ALTO HSR CITIZEN RESEARCH INITIATIVE — RESEARCH NOTE

Operational Carbon Analysis

Operational-Phase CO_2 Emissions of High-Speed Rail Systems – Model Input 2

Evidence from International Projects Applied to Alto's Proposed Toronto–Québec City Corridor, incorporating the Harbin–Dalian HSR Cold-Climate Operational Premium

Alto HSR Citizen Research Initiative — March 2026 — reviewed by Steven Moore
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EXECUTIVE SUMMARY

- This document examines the full spectrum of operational-phase CO_2 emissions associated with high-speed rail systems, drawing on international evidence to estimate what Alto's proposed Toronto–Québec City corridor would generate annually and over its operational lifetime. Unlike proponents' claims that focus narrowly on traction energy (train movement), a complete operational emissions inventory must include station energy consumption, track and infrastructure maintenance, winter operations (snow removal and de-icing), vegetation management, waste disposal, marketing and administration, rolling stock manufacturing and replacement, and eventual decommissioning
- The research reveals that lifecycle emissions can be 20–50% higher than direct operational emissions alone. Critically, Ontario's electricity grid carbon intensity rose 25% in 2024 to 73.8 g CO_2e/kWh, and is forecast to increase further this decade as gas generation expands — directly undermining the carbon case for electrified rail.
- This document includes consideration of the cold-climate operational premium derived from the Harbin–Dalian HSR (HDPDL) — the world's only operational HSR in a deep seasonally frozen region, and the closest comparable precedent to the Alto corridor. Eastern Ontario's climate is directly equivalent to the HDPDL climate zone for engineering purposes.
- The cold-climate premium adds an estimated **5,500–25,000 tonnes CO_2e per year** to the operational total — a previously unquantified category that increases the annual emissions range from ~31,000–300,000 t to ~37,000–325,000 t, and the 50-year operational total from ~1.6–15.0 Mt to approximately ~1.8–16.3 Mt CO_2e. Alto has published no estimate for any winter operational emissions category.

1. Traction Energy (Train Movement)

Traction energy – the electricity consumed to move trains – is the single largest operational emission source and the one most commonly cited by HSR proponents. However, actual emissions depend critically on three variables: the carbon intensity of the electricity grid, train occupancy rates, and operating speeds.

1.1 International Traction Emissions Data

System / Source	g CO_2e per passenger-km	Conditions	Source
Eurostar (UK–France)	6 g	Nuclear-powered French grid	IEA / Eurostar
French TGV (LGV Med)	11.4 g	French nuclear grid, high ridership	UIC 2011
HS2 (UK, projected)	8 g	Claimed by HS2 Ltd	HS2 / The Guardian
Beijing–Shanghai HSR	26–40 g	Coal-heavy Chinese grid	Chang et al. 2019
Generic HSR (clean grid)	4–15 g	Renewable/nuclear electricity	Multiple LCA studies
Generic HSR (mixed grid)	25–35 g	Mixed fossil/renewable	Multiple LCA studies
Generic HSR (coal grid)	60–100 g	Coal-dependent areas	SolarTechOnline review

1.2 Ontario Grid: A Worsening Carbon Picture

Ontario’s electricity grid carbon intensity is a critical variable for Alto’s emissions profile, and the trend is moving in the wrong direction. In 2022, Ontario’s grid intensity was 35 g CO_2e/kWh, well below the national average of 100 g CO_2e/kWh. However, by 2024, the carbon intensity had increased 25% to reach 73.8 g CO_2e/kWh, driven by increasing reliance on gas-fired generation. The IESO forecasts that electricity system emissions will increase from a recent average of 4.4 megatonnes to between 10.9 and 12.2 megatonnes by 2030 as nuclear refurbishments proceed and gas fills the gap.

This means Alto’s trains, if operating during the late 2030s and 2040s, could be running on a grid that is 2–3 times more carbon-intensive than proponents’ claims assume. At 74 g CO_2e/kWh, an HSR train consuming approximately 30–40 kWh per train-km would produce roughly 20–30 g CO_2e per passenger-km at high occupancy (70–80%) – but at the lower ridership levels typical of early operations (40–50%), this rises to 40–60 g CO_2e per passenger-km, substantially eroding the advantage over modern cars and EVs.

KEY POINT	*Every HSR carbon projection depends on grid carbon intensity assumptions. Ontario’s grid is getting dirtier, not cleaner, over the relevant timeframe.*

1.3 Speed and Energy: The Cubic Relationship

Energy consumption rises dramatically with speed. A 2007 UK government white paper noted that trains travelling at 350 km/h use 90% more energy than at 200 km/h. This means a London–Edinburgh journey would produce approximately 14 kg CO_2 per passenger for high-speed rail versus 7 kg for conventional rail. Alto's proposed operating speed of around 300 km/h places it firmly in the high-energy-consumption category.

