Incorporating climate scenario analysis into public transport emissions modelling

(This paper has been peer reviewed)

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ABSTRACT

Public transport (PT) services are Auckland Transport's (AT's) second-largest source of emissions, accounting for 37% of AT's 2024/25 emissions inventory. PT has therefore been a major focus of AT's decarbonisation work over the past decade. The pace at which AT transitions to low-emission PT fleets significantly influences its overall emissions trajectory and can help offset increases from service growth. Rail services are already fully electrified, and Auckland's Low Emission Bus Roadmap outlines a pathway to a fully electric bus fleet by 2035, with the fleet currently 19% electric.

Progress on electric buses and ferry decarbonisation, however, depends on adequate funding. While Auckland Council supports bus electrification at the current pace, the ferry fleet has not yet secured funding for its next phase of decarbonisation. Given ferries' long asset lifespans, delays in near-term investment risk locking in higher emissions for decades, which would undermine AT's targets of achieving 50% operational emissions reduction by 2031/32 and net-zero emissions by 2049/50 (relative to the 2021/22 baseline).

To assess the robustness of AT's decarbonisation pathways under uncertain future conditions, the policy and sustainability teams examined how different levels of climate ambition and funding affect the transition. This paper applies scenario analysis within the emissions-modelling framework with the end goal to evaluate the resilience of AT's low-emission pathways and provide long-term climate-risk insights for decision-makers.

We assessed three plausible climate scenarios: Orderly, Disorderly, and Hot House World to evaluate risks and opportunities for AT's decarbonisation transition. Scenario modelling to 2050 compares PT emissions outcomes under current funding settings with scenarios involving accelerated low-emission fleet adoption. The results show clear emissions-reduction benefits from increased investment as well highlights the risk of underinvesting in bus and ferry services.

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1 INTRODUCTION

Climate scenarios are widely used to explore plausible futures under conditions of uncertainty and to inform strategic responses to climate change. Rather than predicting a single outcome, scenarios provide structured pathways that combine assumptions about socio-economic trends, technological developments, and policy actions (IPCC, 2024). They are useful for organisations seeking to understand long-term risks and opportunities, particularly in sectors with high emissions such as transport.

Global frameworks such as the Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) underpin much of the scenario work in climate science. These pathways describe different trajectories for greenhouse gas concentrations and socio-economic development, enabling integrated assessment models to simulate energy and emissions futures (van Vuuren et al., n.d.). Similarly, the Network for Greening the Financial System (NGFS) provides widely adopted scenarios—Orderly, Disorderly, and Hot House World—that are used by financial institutions and public agencies to assess transition and physical risks (NGFS, 2025).

Scenario analysis is particularly valuable for emissions transition planning because it allows organisations to test the resilience of strategies under varying climate and socio-economic conditions. It supports policy appraisal by comparing the potential impact of different interventions, such as electrification, modal shifts, and alternative fuels (Thema J, 2024). However, the effectiveness of scenario modelling depends on the quality of assumptions and the ability to capture interactions between variables. For example, the benefits of electric vehicle adoption depend on the emissions intensity of electricity generation and the performance of competing technologies (Craglia & Cullen, 2020).

Recent studies have introduced advanced techniques to address these challenges. Craglia and Cullen (2020) applied sensitivity analysis to rank input variables by their influence on transport emissions, enabling policymakers to prioritise actions with the greatest impact. Similarly, Wang et al. (2020) combined machine learning with scenario analysis to forecast emissions under different policy and technology pathways, demonstrating the potential of hybrid approaches for robust planning.

Despite these advances, most scenario analyses focus on operational private vehicle fleets or national-level transport systems. There is limited research on applying scenario modelling to public transport operational and life-cycle emissions. This gap underscores the originality of studies that integrate scenario analysis with operational data to guide investment decisions and compliance with climate reporting standards. This paper applies transport scenario analysis in the context of public transport emissions modelling for Auckland, New Zealand.

Entities classified as Climate Reporting Entities (CREs) under Part 7A of the Financial Markets Conduct Act 2013 are required to disclose climate-related risks, impacts, and scenario analysis in accordance with the New Zealand Climate Standards (NZ CS 1–3).

As a Council Controlled Organisation (CCO) under Auckland Council (AC), Auckland Transport (AT) contributes to the Auckland Council Group (ACG) Climate Statement and manages a multi-modal network of buses, trains, and ferries. Public transport services are a major contributor to AT's operational emissions—approximately 37% of its emissions inventory in FY2024/25, with diesel-powered buses and ferries being the most emissions-intensive modes.

Despite progress, including a fully electrified rail network and 19% of the bus fleet now electric, emissions have continued to rise due to post-COVID service recovery and growing demand.

To meet its Sustainability Strategy 2024–31 targets of halving operational and embodied emissions by 2031/32 and supporting Auckland's net-zero commitment by 2050, AT must accelerate its transition to low-emission fleets. This includes scaling up low emissions bus (LEB) deployment, decarbonising ferries, and expanding services to meet population growth.

