle, including raw material extraction, component manufacturing (notably battery production for EVs), and final assembly.

Phase 2: Operational carbon (operating phase) — CO_2eq. emissions generated during vehicle operation, determined by fuel or electricity consumption per kilometre multiplied by the appropriate emission factor.

Total lifecycle emissions are modelled as a linear function with respect to distance driven:

$$E_{tot} = E_{em} + (E_{op} \times distance) \quad (1)$$

where E_{tot} is the cumulative CO_2eq. (in tonnes) at a given mileage, E_{em} is the embodied carbon at time of manufacture (tonnes CO_2eq.), and E_{op} is the operational emission rate (g CO_2eq./km). The ecological breakeven point is the distance at which the EV's cumulative emissions curve intersects the ICE vehicle's cumulative emissions curve.

2.2. System Boundary and Scope

This study adopts a cradle-to-grave system boundary covering (1) vehicle manufacturing, including battery production for EVs; and (2) operational emissions from fuel combustion or electricity consumption during driving.

The following components are explicitly excluded and the rationale provided. Fuel production (well-to-tank) for gasoline is excluded — combustion emissions at the tailpipe (Section 4.1) are used directly; including upstream refinery emissions would increase ICE emissions by approximately 20–25% [10] and would therefore strengthen, not weaken, the EV advantage. Electricity transmission and distribution losses are excluded because provincial emission factors from ECCC [10] are reported at the point of generation and do not include grid losses (typically 6–8% in Canada); their inclusion would modestly increase EV operational emissions and is flagged as a sensitivity consideration. Vehicle disposal and recycling are excluded due to limited data availability and broadly comparable end-of-life treatment between vehicle types; this is a recognised limitation of the study.

These boundary choices are consistent with comparable LCA studies [8, 9]. The exclusions have mixed directional effects — excluding well-to-tank fuel emissions understates ICE emissions (favouring EVs), while excluding T&D losses understates EV operational emissions (partially offsetting this). Results should be interpreted with both effects in mind.

2.3. Seasonal Scenario Parameters

Two scenarios are used to capture a realistic range of annual driving conditions:

Scenario A (Worst-Case): All driving throughout the year is assumed to happen at winter efficiency levels (−7°C). This is obviously unrealistic, but it provides an upper bound for EV emissions. If EVs still produce lower emissions overall, the hypothesis holds under any plausible conditions.

Scenario B (Four-Season): Annual driving is split into three periods based on Calgary, Alberta climate data [6]. Winter (November to March, 5 months, 42% of annual km), full cold-temperature penalty at −7°C; shoulder season (April to June, 3 months, 25% of annual km), partial penalty of +18%; summer (July to October, 4 months, 33% of annual km), baseline consumption at 23°C.

Under Scenario B, the blended annual operational emission rate for EVs is:

$$E_{op} = 0.42 \times E_{op,winter} + 0.25 \times E_{op,shoulder} + 0.33 \times E_{op,summer} \quad (2)$$

It should be noted that −7°C represents a central estimate only. At temperatures below −20°C, which occur regularly in Alberta, Saskatchewan, and northern regions, efficiency losses are disproportionately larger and are not captured by the single-point assumption used here.

3. Data and Assumptions

3.1. Operational Consumption — Electric Vehicles

The warm-weather baseline electricity consumption for a mid-size EV (comparable to a Tesla Model 3 Long Range) is taken as 26 kWh per 100 km at approximately 23°C. This is consistent with the Natural Resources Canada Fuel Consumption Guide rating for this vehicle class and is corroborated by laboratory and real-world evidence [3, 4]. At −7°C, which is representative of the January daily average temperature in Calgary, Alberta and many other Canadian cities, electricity consumption rises to approximately 40 kWh per 100 km, corresponding to a 36% increase [3, 4]. Published estimates of EV efficiency loss at sub-zero temperatures are summarised in Table 1.

Table 1. Summary of published EV efficiency loss estimates at sub-zero temperatures.