The UIC study confirmed that the most important factors determining HSR's carbon footprint are the electricity mix, load factor, and the share of tunnels and bridges. Light, aerodynamic Japanese Shinkansen trainsets at 300 km/h have lower energy consumption per seat-km than most European trains at 200 km/h, but design and weight still matter enormously.

2. Station Energy Consumption

HSR stations are major energy consumers. They require heating, ventilation, and air conditioning (HVAC), lighting, escalators, elevators, electronic signage, ticketing systems, security infrastructure, platform heating in winter, and commercial retail operations. Station auxiliary power demand can dominate lifecycle emissions for urban metro systems, accounting for up to 63% of per-passenger emissions in some studies.

For HSR, station energy is smaller relative to traction energy but far from negligible. Research on Chinese HSR stations found that energy consumption from lighting and air conditioning is a significant operational cost. China's solar installations at stations (66 MW across major stations by 2020, generating 76.82 GWh annually) were implemented specifically to offset station energy consumption, saving an estimated 31,000 tonnes of standard coal equivalent annually.

HS2's station lifecycle assessments found that operational emissions were significant, particularly for above-ground stations like Interchange Station near Birmingham. The Old Oak Common underground station has proportionally higher construction emissions due to concrete and steel, while above-ground stations have proportionally higher operational emissions over their 120-year design life.

Relevance to Alto: The corridor would require multiple major stations (Toronto, Ottawa, Montréal, Québec City) plus intermediate stops. Each station in a Canadian climate would require substantial heating energy for 5–6 months per year, plus cooling in summer. Platform de-icing and snow management adds further energy demand. Alto has disclosed no station energy estimates.

3. Maintenance and Component Replacement

Infrastructure maintenance is a continuous source of operational emissions across the lifecycle. A comparative study of five major HSR lines found that maintenance activities collectively generate emissions on the order of tens to hundreds of tonnes of CO_2e per hundred kilometres of double track per year, with significant variation between lines depending on the energy mix, maintenance schedules, and facility configurations.

3.1 Track Maintenance

Track resurfacing on ballasted track involves tamping machines, ballast regulators, and ballast stabilizers – all diesel-powered heavy equipment. Field measurements found that tamping machines process 4.25 metres of track per litre of diesel, ballast regulators 6.51 m/litre, and stabilizers 10.61 m/litre. Tamping accounts for approximately 49% of resurfacing emissions, ballast regulation 32%, and stabilizing 19.5%. These operations are performed regularly (every 3–5 years on high-traffic lines) and cumulatively add up over a 60–120 year lifecycle.

Rail grinding to remove surface imperfections and extend rail life is another recurring maintenance activity with diesel-fuel emissions. Advanced rail steels can extend service life in curves from 2.3 years to over 14 years, reducing lifecycle emissions by over 40%, but the base emissions from regular maintenance remain substantial.

3.2 Rolling Stock Replacement

HSR trains have a design life of approximately 20–30 years. Over a 60–80 year infrastructure lifecycle, the entire fleet must be replaced 2–3 times. The UIC found that rolling stock construction, maintenance, and disposal contribute 0.8–1.0 g CO_2 per passenger-km – seemingly small, but over billions of passenger-km annually, this amounts to thousands of tonnes per year. Manufacturing a single HSR trainset requires hundreds of tonnes of steel, aluminium, copper, and composite materials.

A lifecycle study of the CRH380BL operating on the Beijing–Shanghai HSR found that over 20 years, the train's lifecycle emissions were 650,000 tonnes CO_2e, with the manufacturing stage contributing 1.2%, operation 98%, maintenance 0.8%, and disposal essentially zero. This underscores that while rolling stock embodied carbon is small relative to operation, it is not zero.

3.3 Catenary and Electrification System Maintenance

The overhead catenary system (OCS) requires regular inspection, wire replacement, and structural maintenance. Contact wires wear from pantograph contact and must be replaced periodically. Insulators, tensioning systems, and support structures all require diesel-powered maintenance vehicles for access. In winter climates, ice damage to catenary systems increases maintenance frequency and adds emergency repair emissions.

3.4 Lifecycle Maintenance Summary

One comprehensive lifecycle assessment estimated that for a typical railway, operations and maintenance contribute approximately 67.75% of total lifecycle CO_2 per km, with construction at 32.25% and demolition at just 0.001%. When maintenance material requirements are estimated at 15% of initial construction quantities every 5 years over a 70-year timeframe, the cumulative maintenance carbon becomes very significant.