AT has adapted AC's three climate scenarios—Orderly, Disorderly, and Hot House World—to test the resilience of its transition pathways under different global and local conditions. These scenarios compare emissions outcomes under current funding settings versus enhanced investment, revealing that greater funding significantly improves emissions performance. While bus electrification is funded and progressing toward a 2035 target, ferry decarbonisation remains unfunded, creating a risk of long-term emissions lock-in.

Building on these frameworks this paper demonstrates how scenario analysis can be integrated with operational data to inform strategic planning under uncertainty. By combining scenario modelling with Auckland-specific emissions data, the study provides insights into risks, opportunities, and funding priorities for public transport decarbonisation, supporting both regulatory compliance and climate resilience objectives.

2 BOUNDARY SETTING & BASELINE EMISSIONS

Prior to modelling AT's public transport (PT) emissions to 2050 it was necessary to understand its current and historical emissions profile. AT annually discloses its greenhouse gas (GHG) emissions, covering its organisational operational activities for the financial year (July–June). AT GHG inventory data for the financial years 2021/22, 2022/23, 2023/24 and 2024/25 was used to test that the scenario modelling which begins in 2025/26 aligned in terms of orders of magnitude.

According to the FY25 emissions inventory AT's public transport services are responsible for approximately 94 kilotonnes of CO2 equivalent (ktCO2e) in operational emissions, excluding upstream emissions of fuel and assets. Of this total, 95% is attributable to diesel consumption, while the remaining 5% is associated with electricity usage. Bus services are responsible for approximately 82% (78 ktCO2e) of AT's total public transport-related operational emissions, while ferry and train services contribute 14% (13 ktCO2e) and 4% (3 ktCO2e), respectively.

Emissions intensity across various transport modes and fuel types indicates that diesel-powered ferry and bus services exhibit the highest emissions per passenger kilometre, underscoring their significant environmental impact within Auckland's public transport network.

The emissions scope of this paper is limited to operational PT service emissions, embodied emissions associated with vehicle manufacturing and upstream fuel electricity emissions. This is provided in detail in Table 2-1 below.

Table 2-1: Emissions boundary inclusions and exclusions

Source ID	Emissions Source	ISO 14064-1 category	Included in 2025 Inventory?	Included in this Paper?
1	Operational energy PT operator owned (non-commercial)	4	Yes	Yes
2	Operational Energy PT AT owned	2	Yes	Yes
3	T&D Losses	4	Yes	Only for sources 1,2
4	Upstream Energy	4	No	Only for sources 1,2
5	Embodied emissions from procurement & maintenance of PT motor assets	4	No	Yes
6	Operational energy PT operator owned (commercial e.g. Waiheke)	4	No	No

Source ID	Emissions Source	ISO 14064-1 category	Included in 2025 Inventory?	Included in this Paper?
7	Embodied & operational emissions network facilities	1-4	Yes	No
8	Embodied and maintenance emissions from infrastructure roading assets	4	Yes	No
9	Corporate emissions	1-4	Yes	No

Note that while AT owns the trains, buses and majority of ferries are owned by contractors who supply operational services to AT through tendered route contracts.

3 OVERVIEW OF CLIMATE SCENARIOS

Climate scenarios are plausible representations of future conditions that combine assumptions about emissions, socio-economic change, technology, and policy. They are not forecasts, but structured narratives or model-based pathways used to explore uncertainty and support strategic decision-making (IPCC, 2024).

AT has adapted three integrated climate scenarios to identify climate-related risks. These scenarios align with New Zealand's Nationally Determined Contribution, the First and Second Emissions Reduction Plans, and Auckland Council's Auckland Climate Plan, and draw on pathways from NGFS and CS1. While consistent with ACG scenarios, AT's scenarios place greater emphasis on the impacts of climate change on Auckland's transport network and public transport operations.

The **Orderly** scenario assumes immediate, well-coordinated policy action; rapid climate-technology deployment; medium carbon-removal uptake; and moderate regional policy variation. It represents an ambitious global transition consistent with 1.5°C pathways. Strong alignment across jurisdictions enables rapid decarbonisation, limiting physical climate impacts. However, the speed of transition is highly disruptive and requires substantial structural and technological shifts.

The **Disorderly** scenario assumes delayed policy action followed by abrupt, uncoordinated decarbonisation; initially slow but later accelerating technology change; and low carbon-removal uptake. This pathway achieves <2°C warming, avoids major tipping points, and results in significant but manageable physical climate impacts through the century.

The **Hot House World** scenario assumes weak, unambitious policies that fail to constrain emissions, resulting in >3°C warming. Technology adoption remains slow, carbon-removal negligible, and policy variation minimal. Physical climate impacts intensify steadily before accelerating after 2050, with the world likely crossing major climate tipping points and experiencing severe, irreversible consequences.

4 FORECASTING PUBLIC TRANSPORT EMISSIONS

4.1 Mathematical modelling

The purpose this section is to outline the formulation for the AT Public Transport Transition Pathways Mathematical Model (“the model”) and the data sets selected for use in the model (“the data”).