Source	Temperature (°C)	Efficiency Loss (%)	Testing Condition
U.S. DOE [3]	−7 to −18	−25 to −50	Laboratory and fleet review
Zhao et al. [4]	−7	−36 to −40+	Chassis dynamometer, six EVs
Geotab [5]	−10 to 0	−20 to −40	Real-world fleet telematics
NRCan [6]	< 0	−14 to −39	Canadian sub-zero conditions

Based on the reported range, this study adopts the 36% efficiency loss figure from Zhao et al. [4] as the working assumption. This value was selected because the Zhao study drew on chassis-dynamometer testing of multiple EVs at −7°C, which better represents typical mid-size EV behaviour than a single laboratory test vehicle under controlled conditions. The figure is also close to the midpoint of the broader 14–50+% range reported across the cited sources, making it a reasonable central estimate.

3.2. Operational Consumption — ICE Vehicles

A representative mid-size gas-powered sedan is assumed to have a fuel consumption of 9.0 L/100 km in summer. At -7°C in winter, the increase in fuel consumption is about 20%, and it falls within the range of 12-28% reported by NRCan [6]. Therefore, the assumed fuel consumption values for a typical mid-size gas car are 9.0 L/100 km in summer and 10.8 L/100 km in winter.

For the shoulder season, a 10% increase in fuel consumption is assumed; that is, 9.9 L/100 km. This is between the summer baseline and the full winter penalty, so the effect at mild to cool temperatures is relatively small.

3.3. Embodied Carbon

Manufacturing a typical mid-size ICE sedan produces approximately 7.0 tonnes CO_2eq. [8]. For EVs, manufacturing emissions are higher due to the battery. A 75 kWh NMC lithium-ion battery pack produced using a global mixed-energy grid emits approximately 155 kg CO_2eq. per kWh of capacity [9, 11]. For a 75 kWh pack, the calculation is as follows.

$$E_{\mathrm{battery}} = 75\ \mathrm{kWh} \times 155\ \mathrm{kg\ CO_2eq./kWh} \times 10^{-3} = 11.6\ \mathrm{t\ CO_2eq.}$$

The non-battery portion of the EV (body, chassis, motor, and electronics) produces about 7.0 tonnes of CO_2eq. during manufacturing, which is slightly above that of an ICE vehicle, primarily due to higher aluminium content. Total embodied carbon for the EV is therefore as follows.

$$E_{\mathrm{em,EV}} = 7.0\ \mathrm{t\ CO_2eq.} + 11.6\ \mathrm{t\ CO_2eq.} = 18.6\ \mathrm{t\ CO_2eq.}$$

where 7.0 t CO_2eq. is the estimated carbon emission in the non-battery portion production, and 11.6 t CO_2eq. is the emission during battery production. Table 2 summarises the embodied-carbon breakdown for both vehicle types.

Table 2. Estimated embodied CO_2eq. by vehicle component. Battery footprint calculated at 155 kg CO_2eq./kWh for a 75 kWh pack.

Component	EV (t CO_2eq.)	ICE Vehicle (t CO_2eq.)	Source
Glider (body, chassis, electronics)	~7.0	~7.1	[8]
Battery pack (75 kWh NMC)	~11.6	N/A	[9, 11]
Total	**~18.6**	**~7.1**	—

4. Emissions Calculations

4.1. Gasoline Emission Factor

The GHG emissions of an ICE vehicle per kilometre are calculated as follows.

$$E_{op} = (L\ /\ 100\ km) \times EF\ /\ 100 \tag{3}$$

where *EF* is the total CO_2eq. emission factor for motor gasoline. According to ECCC [10], burning one litre of gasoline releases the following emissions.

$$CO_2\text{: } 2{,}307\ \mathrm{g/L}$$

$$CH_4\text{: } 0.10\ \mathrm{g/L} \times \mathrm{GWP}(28) = 2.8\ \mathrm{g\ CO_2eq./L}$$

$$N_2O\text{: } 0.02\ \mathrm{g/L} \times \mathrm{GWP}(265) = 5.3\ \mathrm{g\ CO_2eq./L}$$

$$\mathrm{Total\ EF} = 2{,}307 + 2.8 + 5.3 = 2{,}315.1\ \mathrm{g\ CO_2eq./L}$$

Applying this to the two ICE scenarios yields the following.