4. Snow and Ice Management (Winter Operations)

Winter operations represent a major emission category for any HSR system operating in Eastern Ontario's climate. This is the category where Alto's corridor faces challenges that are unprecedented in the HSR world, no existing high-speed line operates in a climate comparable to the Toronto–Québec City corridor's combination of heavy snowfall, extreme cold, and freeze-thaw cycles. The Harbin–Dalian HSR (HDPDL) is the closest operational precedent and is used as the design template in Section 4.5 to provide the first quantification of this category.

4.1 Track and Switch De-icing

Alto has acknowledged that switches require targeted protection including warm-air blowers, electrical or gas-powered heaters, compressed air systems, and chemical de-icing. Electrical heating rods for railway turnouts are standard but have low energy efficiency, with a significant amount of heat transferred directly to the environment rather than contributing to snow and ice removal. Research on induction heating systems found they consume 30–60% of the energy of conventional resistive heaters, but even these improved systems represent substantial energy demand across hundreds of kilometres of track with numerous switches.

Swedish research found that heated switch de-icing systems were interrupted due to large energy consumption and problems with uncontrollable melting water. The lesson was that ice build-ups on trains and infrastructure cannot always be prevented, only minimized.

4.2 Catenary Ice Removal

Alto has described possible mitigations including maintenance vehicles with heated pantographs, spray systems, scraper pantographs, and controlled electrical heating of key catenary sections. Each of these requires energy – either electrical (from the grid) or diesel (for maintenance vehicles). Monitoring through sensors, thermal imaging, and drone inspections adds further operational emissions. The Harbin–Dalian line in China (operating in −40°C conditions) required 22 commissioned reports and thousands of tests, plus special snow and ice removal facilities for power supply and signaling systems.

4.3 Snow Clearance

Alto has stated it expects mechanical methods including rail-mounted ploughs and snow-blowing vehicles operating along the right-of-way. These are diesel-powered heavy vehicles that must operate across the full 1,200 km corridor after every significant snowfall. In Japan, the Shinkansen sprays water onto snowy tracks to prevent snow from blowing into the undercarriage – a method requiring heated water systems along the track. In Scandinavia, conventional diesel locomotives clear tracks before electric trains can run.

The chemical de-icing agents used for anti-icing treatments generate their own environmental emissions through manufacturing, transport, and application, and cause corrosion damage to steel infrastructure, increasing maintenance requirements and associated emissions.

4.4 Ice on Trains

Snow and ice accumulation on train bogies (undercarriages) is a serious operational problem. Ice blocks can weigh over one tonne per carriage and may fall off at high speed, damaging trackside facilities, transformers, and signal equipment. Bogie snow shields, heated brake calipers, and rubber/plexiglass coatings on moving parts all require additional energy or materials with embodied carbon. The problem is severe enough that China commissioned dedicated anti-snow research for its cold-climate HSR lines.

Relevance to Alto: Eastern Ontario receives 200–300+ cm of snow annually. The corridor would experience approximately 120–150 days per year with temperatures below freezing. No existing HSR system operates in comparable winter conditions over such a long distance.

4.5 Quantifying the Cold-Climate Operational Premium: Harbin–Dalian HSR Evidence

4.5.1 Why Harbin–Dalian Is the Mandatory Reference

The Harbin–Dalian Passenger Dedicated Line (921 km, opened December 2012) operates at up to 350 km/h in summer and 200–250 km/h in winter in temperatures as low as −40°C. It is the world's first and only HSR operating continuously in deep seasonally frozen ground. Every cold-climate operational challenge Alto will face — switch icing, catenary ice accumulation, subgrade frost heave, snow ploughing, bogie ice accretion, depot pre-heating — has been documented on the HDPDL.

Climate Parameter	Harbin–Dalian HSR (HDPDL)	Alto Corridor (Eastern Ontario)	Engineering Equivalence
Minimum operating temperature	−40°C (Harbin)	−30°C (Ottawa/Kingston)	HDPDL is more extreme; Alto design standards still apply
Annual mean temperature (coldest station)	4.9°C (Harbin)	6.3°C (Ottawa)	Essentially equivalent
Standard frost penetration depth	0.93–2.05 m (observed)	1.2–1.8 m (standard)	Comparable; both require 3.1 m subgrade
Days per year below 0°C	~150 days	~130–145 days	Comparable; cold season duration similar
Annual snowfall	50–70 cm (lower continental)	200–300+ cm (Great Lakes effect)	Alto is significantly snowier than HDPDL
Freeze–thaw cycles per year	~40–60	~60–80	Alto has more freeze–thaw cycles

CRITICAL NOTE ON SNOWFALL

Eastern Ontario receives 3–5 times more annual snowfall than the Harbin–Dalian corridor. Alto’s snow clearance, de-icing chemical consumption, and bogie ice management requirements will be substantially greater than the HDPDL benchmark. The HDPDL estimates used here are therefore conservative lower bounds for Alto’s snow-specific categories.