Overall PT Emissions Model (1):

$$PT_{i,s} = B_{i,s} + W_{i,s} + T_{i,s} \qquad \forall\, i \in I, \forall\, s \in S \quad (1)$$

Where:

I = The set of three-year time periods aligned to LTP funding decisions.
S = The set of Auckland Council Group's three climate scenarios.
$PT_{i,s}$ = The total public transport emissions in period i under scenario s.
$B_{i,s}$ = Bus public transport emissions in period i under scenario s.
$W_{i,s}$ = Ferry public transport emissions in period i under scenario s.
$T_{i,s}$ = Train public transport emissions in period i under scenario s.

Equation template of the bus, ferry and train model as demonstrated for Bus (2):

The current model formulation has been initially drafted based on AT’s bus transition roadmap given the data availability. This will also form the structure of the ferry and train models.

$$PT_{i,s} = \sum_{j} \left(\alpha_{i,j,s}\; E^{B}_{i,j,s} + \sum_{f} \left(\beta_{i,j,s,f}\, \vartheta_{i,j,f}\, \delta_{i,j,s,f}\, O^{B}_{i,s,f} \right) + \gamma_{i,j,s,f}\; D^{B}_{i,j,s} + \sum_{f} \left(\delta_{i,j,s,f} \right) M^{B}_{j,s,f} \right)$$

$$\forall j \in J, \forall f \in \mathrm{F}, \forall s \in \mathrm{S}, \forall i \in \mathrm{I} \quad (2)$$

Where:

$\boldsymbol{J_{b,t,w}} =$	The set of bus/train/ferry types included in the model.
$\boldsymbol{F} =$	The set of engine fuel types available.
$\boldsymbol{\alpha_{i,j,s}} =$	The number of bus/train/ferry vehicles of type *j* using fuel type *f* **procured** in period *i* under scenario *s*.
$\boldsymbol{\beta_{i,j,s,f}} =$	The average number of **kilometres travelled** annually, for both in- and out-of-service trips, by one bus/train/ferry of type *j* using fuel type *f* in period *i* under scenario *s*.
$\boldsymbol{\vartheta_{i,j,f}} =$	The fuel efficiency per kilometre travelled by bus/train/ferry of type *j* using fuel type *f* in period *i*. This is assumed to be invariant across ACG’s climate scenarios. Unit: L / km or kWh / km.
$\boldsymbol{\gamma_{i,j,s,f}} =$	The number of bus/train/ferry vehicles of type *j*, using fuel type f, **disposed** in period *i* under scenario *s*.

$\delta_{i,j,s,f}$ = The number of bus/train/ferry vehicles of type *j* **in operation** using fuel type *f* during period *i* under scenario *s*.

$E^{B}_{i,j,s}$ = The embodied emissions of **producing** a bus/train/ferry of type *j* in period *i* under scenario *s*. Unit: tCO_2-e / chassis.

$O^{B}_{i,s,f}$ = **Operational emissions** factors for fuel type *f* in period *i* in scenario *s*. Unit: tCO_2-e / L or tCO_2-e / kWh.

$D^{B}_{i,j,s}$ = The end-of-life emissions arising from **disposing of** a bus/train/ferry of type *j* in period *i* under scenario *s*. Unit: tCO_2-e / chassis.

$M^{B}_{j,s,f}$ = The emissions arising from general **maintenance** of a bus/train/ferry of type *j* under scenario *s*, annualised over the 20-year lifespan of a bus. Unit: tCO_2-e / chassis.

5 INCORPORATING CLIMATE SCENARIOS INTO FORECAST

The variables in equations (1) and (2) with the S subscript are subject to change between climate scenarios. The following sections outline the inputs and assumptions made to quantitatively apply the effects of the integrated scenarios into the emissions model. For the remainder of this paper O_T, D_T and HH_T will be used as shorthand for Orderly, Disorderly and Hot House World trajectories.

5.1 Bus model inputs

Vehicle procurement and Engine type: Workshops were held with the AT Bus team who agreed to utilise modified fleet trajectories sourced from AT's Low Emission Bus Roadmap[3]. The plan involved reviewing the options present in the document and then adjusting them to align with the 3 climate scenarios.

Option G was applied to the O_T, Option E to D_T, and a modified version of Option E for HH_T, where ZEB adoption reaches only about 60% of the fleet by 2050 due to significant headwinds in adoption.

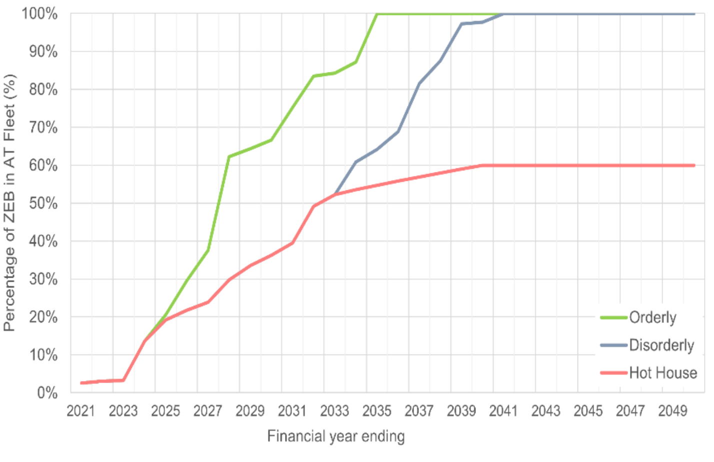

Figure 5-1: Estimated proportion of AT bus fleet that is using Zero Emission technology for each climate scenario