$$E_{\mathrm{op,summer}} = 9.0\ \mathrm{L/100\ km} \times 2{,}315.1\ \mathrm{g/L}\ /\ 100 = 208.4\ \mathrm{g\ CO_2eq./km}$$

$$E_{\mathrm{op,winter}} = 10.8\ \mathrm{L/100\ km} \times 2{,}315.1\ \mathrm{g/L}\ /\ 100 = 250.0\ \mathrm{g\ CO_2eq./km}$$

4.2. Electricity Emission Factors by Province

The GHG emissions of an EV per kilometre are calculated as follows.

$$E_{op,EV} = (kWh / 100\ km) \times EF_{electricity} / 100 \quad (4)$$

where $EF_{electricity}$ is the provincial electricity emission factor with the unit of g CO_2eq./kWh. Since each province generates electricity from a different mix of sources, this value varies enormously across Canada, from near-zero in Quebec to very high in provinces that rely on fossil fuels. Table 3 lists the values used in this study, taken from ECCC [10] and NRCan [6].

Table 3. Provincial electricity emission factors (g CO_2eq./kWh) used in this study.

Province	EF (g CO_2eq./kWh)	Primary Generation Source
Quebec	1.7	Hydroelectric (~99%)
British Columbia	14	Hydro and wind
Manitoba	3	Hydroelectric (~97%)
Ontario	29	Nuclear, hydro, gas
Saskatchewan	680	Natural gas and coal
Alberta	490	Natural gas and coal
Nova Scotia	620	Coal and natural gas
Nunavut	840	Diesel generation

These emission factors reflect 2025 grid conditions and are treated as static throughout. Over a 10–15 year vehicle lifetime, provincial grids, particularly Alberta, are expected to decarbonise, meaning the breakeven distances calculated here are likely overestimates for vehicles purchased today.

While emission factors are listed for eight provinces (Table 3), the breakeven analysis in Section 5 focuses on three representative provinces — Quebec, Ontario, and Alberta. These three provinces were selected to represent the full range of Canada's electricity grid carbon intensity, from the cleanest (Quebec, 1.7 g CO_2eq./kWh, nearly 100% hydroelectric) to a mid-range mixed grid (Ontario, 29 g CO_2eq./kWh, predominantly nuclear and hydro) to one of the highest-emission grids in the country (Alberta, 490 g CO_2eq./kWh, natural gas and coal). Together, they represent the best-case, middle-case, and near-worst-case outcomes for EV lifecycle emissions in Canada.

4.3. Operational CO_2eq.

Combining the gasoline emission factor of Section 4.1 with the provincial electricity emission factors of Section 4.2 gives the operational emissions per kilometre, summarised in Table 4 for both summer and winter conditions.

Table 4. Calculated operational CO_2eq. per km by vehicle type, province, and season.

Vehicle / Province	EF or Fuel Factor	Energy Use	CO_2eq./km (summer)	CO_2eq./km (winter)
ICE vehicle (gasoline)	2,315 g/L	9.0 / 10.8 L/100km	208.4 g/km	250.0 g/km
EV — Quebec (1.7 g/kWh)	1.7 g CO_2eq./kWh	26 / 40 kWh/100km	0.44 g/km	0.68 g/km
EV — Ontario (29 g/kWh)	29 g CO_2eq./kWh	26 / 40 kWh/100km	7.54 g/km	11.60 g/km
EV — Alberta (490 g/kWh)	490 g CO_2eq./kWh	26 / 40 kWh/100km	127.4 g/km	196.0 g/km

Table 4 shows the calculated operational CO_2eq. emissions per km for each vehicle type and province, under both warm and cold conditions. In all provinces, EV operational emissions are substantially lower than ICE emissions in summer. In winter, the gap narrows most dramatically in Alberta (127.4 vs. 196.0 g/km EV, compared to 250.0 g/km ICE), underscoring the grid-dependence of EV benefits.