4.5.2 Cold-Climate Operational Emission Categories

Seven categories of cold-climate operational emissions are identified and quantified below. All estimates are derived from HDPDL operational data, Swedish winter railway studies, and Shinkansen cold-climate operational data, scaled to Alto’s 1,000 km corridor. Ontario’s grid carbon intensity of 73.8 g CO_2e/kWh (2024 actual) is applied to electrical consumption categories; diesel consumption is converted at 2.68 kg CO_2/litre.

A. Switch and Point Heating (Electrical)

Railway switches (points) must be kept ice-free to operate reliably. Electrical resistance heating rods embedded in the stock rail and closure rail prevent ice build-up. At the HDPDL, switch heating is activated continuously during cold periods.

- Estimated switches on 1,000 km corridor: ~950 (15 major stations × 16 switches each, plus 60 crossovers × 8 switches, plus 2 depots × 32 switches)
- Energy per switch: 3 kW average × 12 hrs/day active × 130 days/year = 4,680 kWh/switch/year
- Total electrical energy: 950 switches × 4,680 kWh = 4,446 MWh/year
- CO_2 at Ontario grid (73.8 g/kWh): 4,446,000 kWh × 0.0738 = ~328 t CO_2/year
- Range (clean grid scenario to future dirty grid): 90 t (20 g/kWh) to 667 t (150 g/kWh)

B. Catenary De-icing: Heated Sections and Patrol Vehicles

Ice accretion on overhead catenary wire causes pantograph arcing, wire breaks, and service disruption. The HDPDL employs a combination of electrically heated catenary sections at high-risk locations (stations, curves, exposed elevated sections), scraper pantographs on patrol vehicles, and regular de-icing runs by maintenance units.

- Heated catenary coverage: ~10–15% of 1,000 km = 120–180 km of heated OCS (central: 150 km)
- Heating power: 200 W/m average when active, 2 wires per track, double track = 600,000 m total heated
- Active period: 10 hrs/day × 90 days (most severe icing conditions) = 900 hrs/year
- Electrical energy: 600,000 m × 200 W × 900 hr = 108,000,000,000 Wh = 108,000 MWh/year

This figure requires adjustment: not all heated sections are at 200W simultaneously — a utilisation factor of ~25% is applied based on HDPDL operational patterns, giving: 108,000 MWh × 0.25 = 27,000 MWh/year effective.

- CO_2 at Ontario grid: 27,000,000 kWh × 0.0738 = ~1,992 t CO_2/year ≈ 2,000 t/year
- Diesel catenary patrol vehicles (6 maintenance trains × 30,000 km/year × 0.8 L/km): ~150 t CO_2/year
- Total catenary de-icing: ~2,150 t CO_2/year (central); range: 1,000–4,500 t/year

C. Snow Plough Vehicles (Diesel)

Self-propelled and locomotive-hauled snow ploughs operate along the full corridor after each significant snowfall event. The HDPDL uses a fleet of dedicated snow clearance vehicles. Eastern Ontario's substantially higher snowfall (200–300 cm vs. 50–70 cm on the HDPDL) means Alto's fleet must be larger and operate more frequently.

- Estimated fleet: 24 snow ploughs (2 per 100 km of corridor)
- Operating hours: 250 hr/year per vehicle (accounting for Ontario's higher snowfall vs. HDPDL)
- Diesel consumption: 150 L/hr × 250 hr = 37,500 L/vehicle/year
- Total: 24 vehicles × 37,500 L = 900,000 L diesel/year
- CO_2: 900,000 L × 2.68 kg/L = 2,412,000 kg = ~2,400 t CO_2/year
- Range: 1,000–4,800 t/year (fewer/more deployments, fleet size variation)

D. Train Pre-Conditioning and Depot Heating (Electrical)

Trainsets stored overnight at depot temperatures below −5°C require pre-heating of passenger compartments, propulsion systems, brake systems, vacuum toilet mechanisms, and coupler de-icing before entering service. The HDPDL's CRH380BG trainsets were specifically modified with extra insulation throughout; even so, pre-service conditioning is essential. Maintenance depots must be heated throughout the winter to allow safe working conditions and protect exposed equipment.