In the Roadmap options G and E are compared against a full diesel option O which was found not suitable for the HH_T, as it was deemed unlikely that the HH_T would have no ZEB at all based on recent funding decisions and the expected price parity of electric buses by 2035 Auckland Transport (2023). All fleet projections include the planned transition of approximately 1,350 existing vehicles and procurement of 603 new vehicles of varying fuel types. The proportion of ZEB in the AT fleet is visualised in Figure 5-1.

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[3] Options G/E are ZEB transition pathways taken from Auckland Transport (2023)

Embodied Life cycle emissions: To estimate lifecycle emissions, buses were broken down into components chassis, batteries, fuel cells, and internal combustion engines and assumptions were made for maintenance over a 20-year lifespan. Manufacturing efficiency improvements were also factored in, with emissions reductions of approximately 20%, 45%, and 75% by 2050 across the three scenarios, based on forecasts for steel, battery, and energy production in China. Embodied emissions of vehicles are not considered in Auckland Transport (2023) thus this study shines a light on its effect when comparing the financials against emission reductions.

Financial Inputs: The AT Low Emission Bus Roadmap (Auckland Transport, 2023) outlines the financial impacts on AT via operator costs of adopting options G and E compared with option O. These impacts include Peak Vehicle Requirement (PVR) costs, in-service operating costs, and infrastructure costs such as charging stations. While the roadmap's cost estimates run from 2021 to 2040, for this paper we extrapolate them to 2050 to quantify the emissions requiring offsetting to achieve AT's net-zero target, the result of this extrapolation is shown in Table 5-1.

Table 5-1: Adjusting additional funding requirements Auckland Transport (2023) compared with option O to 2050 end

Scenario	Additional funding to 2040 (\$m)	Additional funding to 2050 (\$m)	Additional funding to 2050 (Discounted to 2021 PV, \$m, ~6%)
Orderly (Option G)	\$620	\$720	\$313
Disorderly (Option E)	\$437	\$507	\$193
Hothouse (Option E adjusted)	\$262	\$304	\$116

This paper also evaluates the social costs and savings arising from greenhouse-gas emissions and tailpipe pollutant damages ($PM_{2.5}$, NO_x, VOC, CO). Emissions quantities are calculated using the model described in Section 4.1, and their monetary value is based on an estimated \$63–\$250 per tCO_2-e for the period 2021–2050, as reported in Auckland Transport (2023). The social cost of pollutants is estimated at \$2.19 per kilometre, derived by multiplying the pollutant social-cost values from page 285 of Auckland Transport (2023) with the standard per-kilometre diesel-bus pollutant weightings from VEPM 7.1 (Waka Kotahi NZ Transport Agency, 2025).

5.2 Ferry model inputs

Vehicle procurement and Engine type: Unlike buses which benefit from a detailed ZEB uptake roadmap that can be aligned with climate scenarios ferries lack fleet projections beyond 2030, requiring several assumptions on future growth and composition. Workshops were held with the AT ferry team to map each of the current ferry's lifecycle across the next 30 years as well as plan the introduction of new ferries of varying fuel types based on the climate scenario. This map is visually represented in Figure 5-2.

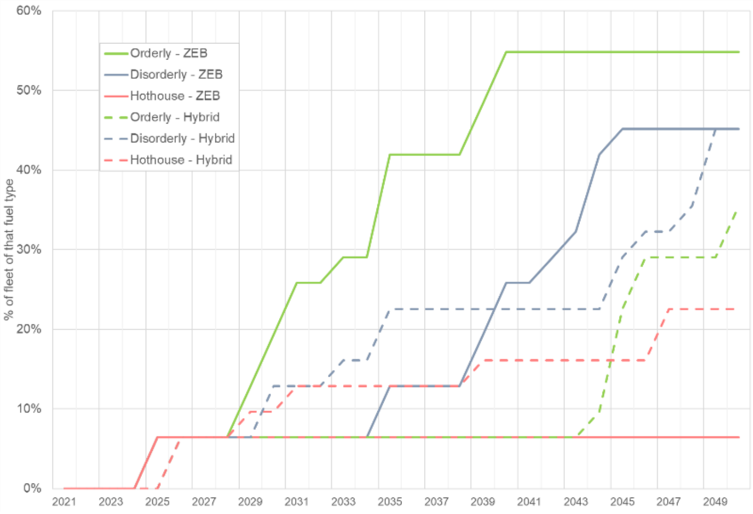

Figure 5-2: Estimated proportion of AT ferry fleet that is using Zero Emission/hybrid technology for each climate scenario.