4.4. Annual Emission Rates

Applying the Scenario B seasonal weighting defined in Section 2.3, the blended annual operational emission rate is calculated for each province. Using Ontario as an example, the calculation is as follows.

$$E_{\text{op,shoulder}} = 26 \times (1 + 0.18) \times 29 / 100 = 8.90 \text{ g } CO_2\text{eq./km}$$

$$E_{\text{op,winter}} = 40 \times 29 / 100 = 11.60 \text{ g } CO_2\text{eq./km}$$

$$E_{\text{op,summer}} = 26 \times 29 / 100 = 7.54 \text{ g } CO_2\text{eq./km}$$

$$E_{\text{op,tot,ON}} = (0.42 \times 11.60) + (0.25 \times 8.90) + (0.33 \times 7.54) = 9.59 \text{ g } CO_2\text{eq./km}$$

Table 5. Total annual operational emission rates (g CO_2eq./km) under Scenario B, calculated using the seasonal distribution (42% winter / 25% shoulder / 33% summer) derived from Calgary, Alberta climate data.

Province / Vehicle	$E_{\text{op,summer}}$ (g/km)	$E_{\text{op,shoulder}}$ (g/km)	$E_{\text{op,winter}}$ (g/km)	$E_{\text{op,scenario B}}$ (g/km)
ICE vehicle	208.4	229.2	250.0	231.1
EV — Quebec	0.44	0.52	0.68	0.56
EV — Ontario	7.54	8.90	11.60	9.59
EV — Alberta	127.4	150.3	196.0	161.9

Based on Table 5, even under the four-season blended rate, EV emissions remain well below ICE emissions in Quebec and Ontario. In Alberta, the gap narrows substantially; the blended EV rate of 161.9 g/km is only 69.2 g/km below the ICE rate of 231.1 g/km, compared to a gap of over 200 g/km in Quebec.

5. Results

5.1. Breakeven Distance Calculations

The breakeven distance D_{BE} is the point at which the EV's total lifetime emissions equal those of the ICE vehicle, and is calculated using equation (5).

$$E_{em,EV} + E_{op,EV} \times D_{BE} = E_{em,ICE} + E_{op,ICE} \times D_{BE}$$

$$D_{BE} = \frac{E_{em,EV} - E_{em,ICE}}{E_{op,ICE} - E_{op,EV}} \tag{5}$$

Plugging in the embodied carbon values (EV = 18.6 t, ICE = 7.1 t, difference = 11.5 t) and the operational rates from Tables 4 and 5 yields the breakeven distances summarised in Table 6.

Table 6. Calculated ecological breakeven distances (km) by province and scenario. ΔE_OP = ICE operational rate minus EV operational rate (g CO_2eq./km).

Province	ΔE_{OP} (summer)	ΔE_{OP} (winter)	D_{BE} Scenario A (km)	D_{BE} Scenario B (km)
Quebec (1.7 g/kWh)	207.96	249.32	≈46,100	≈49,800
Ontario (29 g/kWh)	200.86	238.40	≈48,200	≈51,900
Alberta (490 g/kWh)	81.0	54.0	≈212,900	≈166,100

As shown in Table 6, there is a large difference in the range of the breakeven distance — about 46,100-51,900 km in Quebec and 166,100-212,900 km in Alberta. The Alberta range is about four to five times larger than that of Quebec and Ontario. Breakeven has been achieved relatively early in Quebec and Ontario, well within a typical vehicle lifetime of around 250,000-300,000 kilometres; however, under Scenario A in Alberta, the breakeven point is approximately 213,000 km, which is close to the upper end of the service life for cars and may not realise the benefits of EVs until later in their life given the current grid situation. Therefore, if the emission factor of the Alberta grid is higher than assumed (e.g., due to estimation uncertainty), the benefits of electric vehicles will be delayed and reduced compared with those in provinces with cleaner grids, but will still occur in both scenarios modelled. For example, if the provincial EF were 600 g CO_2eq./kWh instead of 490, DBE under Scenario A would exceed 300,000 km.

5.2. Graphical Analysis

Fig. 1 plots cumulative lifecycle CO_2eq. emissions for EVs and ICE vehicles as a function of distance driven, for Quebec (Fig. 1(a)), Ontario (Fig. 1(b)), and Alberta (Fig. 1(c)). The figure shows both Scenario A (all-winter, worst case) and summer-only conditions for each province. The orange dot marks the ecological breakeven point.