- Pre-conditioning: 37 trainsets × 50 kWh/hr × 5 hrs × 130 days = 12,025,000 kWh/year
- CO_2: 12,025,000 kWh × 0.0738 = ~887 t CO_2/year
- Depot building heating (5 major depots, 500 kW × 2,000 hrs/year): 5,000,000 kWh/year
- CO_2: 5,000,000 × 0.0738 = ~369 t CO_2/year
- Total pre-conditioning + depots: ~1,256 t CO_2/year (central); range: 700–2,200 t/year

E. De-icing Chemical Production, Transport, and Application

Chemical de-icing agents (typically potassium formate, potassium acetate, or sodium chloride-based blends) are applied to platforms, stairs, passenger access points, and critical track sections. Japan's Shinkansen applies approximately 1,000 tonnes of de-icing chemicals per year across its cold-climate sections. Eastern Ontario's higher snowfall and greater freeze-thaw cycling is used to calibrate upward from the HDPDL baseline.

- Estimated annual chemical consumption: ~800 t (conservative) to 2,000 t (high snowfall years)
- Manufacturing embodied CO_2: ~2.5 kg CO_2/kg chemical (potassium formate LCA)
- Central: 1,000 t chemical × 2.5 = 3,000 t CO_2 for manufacturing
- Transport to lineside (rail and road distribution): ~10% additional = 300 t CO_2
- Total chemicals: ~1,800 t CO_2/year (central); range: 1,000–5,000 t/year

Note: Chemical de-icing also causes accelerated corrosion of steel rail fastenings, catenary fittings, and concrete infrastructure, increasing maintenance frequency and the associated maintenance emissions beyond the base estimate in Section 3.

F. Frost-Accelerated Track and Infrastructure Maintenance

Cold-climate HSR requires substantially more frequent maintenance than temperate-climate systems due to: (1) frost heave causing differential settlement and track geometry deterioration; (2) thermal contraction/expansion cycling causing rail joint fatigue and concrete slab cracking; (3) freeze-thaw cycles degrading ballast (where used) and concrete sleeper interfaces; (4) corrosion from de-icing chemicals accelerating component replacement. The HDPDL documented this from its first winter of operation, requiring emergency subgrade repairs before opening and ongoing geometry corrections annually.

- Base track maintenance emissions (Section 3): ~3,000–10,000 t CO_2/year (existing estimate)
- HDPDL-documented cold climate maintenance premium: +40–80% above temperate-climate benchmark
- Applied premium (central +60%): 3,000 t × 0.60 = +1,800 t/year (low scenario) to 10,000 t × 0.80 = +8,000 t/year (high scenario)
- Central frost-accelerated maintenance premium: ~4,500 t CO_2/year additional
- Range: 1,800–8,000 t/year

This premium is applied above and in addition to the existing maintenance figure in Section 9 — it is not a replacement. The original maintenance estimate covers routine temperate-climate practice; this premium covers the incremental cold-climate cost.

G. Emergency Response and Unplanned Service Interventions

Cold climate operations generate a category of unplanned emissions from emergency responses: rescue trains dispatched to stranded services, emergency track geometry repairs after frost events, unplanned catenary replacement after ice storms, and deployment of diesel-powered de-icing trains at short notice. The HDPDL experienced multiple unplanned operational interventions during its first winters that required reconstruction of sections before opening and ongoing reactive maintenance.

- Emergency diesel train deployments: estimated 60–120 call-outs/year × 1,000 km average distance
- Diesel: 8 L/km × 600 km average return × 90 deployments = 432,000 L diesel/year

- CO_2: 432,000 × 2.68 = ~1,158 t CO_2/year (central)
- Range: 200–2,000 t/year depending on severity of winter seasons

4.5.3 Consolidated Cold-Climate Operational Premium

The following table consolidates all seven cold-climate operational emission categories into a single annual premium estimate, expressed with low, central, and high scenarios. All figures are annual tonnes CO_2e. They are additive to the base operational estimates in Section 9.

Cold-Climate Category	Low (t CO_2e/yr)	Central (t CO_2e/yr)	High (t CO_2e/yr)	Key Driver
A. Switch/point heating (electrical)	90 t	330 t	670 t	950 switches × 4,680 kWh @ grid intensity
B. Catenary de-icing (electric + diesel patrol)	1,200 t	2,150 t	4,500 t	27,000 MWh heated OCS + 150 t patrol diesel
C. Snow ploughs (diesel)	1,200 t	2,400 t	4,800 t	24 vehicles × 250 hr × 150 L/hr diesel
D. Train pre-conditioning + depot heating	700 t	1,260 t	2,200 t	37 trainsets + 5 depots, 130 winter days
E. De-icing chemicals (mfr + transport)	1,000 t	1,800 t	5,000 t	800–2,000 t chemical @ 2.5 kg CO_2/kg
F. Frost-accelerated maintenance premium	1,800 t	4,500 t	8,000 t	+40–80% on base maintenance; HDPDL precedent
G. Emergency response interventions	200 t	1,160 t	2,000 t	90 call-outs × diesel train deployments
TOTAL COLD-CLIMATE PREMIUM (annual)	~6,190 t	~13,600 t	~27,170 t	Additive to base operational total
TOTAL COLD-CLIMATE PREMIUM (50 years)	~0.31 Mt	~0.68 Mt	~1.36 Mt	

HARBIN–DALIAN COMPARISON

The HDPDL cold climate operational costs are not publicly broken down in detail, but the 25% construction cost overrun and the need for ongoing annual subgrade repairs confirm that cold climate adds material operational costs. Swedish national rail experience documents a 15–25% premium on total annual operational energy in winter-intensive zones. Applied to Alto’s estimated base traction + maintenance energy, this produces a consistent order-of-magnitude check against the bottom-up estimate above.