Based on the results of the workshop we assume operational fleets of 30 vessels in 2030, 36 in 2040, and 37 in 2050 across all scenarios Auckland Transport (2021), with indicative retirement timing and selective retrofits to avoid unrealistic procurement spikes. The model includes hybrid, electric, new diesel, and second-hand diesel vessels, with VKT held constant year-on-year. Renewable diesel uptake was included as a parameter to test alternative strategies such as fuel switching versus full electrification.

Fleet composition varies significantly: in the O_T scenario, electric ferries dominate by 2050 with a few hybrids and diesels remaining; in the D_T scenario, electric and hybrid vessels are balanced, with more diesels persisting through the 2030s and 2040s; and in the HH_T World scenario, only a few hybrids are introduced while most vessels remain diesel-powered.

Embodied Life cycle emissions: Due to the lack of Environmental Product Declarations (EPDs) for diverse ferry types, we used a life-cycle assessment report and scaled hull size and battery capacity to approximate new hybrid and electric vessels, providing an order-of-magnitude estimate. For manufacturing emissions, we conservatively assumed ferries decarbonise at half the rate of buses, reflecting material variability, resulting in emissions reductions of ~60%, ~72%, and ~87% by 2050 across the three scenarios.

Financial input: Due to limited data it was challenging to identify and separate CAPEX and OPEX costs for ferries specific for AT. Another challenge is that while most of the ferry fleet is owned and operated by contractors there are a select number ferries that AT owns and plans to purchase. In lieu of this additional information for the purposes of this paper only the financial capex of purchasing a ferry will be considered, we assumes that AT plans to own all new and replaced ferries. The following 2021 costs are attributed to diesel, second hand diesel, hybrid and electric ferries respectively: $14m, $3.75m, $20m, $25, they are from Cooke, H. (2022) with an assumption that electric ferries cost 25% more than electric hybrids.

Table 5-2: Developing addtional CAPEX funding required for each scenario compared to the 2021 fully diesel fleet

Scenario	Additional CAPEX funding to 2050 (Undiscounted $m)	Additional CAPEX funding to 2050 (Discounted to 2021 PV, $m, ~6%)
Orderly	$729	$346
Disorderly	$709	$298
Hothouse	$404	$202

Social costs associated with GHG emissions reduction is calculated the same was as buses however tail pipe savings was not assessed as compared to buses which run in urban environments, air pollutants from ferries are spread over the waterways BRICHBY D., et al. (2023).

5.3 Train model inputs

Vehicle procurement and Engine type: The train model is relatively straightforward because AT's electric multiple units (EMUs) are already fully electrified, making fleet size and vehicle kilometres travelled (VKT) the primary drivers of emissions. Diesel trains are included up to 2023, with assumed disposal emissions for decommissioned units. Fleet numbers remain consistent across scenarios, aligned with the AT/KiwiRail 30-Year Rail Programme. VKT assumptions were informed by KPMG's growth projections, starting at approximately 45,000 km per train and increasing to 75,000 km by 2034.

Embodied Life cycle emissions: A EPD Alstom (2022) has been used to assess the embodies emissions associated with purchasing a three car EMU. Manufacturing efficiency improvements assume reductions of roughly 20%, 40%, and 65% by 2050 across the three scenarios, based on steel and energy forecasts for Mexico shown in European Aluminium. (2023).

Financial Input: Due to the minimal changes in fleet composition and size across the three scenarios the financial impacts of train LEV uptake has not been measured in this paper.

5.4 Operational and Upstream Emissions Factors

To model electricity emissions factors for Auckland Transport's decarbonisation scenarios, the analysis draws on the MBIE Electricity Demand and Generation Scenarios (EDGS) (MBIE, 2024). These provide national projections of New Zealand's future electricity mix and emissions intensity under varying policy and technology pathways. Three EDGS scenarios were aligned with the global climate scenarios used in this study: the Environmental scenario with the O_T pathway (rapid renewable uptake and near-zero grid emissions by mid-century), the Combination of Reference and Innovation scenario with the D_T pathway (moderate decarbonisation and residual fossil generation), and the Reference scenario with the HH_T pathway (slower decarbonisation and persistently higher emissions factors). This ensures emissions forecasts for electric buses, ferries, and trains reflect realistic future grid conditions.

6 MODELLING RESULTS AND ANALYSIS

The following section is split into analysing the total emissions results of each mode and then reviewing the operational emissions of the PT network as a whole against AT's emissions targets.

Bus Results: Figure 6-1 shows the results of the bus emissions model while Table 6-1 is a NPV comparison of the additional funding requirements, GHG reduction and social cost savings of the O_T and D_T compared with HH_T based on the data in Table 5-1. Note that both social cost and non-social costs have been discounted to 2021 by 5% and 6% respectively.