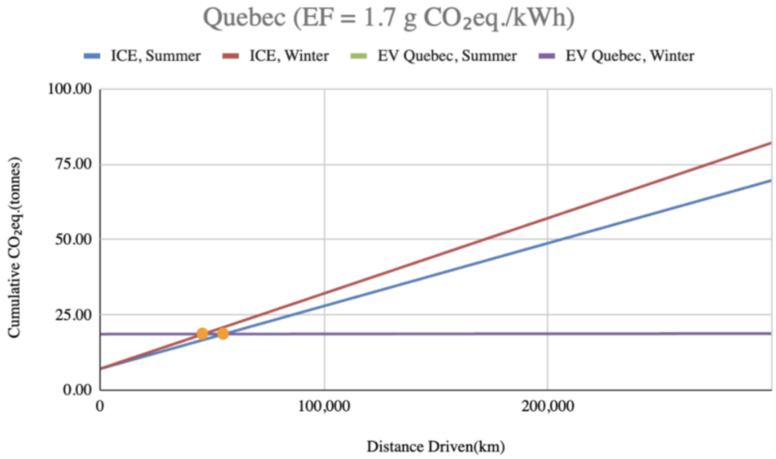

Fig. 1(a) Cumulative lifetime CO_2eq. emissions (tonnes) for a mid-size EV vs. ICE vehicle in Quebec (EF = 1.7 g CO_2eq./kWh). The orange dot marks the ecological breakeven point.

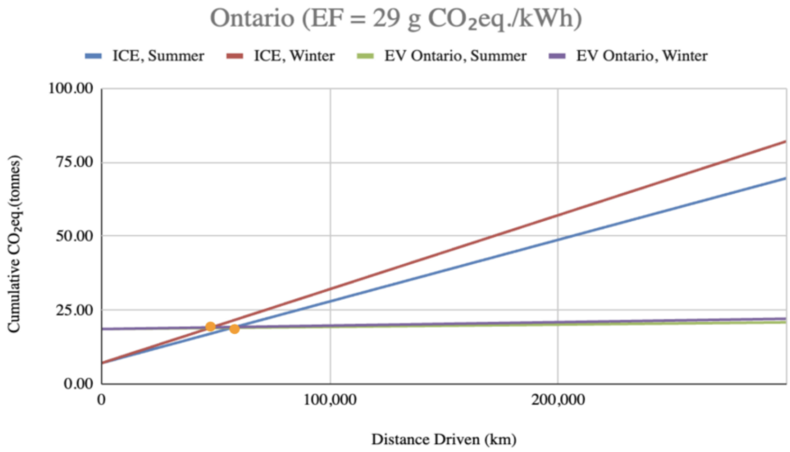

Fig. 1(b) Cumulative lifetime CO_2eq. emissions (tonnes) for a mid-size EV vs. ICE vehicle in Ontario (EF = 29 g CO_2eq./kWh). The orange dot marks the ecological breakeven point.

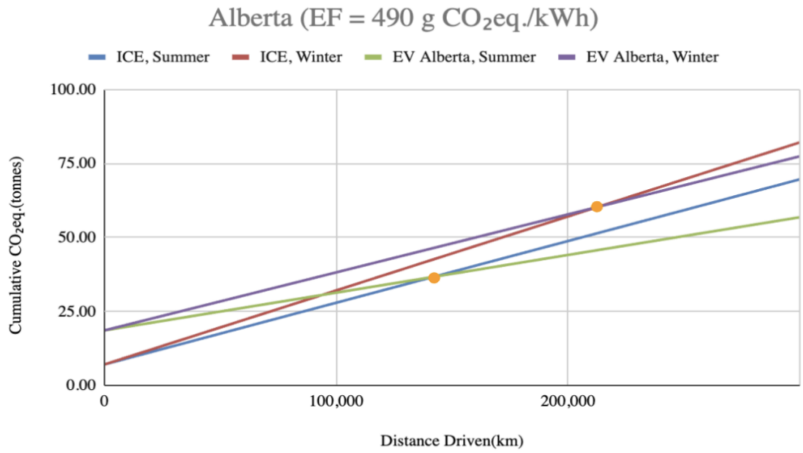

Fig. 1(c) Cumulative lifetime CO_2eq. emissions (tonnes) for a mid-size EV vs. ICE vehicle in Alberta (EF = 490 g CO_2eq./kWh). The orange dot marks the ecological breakeven point.