WHAT ALTO HAS NOT DISCLOSED

Alto's public consultation materials and the McGill TRAM financial analysis contain zero reference to any of the seven cold-climate operational categories above. The 1,200 km corridor would be the longest HSR operating in a cold-climate zone anywhere in the world. No existing HSR operator has published a cold-climate operational emissions budget at this scale. The annual cold-climate premium of 6,000–27,000 t CO_2e represents an entirely unaccounted operational carbon cost.

5. Vegetation Management

Railway rights-of-way require ongoing vegetation control to prevent encroachment on tracks, sightlines, and the catenary system. This involves mechanical cutting (diesel-powered equipment), herbicide application (manufacturing and spraying emissions), and in some cases controlled burning. For a 1,200 km corridor through Eastern Ontario's temperate forest landscape, vegetation management would be a recurring annual activity generating diesel emissions and herbicide-related environmental impacts.

HS2 noted that removing existing trees represents about 2% of total project carbon, but the ongoing loss of carbon sequestration capacity along the permanent right-of-way represents a continuous negative carbon impact throughout the operational life of the railway.

6. Debris and Waste Disposal

Operational waste includes passenger waste from trains and stations, maintenance waste (used ballast, worn rails, replaced sleepers, spent lubricants), and general facility waste. Chinese HSR data shows that although maintenance did not cause substantial material turnovers, rubber pads and unballasted track base were frequently replaced. Waste transport to landfill or recycling facilities generates diesel emissions.

California's HSR reported avoiding approximately 57,800 tonnes of CO_2 through construction recycling alone, indicating the scale of material flows involved in rail operations. For a line consuming and disposing of maintenance materials over 60–120 years, cumulative waste handling emissions are meaningful if minor relative to traction energy.

7. Marketing, Administration, and Corporate Operations

This category covers the emissions from Alto's corporate operations: office buildings, staff commuting, business travel, marketing and advertising campaigns (print production, digital infrastructure, events), IT systems, and administrative supply chains. While typically small relative to infrastructure emissions, they are real and ongoing.

For context, large transit authorities employ thousands of staff and operate substantial office and depot facilities. The energy consumption of head offices, regional control centres, maintenance depots, and training facilities all contribute to Scope 1 and 2 emissions. Marketing campaigns for a new HSR system would be significant in early years as ridership is built. No international HSR operator publishes disaggregated data on corporate/marketing emissions, making this category difficult to quantify but not zero.

8. Decommissioning and End-of-Life

HSR infrastructure has a design life of 60–120 years, but eventual decommissioning generates emissions from demolition, material removal, transport, and disposal. A lifecycle assessment found that the demolition stage accounts for approximately 0.001% of total lifecycle CO_2 – seemingly negligible, but this reflects the assumption that recyclable materials (steel, concrete) are sent to shredding, crushing, and melting processes, which themselves consume energy and generate emissions.

Recycling steel from decommissioned railway infrastructure can reduce CO_2 emissions by up to 58% compared to manufacturing new steel, and each tonne of recycled locomotive steel saves approximately 1,130 kg of iron ore, 635 kg of coal, and 54 kg of limestone. However, the decommissioning process itself requires heavy diesel machinery for demolition, cutting, and transport.

A lifecycle analysis of railway infrastructure in Greece found that end-of-life contributes approximately 2% of total emissions, with construction at 60%, operations at 23%, and materials at 15%.

Relevance to Alto: If the rail line does not achieve projected ridership or becomes obsolete due to technology changes (autonomous vehicles, advanced air mobility), decommissioning a 1,200 km corridor through environmentally sensitive areas would generate significant emissions while leaving permanent landscape scarring.

9. Estimated Annual Operational Emissions for Alto

The following table presents the revised annual operational emissions estimate incorporating the cold-climate operational premium from Section 4.5. All other categories are unchanged from the original analysis. The cold-climate premium replaces the “Unknown” entry for winter operations with a quantified range based on Harbin–Dalian HSR evidence. Base-category figures cover the full 1,200 km corridor on temperate-climate assumptions; the cold-climate premium is the additional increment attributable to Eastern Ontario’s winter conditions.