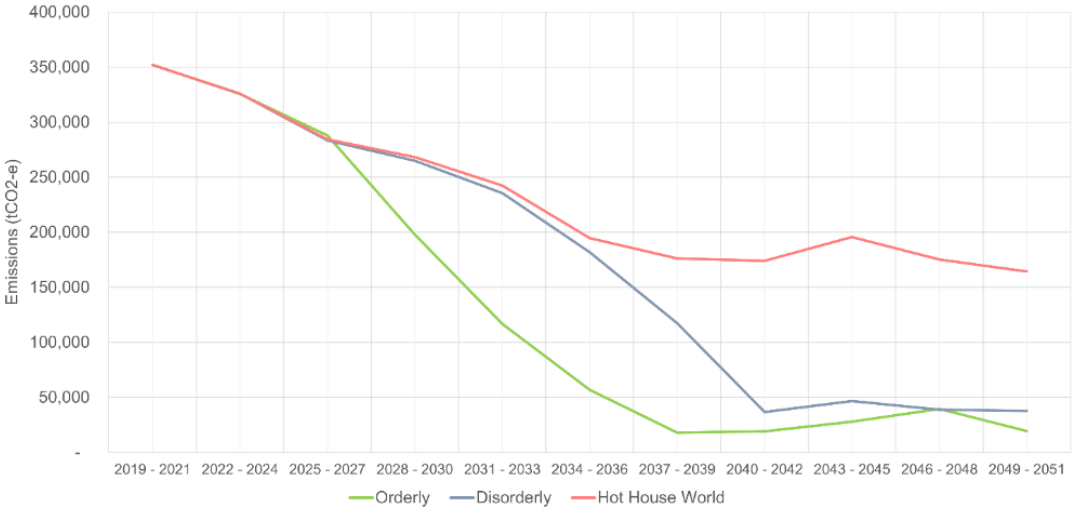

Figure 6-1: 3-Yearly Annual Bus Operational and Lifecycle Emissions by Climate Scenario

Reviewing Figure 6-1 in the O_T between 2025 and 2035, despite the accelerated replacement of existing diesel buses with ZEB alternatives, which would have an embodied emissions cost, there is a net emissions decrease. This shows how the reductions gained in operational energy emissions outweigh the initial manufacturing emissions. Further amplifying this effect is the decarbonisation of the national grid shown as bus emissions continue to reduce until 2038 despite having a fully ZEB fleet by 2035. There is a spike in emissions during the 2040s due to ZEB replacements after 20 years, although this is mitigated by ongoing decarbonisation pathways.

Table 6-1: NPV ($2021) analysis comparing funding, emissions and social cost differences compared to the bus HH_T

Scenario	Additional funding PV ($m)	Emissions Reduction (tCO2-e)	Social Cost Savings ($m)		Total Social Savings ($m)
			GHG Emissions	Tailpipe Pollutants	
Orderly	$198	1,092,500	$72	$735	$808
Disorderly	$77	632,453	$40	$386	$427

Reviewing Table 6-1 in both the O_T and D_T the total operating expenditure of accelerated electrification is offset by significant savings in social costs of pollutants alone. When comparing the trade-offs in GHG between the D_T and O_T a 150% increase in present value funding results in a 72% increase in emissions reductions.

Ferry Results: Figure 6-2 and Table 6-2 respectively show the ferry results of the GHG model and subsequent NPV analysis, similar to the bus results.

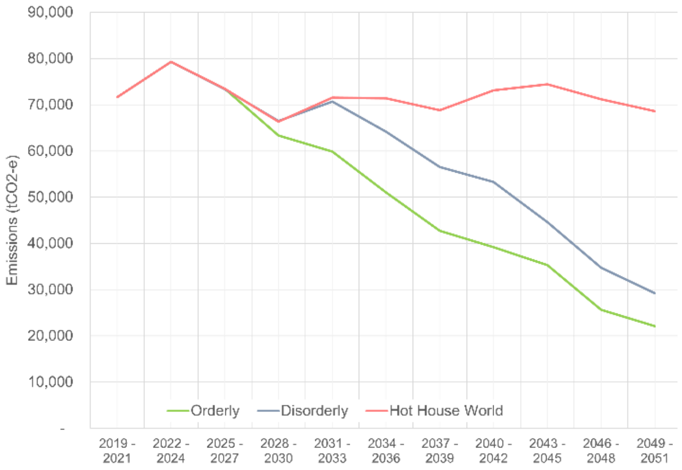

Figure 6-2: 3-Yearly Annual Ferry Operational and Lifecycle Emissions by Climate Scenario

Table 6-2 NPV ($2021) analysis comparing funding, emissions and social cost differences compared to the ferry HHT

Comparison	Scenario	
	Orderly	Disorderly
Additional Funding ($m)	$144	$96
Emissions Reduction (tCO2-e)	224,259	144,647
Social GHG Emission Savings ($m)	$14	$9

Reviewing Figure 6-2 the annual emissions reduction achieved in the HH_T model between 2019-21 and 2049-2051 is negligeable whereas the HH_T for buses has a ~ 50% reduction. This is because this model assumes that AT cannot fund the use of hybrid and electric ferries into their contracts by 2030 and thus due to the longevity of the ferry assets it is only until 2040 that more hybrid ferries are introduced into the fleet. The high embodied emissions associated with ferry retrofit and purchase compared to buses also adds to this difference.