As shown in the figure, the provinces have different structures. Quebec and Ontario have low break-even points for EVs versus ICE vehicles, and because of their near-zero per-km emissions, EVs build up emissions much more slowly. In Alberta, the two curves are much closer together; it has a high grid emission factor, and the Scenario A (all-winter) EV line is almost parallel to the ICE lines, accounting for the very high Scenario A breakeven.

6. Discussion

EVs are leading ICE vehicles in the three representative provinces of Canada. However, the size and timing of the benefit differ significantly, and the break-even distance ranges from about 50,000 kilometres to more than 200,000 kilometres depending on the provincial grid conditions. The above range is a main result. EV benefits in high-carbon grid areas will likely not appear until much later in a vehicle's life under the present circumstances.

6.1. Quebec and Low-Carbon Grid Provinces

Quebec is almost entirely reliant on hydropower for electricity generation; thus, the per-kilometre emission of electric vehicles (0.44-0.68 g CO_2eq./km) is less than 1% of that of internal combustion engine (ICE) vehicles (208-250 g CO_2eq./km). The break-even points are about 46,100 km in Scenario A and around 49,800 km in Scenario B. At a typical driving rate of 15,000-20,000 kilometres per year [6], this payback will be realised in about 3 years. After this point, EVs save approximately 207-208 g CO_2eq. The results are generally in line with published LCA comparisons of low-carbon grids [9], and these also find a breakeven distance of less than 50,000 km. Even in the worst-case scenario, there are still some ecological benefits of electric vehicles, and the break-even point will be reached well before the end of the vehicle's service life. The same results would be expected for British Columbia (EF = 14 g CO_2eq./kWh) and Manitoba (EF = 3 g CO_2eq./kWh).

6.2. Ontario and Mixed-Grid Provinces

Ontario's grid has a high proportion of nuclear and hydroelectric power generation, with an emission factor of 29 g CO_2eq./kWh. EV per-km emissions are as low as 7.54 g/km in summer and up to 11.60 g/km in winter; these are far lower than the 208-250 g CO_2eq./km for ICE vehicles. The break-even points under Scenario A and Scenario B are about 48,200 km and 51,900 km, respectively, which corresponds to roughly 3 years at the normal driving speed. The hypothesis is clearly true for Ontario. The results in Ontario and Quebec are similar; as the grid has a low-carbon intensity, even a relatively large increase in cold-weather electricity consumption (from 26 to 40 kWh/100 km) leads to only a small rise in per-km emissions.

6.3. Alberta and High-Carbon Grid Provinces

Alberta's grid emission factor is 490 g CO_2eq./kWh. When an EV is driven in winter, it emits only 196.0 g CO_2eq./km, which is significantly lower than the 250.0 g CO_2eq./km emitted by a gasoline vehicle in winter. Under Scenario A, DBE is about 212,900 km, which corresponds to about 11 to 14 years of driving at typical rates. This is barely within the normal service life of a car, so the environmental benefits of EVs in areas with high-carbon grids are delayed and reduced compared to those in cleaner areas, although they are still present in both scenarios modelled.

Under Scenario B, the total annual emission rate drops to 161.9 g CO_2eq./km, and D_{BE} falls to approximately 166,100 km, or approximately 8 to 11 years of driving. Over a full vehicle lifetime of 300,000 km, an Alberta EV emits approximately (231.1 − 161.9) g/km × 300,000 km = 20.8 t CO_2eq. less than a gas car, despite its higher embodied carbon.

The hypothesis is therefore supported, but with important caveats. In Alberta, the benefit of EVs is considerably smaller than in cleaner-grid provinces, the breakeven takes longer, and the outcome is more sensitive to assumptions about driving patterns, the efficiency penalty assumed, and the rate at which the Alberta grid decarbonises. Saskatchewan and Nova Scotia would likely show similar or worse outcomes given their grid emission factors. As noted in Section 5.1, even moderate uncertainty in the assumed EF can substantially shift the Alberta breakeven.