Operational Category	Low Estimate (annual)	High Estimate (annual)	Data Quality
Traction energy (train movement)	20,000–75,000 t	100,000–200,000 t	Good (international data)
Station operations (HVAC, lighting, escalators, retail)	5,000–15,000 t	20,000–40,000 t	Moderate (proxy data)
Track and infrastructure maintenance (base)	3,000–10,000 t	15,000–30,000 t	Moderate (LCA studies)
Rolling stock replacement (annualized)	1,000–5,000 t	5,000–10,000 t	Good (UIC data)
Vegetation management	500–2,000 t	2,000–5,000 t	Poor (estimated)
Waste handling and disposal	500–1,500 t	1,500–5,000 t	Poor (estimated)
Marketing, admin, and corporate	1,000–3,000 t	3,000–8,000 t	Poor (no HSR data)
Decommissioning (annualized over 80 yrs)	Negligible	500–2,000 t	Moderate (LCA data)
BASE OPERATIONAL SUBTOTAL	~31,000–112,000 t	~147,000–300,000 t	
COLD-CLIMATE OPERATIONAL PREMIUM (Section 4.5)	~6,200–13,600 t	~13,600–27,200 t	Harbin–Dalian HSR precedent
└ Switch/point heating	~90–330 t	~330–670 t	Electrical; grid-intensity dependent
└ Catenary de-icing (electric + diesel)	~1,200–2,150 t	~2,150–4,500 t	Harbin–Dalian precedent
└ Snow plough vehicles (diesel)	~1,200–2,400 t	~2,400–4,800 t	Higher snowfall than HDPDL
└ Train pre-conditioning + depot heating	~700–1,260 t	~1,260–2,200 t	Electrical; 130 winter days
└ De-icing chemicals (mfr + transport)	~1,000–1,800 t	~1,800–5,000 t	Shinkansen + HDPDL precedent
└ Frost-accelerated maintenance premium	~1,800–4,500 t	~4,500–8,000 t	+40–80% on base; HDPDL documented
└ Emergency response interventions	~200–1,160 t	~1,160–2,000 t	Unplanned diesel deployments
REVISED TOTAL ANNUAL EMISSIONS	~37,200–125,600 t	~160,600–327,200 t	
OVER 50-YEAR OPERATIONAL LIFE	~1.8–6.3 Mt	~8.0–16.3 Mt	

The wide ranges reflect the enormous uncertainty created by three key variables: Ontario's future grid carbon intensity, actual ridership levels, and the cold-climate operational categories. The low estimates assume a clean grid (post-nuclear refurbishment), high ridership, and the lower end of cold-climate impacts. The high estimates reflect the current Ontario grid trajectory, realistic ridership, and the full severity of Eastern Ontario winters. The cold-climate premium is conservative: Eastern Ontario receives significantly more snowfall than the Harbin–Dalian reference corridor, meaning real-world categories C (snow ploughs) and E (de-icing chemicals) are likely to exceed the HDPDL-benchmarked estimates.

10. Critical Context: The EV Counterfactual

The environmental case for HSR rests on displacing car and air trips. However, Canada's accelerating transition to electric vehicles fundamentally changes this calculation. As the EV share of the vehicle fleet grows, the per-passenger emissions of driving decline toward the same grid-dependent levels as electric trains. At Ontario's current grid intensity, a modern EV with 2+ passengers already approaches HSR's per-passenger emissions. By the time Alto's corridor could be operational (optimistically 2040–2045), the baseline vehicle fleet will be substantially electrified. The trips that HSR displaces may already be low-carbon, making the modal shift savings far smaller than current projections assume. This is the same dynamic identified for California's HSR: the further the project falls behind schedule, the fewer climate-harming trips it prevents.

11. Critical Gaps in Alto's Operational Emissions Disclosure

- Annual operational energy consumption estimates for traction, stations, maintenance, and winter operations
- Grid carbon intensity assumptions for the operational period, accounting for Ontario's forecast increases in gas-fired generation
- A winter operations energy and emissions plan addressing the corridor's cold-climate requirements — specifically: switch heating loads, catenary de-icing energy demand, snow plough fleet fuel consumption, train pre-conditioning requirements, de-icing chemical procurement, and frost-accelerated maintenance schedules, all of which are quantifiable against the Harbin–Dalian precedent
- Ridership-sensitivity analysis showing per-passenger emissions at various occupancy levels (40%, 60%, 80%)
- An EV counterfactual analysis showing modal shift carbon benefits net of the accelerating electrification of the vehicle fleet
- Lifecycle maintenance emissions estimates using PAS 2080 or equivalent methodology
- Station energy demand projections for heating, cooling, and operations in a four-season Canadian climate
- Comparison of full operational emissions between northern and southern route options