The NPV analysis in Table 6-2 shows that, for both O_T and D_T, the additional funding required relative to HHT is not recovered through the associated savings in social GHG costs. When comparing GHG trade-offs between D_T and O_T, a 51% increase in funding results in a 50% increase in emissions reductions. Under O_T, the total emissions reduction per million dollars invested is 5,528 tCO_2e for buses and 1,555 tCO_2e for ferries, while under D_T these values increase to 8,193 tCO_2e and 1,511 tCO_2e respectively. This indicates that, when accelerating ZEV uptake relative to HH_T, buses deliver greater emissions reductions per unit of expenditure over the 29-year period.

It is important to note that, unlike buses, the additional funding considered for ferries relates solely to the purchase of new vessels or the replacement of existing ones. It does not account for maintaining current operator costs, potential lifecycle OPEX savings associated with electrification, or changes in CAPEX requirements for vessel or infrastructure upgrades. These omissions present significant limitations and reduce the suitability of this analysis for informing funding decisions. The assumption that AT progressively purchases ownership of its ferry fleet may not reflect current policy. A future scenario worth testing is one in which, similar to buses, AT continues to procure ferry decarbonisation through operators and pays higher service premiums rather than carrying upfront CAPEX obligations.

Train Results: Reviewing Figure 6-3 although operational emissions decline as the electricity grid decarbonises, the model is sensitive to embodied emissions from manufacturing, given that a single three-car EMU has an estimated footprint of around 520 tCO_2-e. Emissions spikes correspond to procurement batches of 20–30 trains, with manufacturing efficiency increasing over time.

These improvements explain why the amplitude of the 2042 procurement peak is lowest in the O_T scenario.

When embodied emissions are excluded, the overall trend reflects a steady decline in operational emissions due to grid decarbonisation.

Figure 6-3: 3-Yearly Annual Train Operational and Lifecycle Emissions by Climate Scenario

Network Results: Table 6-3 shows the operational decarbonisation (excluding embodied) achieved by each of the modes at its two key emission targets (Auckland Transport, 2022): A 50% decrease by the financial year 2031/32 and net zero by 2049/50 (assumed to be 90% reduction compared to 2031/32). Due to the models' three-year groupings, the base year equivalent of 2021/22 will be calculated as an average between 2019-2021 and 2022-2024. Similarly, the 2031/32 target will be measured as the average between 2028-2030 and 2031-2033 and 2049/2050 measured as the average between 2046-2048 and 2049-2051.

This table acts to measure the resilience of AT's climate transition plan against the uncertainties modelled by the various climate scenarios. Figure 6-4 shows the combined PT fleet emissions trajectories across all 3 climate scenarios with the lifecycle emissions removed so that we can analyse the operational decarbonisation independently. It also contains a stacked chart showing the emissions breakdown by mode for a combination of O_T scenario for bus but HH_T scenario for ferry and train.

Table 6-3: Percentage decarbonisation achieved against 2021/22 baseline year for each mode compared to 2031/32 and 2049/50

Scenario		Orderly		Disorderly		Hot House World	
Financial year		2031/32	2049/50	2031/32	2049/50	2031/32	2049/50
Target		50%	Net Zero	50%	Net Zero	50%	Net Zero
Mode	Bus	67%	97%	32%	96%	32%	62%
	Ferry	22%	70%	12%	60%	12%	9%
	Train	39%	41%	24%	24%	24%	0%
Total		58%	90%	28%	87%	28%	51%