7. Sensitivity Analysis

The previous results are based on some central assumptions for the key parameters. Since the conclusions in Alberta are more sensitive to these assumptions, a relatively small range of ±30% is used for four core parameters in a simple sensitivity analysis — battery carbon intensity, winter EV efficiency loss, ICE winter fuel consumption penalty and provincial electricity emission factor. Sensitivity is presented as the change in the break-even point of Scenario A for Alberta under uncertainty. Quebec is also a typical case. The results are shown in Table 7.

Table 7. Effect of ±30% variation in key parameters on Scenario A breakeven distance (km) and reproduced results for Table 6.

Parameter	Central	−30%	+30%	D_{BE} **AB −30%**	D_{BE} **AB +30%**	D_{BE} **QC −30%**	D_{BE} **QC +30%**
Battery (kg CO_2eq./kWh)	155	109	202	~148,800	~277,900	~32,200	~60,200
Winter EV efficiency loss (%)	36%	25.2%	46.8%	~127,300	~182,900	—	—
ICE winter fuel penalty (%)	20%	14%	26%	~277,500	~173,200	~48,700	~44,000
Provincial EF (g CO_2eq./kWh)	490	343	637	~102,100	~269,700	—	—

As shown in Table 7, the breakeven distance for Alberta is relatively sensitive to both the provincial electricity emission factor and battery carbon intensity; the ±30% ranges are about 102,000 to 270,000 km and 149,000 to 278,000 km, respectively.

As shown in the above results, there is a threshold effect — when the Alberta grid EF exceeds approximately 570 g CO_2eq./kWh, the Scenario A breakeven distance approaches or exceeds 250,000 km. This increases the demand for grid decarbonisation due to the spread of electric vehicles. The results also show that battery carbon intensity is also a significant factor; therefore, to lower the breakeven distance across all provinces, the energy for EV manufacturing needs to be low-carbon [11].

8. Conclusion

This paper has calculated the total lifetime greenhouse gas emissions for battery-electric vehicles and conventional gas-powered cars in Canada, and at the same time taken into account the reduced efficiency caused by cold weather during operation in a life cycle assessment. The three representative provinces and the two scenarios were chosen for this study.

The results lead to four main conclusions. First, cold weather imposes a measurable efficiency penalty on EVs — at −7°C, electricity use increases by about 36%, from 26 to 40 kWh/100 km, raising per-km CO_2eq. emissions in all provinces. Second, despite the winter penalty, EVs still outperform gas cars over their lifetime in the majority of Canadian provinces, with breakeven distances of approximately 49,800 km in Quebec, 51,900 km in Ontario, and 166,100 km in Alberta under Scenario B. The hypothesis is supported. Third, the size of the advantage depends heavily on the provincial electricity grid. In low-carbon provinces like Quebec, BC, and Manitoba, lifetime CO_2eq. is reduced by more than 90% compared to a gas car, while in Alberta the reduction is approximately 32–45% depending on the scenario. Fourth, the carbon debt from EV manufacturing must be accounted for, but is repaid relatively quickly in most provinces.

The study has several limitations that constrain interpretation. The system boundary excludes well-to-tank fuel emissions and electricity transmission losses; excluding well-to-tank fuel emissions understates ICE emissions (favouring EVs), while excluding T&D losses understates EV operational emissions. A single temperature point (−7°C) was used to characterise winter conditions; although this is a reasonable central estimate for many Canadian cities, it does not capture the full distribution of temperatures experienced across Canada. The seasonal distribution used in Scenario B is derived from Calgary data and may not be representative of other provinces. Vehicle disposal and recycling are excluded. Future work could address these limitations through more detailed regional analyses incorporating temperature distributions, updated provincial emission factor trajectories, and more granular system boundary treatment. The sensitivity analysis in Section 7 partially addresses parametric uncertainty, but a full Monte Carlo treatment would provide more rigorous uncertainty characterisation.

In short, the above results suggest that electric vehicles will be a feasible climate strategy for Canada in winter. However, the results in Alberta show that the adoption of electric vehicles (EVs) alone is insufficient to reduce carbon emissions from a high-carbon electricity grid; therefore, both policies promoting EV use and those decarbonising the grid need to be implemented simultaneously, and the timing of the benefits for Alberta is closely tied to how rapidly its electricity grid switches to low-carbon power generation.

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