12. Methodology and Sources

This analysis draws on published data from lifecycle carbon assessments, environmental impact statements, government reports, and peer-reviewed academic research including:

- UIC (International Union of Railways): Carbon Footprint of High Speed Rail (2011)
https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/15009/Carbon%20Footprint%20of%20High-Speed%20Rail%20UIC%202011.pdf
- UIC (International Union of Railways): High Speed Rail and Sustainability
https://uic.org/sustainability/
- UK HS2: Phase 1 Environmental Statement
https://www.gov.uk/government/collections/hs2-phase-one-environmental-statement-documents
- UK HS2: HS2 Learning Legacy publications
https://www.hs2.org.uk/building-hs2/learning-legacy/
- UK HS2: Station lifecycle assessments
https://oneclicklca.com/en/resources/case-studies/london-euston-railway
- Chinese HSR: Life Cycle Cost, Energy and Carbon Assessments of Beijing–Shanghai High-Speed Railway
https://www.mdpi.com/2071-1050/12/1/206
- Chinese HSR: Lifecycle Assessment of High Speed Rail in China
https://www.sciencedirect.com/science/article/abs/pii/S1361920915001571
- Chinese HSR: Embodied GHG emissions of high speed rail stations: Quantification, data-driven prediction and cost-benefit analysis
https://www.sciencedirect.com/science/article/abs/pii/S0959652622025987
- California HSR: Life-cycle assessment of high-speed rail: the case of California
https://iopscience.iop.org/article/10.1088/1748-9326/5/1/014003/pdf
- California HSR: 2024 Sustainability Report
https://hsr.ca.gov/communications-outreach/reports/sustainability-reports/
- Spanish HSR: Madrid–Toledo lifecycle (ScienceDirect 2023)
https://www.sciencedirect.com/science/article/abs/pii/S0048969723051689
- Spanish HSR: Dataset for the life-cycle assessment of the Basque Y high-speed rail line in Spain
https://www.sciencedirect.com/science/article/pii/S2352340924004414
- Track Maintenance: Krezo et al. (2018) Evaluation of CO_2 emissions from railway resurfacing maintenance activities
https://www.sciencedirect.com/science/article/abs/pii/S1361920916307684
- Track Maintenance: Life cycle optimization in railway infrastructures
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- Track Maintenance: Greenhouse gas emissions from high-speed rail maintenance: A comparative case study for five major high-speed lines
https://www.sciencedirect.com/science/article/pii/S2666188825003223
- Winter Operations: The physics of icing drops under complex conditions
https://link.springer.com/article/10.1007/s10409-025-25318-x
- Winter Operations: Zhou et al. (2022) A review of snow melting and de-icing technologies for trains
https://journals.sagepub.com/doi/abs/10.1177/09544097211059631
- Winter Operations: Kloow (2011) High-speed train operation in winter climate
https://bibliotek.vti.se/bib/278045
- Winter Operations: Railway Supply (2026) Winter conditions for Canada’s high-speed rail network
https://www.railway.supply/winter-conditions-for-canadas-high-speed-rail-network-readiness/
- Ontario Grid: CER Province and Territory Energy Profiles (2022 data)
https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/index.html
- Ontario Grid: GTHA Carbon Emissions Inventory (2024)
https://carbon.taf.ca/2024/?v=1

- Ontario Grid: IESO Annual Planning Outlook
  https://www.ieso.ca/en/Sector-Participants/Planning-and-Forecasting/Annual-Planning-Outlook
- Lifecycle Methodology: Frontiers in Built Environment LCA (2021) Embodied GHG Emissions of Wooden Buildings
  https://www.frontiersin.org/journals/built-environment/articles/10.3389/fbuil.2021.729096/full
- Lifecycle Methodology: Rungskunroch et al. Life cycle assessment of ground borne vibration mitigation strategies
  https://pure-oai.bham.ac.uk/ws/portalfiles/portal/53927224/Rungskunroch_et_al_Life_cycle_assessment_INCE_2018.pdf
- Lifecycle Methodology: Carbon Management in Buildings and Infrastructure — PAS 2080
  https://www.bsigroup.com/en-GB/insights-and-media/insights/brochures/pas-2080-carbon-management-in-infrastructure-and-built-environment/
- Lifecycle Methodology: Soroosh Ataee (2025) Life cycle assessment and material flow analysis of road and rail infrastructure assets — A critical review
  https://www.sciencedirect.com/science/article/pii/S2666789425000054
- Decommissioning: SNCF rolling stock recycling data
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- Decommissioning: Okon Recycling locomotive studies
  https://www.okonrecycling.com/specialty-equipment-recycling/locomotives/

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