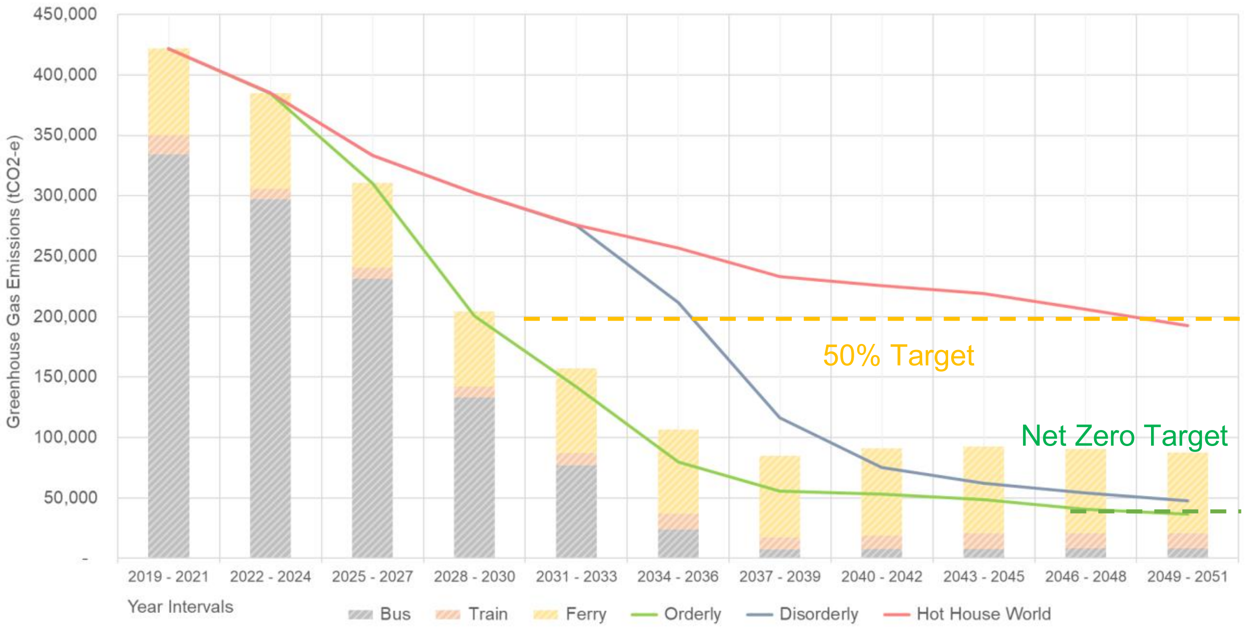

Figure 6-4: 3-Yearly Annual PT Emissions (operational only) by Climate Scenario & Overlaid Stacked Bar Chart of the Orderly Scenario's Bus and Hot House Scenarios Train, and Ferry Annual Emissions.

As expected, analysis from Figure 6-4 shows that buses continue to have an outsized contribution to emissions until the fleet of 1,350 buses is transitioned to zero-emissions, which in the D_T scenario occurs around 2040. In fact, the stacked bar chart shows that in an alternate (AL_T) scenario even if only buses follow O_T and the rest HH the 2031/32 target can still be reached. However, what is unexpected is that after 2040 in the AL_T scenario, if new and second-hand diesels remain in the ferry fleet without further transition to hybrid or electric, by the late 2030s and 2040s ferry fleet emissions will account for more than 80% of remaining emissions, leaving a significant gap to achieve net zero in 2049/51.

Table 6-3 provides a clear measure of resilience by comparing decarbonisation achieved at two key milestones: 50% reduction by 2031/32 and near-net-zero by 2049/50. Under the O_T, AT's transition plan performs strongly, achieving 58% total operational emissions reduction by 2031/32 marginally above the 50% target and 90% by 2049/50, approaching net zero. Buses led this progress with 67% reduction by 2031/32 and 97% by 2049/50, while trains achieve 39% early reductions but plateau at 41% by 2050 due to limited scope for further electrification. Ferries stat slow, delivering only 22% reduction by 2031/32 and then ramp up to 70% by 2049/50, highlighting the need for accelerated investment.

In contrast, the D_T scenario falls short of the 2031/32 target, achieving only 28% total reduction, driven by slow bus transition (32%) and negligible progress for ferries (12%). Despite catching up somewhat by 2049/50 with 87% total reduction, this pathway risks locking in high emissions during critical decades. The HH_T scenario performs worst, with just 28% reduction by 2031/32 and only 51% by 2049/50 far below the net-zero ambition due to persistent reliance on diesel ferries and limited electrification.

In the short term bus funding is critical to meet the 2031/32 target emissions target, using present value figures from Table 5-1 we note that the 40% decrease in bus spend from the O_T will result in buses following the D_T resulting in only a 30% total annual carbon reduction in 2031/32. It is approximated that present value bus spend cannot decrease more than 7-11% to meet the short-term target or at all in in order to reach 90% reduction by 2049/50.

Similarly in the long-term ferry funding becomes more prevalent to reach 90% reductions in 2049/50. Present value data from Table 5-2 show that a 42% decrease in ferry spend from the O_T will result in ferries following the HH_T resulting in only 79% reduction being achieved in 2049/50. Whereas in a D_T scenario for bus and trains an O_T scenario for ferries means that a 90% reduction is achieved in 2049/50.

While the O_T scenario demonstrates that the plan can meet interim and long-term targets under ambitious conditions, the D_T and HH_T scenarios reveal significant vulnerabilities, particularly in bus decarbonisation.

7 CONCLUSIONS AND RECOMENDATIONS

The goal of this research paper was to analyse the resilience of AT’s public transport emissions transition plan to the various uncertainties in funding, polices and technology that may affect AT’s ability to navigate climate change. Uncertainty was modelled by using AT’s integrated climate scenarios to simulate futures where different levels of decarbonisation is achieved across the various elements and modes of PT that AT control.

Growth forecast data from Auckland Transport (2023, 2021) was combined with grid and material decarbonisation into a mathematical formula to generate annual emissions for each mode of transport. This formula was used to project AT’s 2024/25 PT emissions inventory into 2050 resulting in 3 different trajectories for each mode: The O_T scenario assumes rapid, coordinated climate action enabling accelerated adoption of zero-emission technologies, while the D_T scenario reflects delayed action in 2030 followed by abrupt transitions, causing slower early progress. The HH_T World scenario represents minimal climate ambition, resulting in limited decarbonisation. The key performance indicators for measuring resilience in this case is AT’s operational emission targets of 50% reduction of the 2021/22 baseline achieved by 2031/32 and net zero by 2049/50 (assume met at 90% reduction).

The analysis confirms that Auckland Transport’s climate transition plan is effective under ambitious conditions but vulnerable under less favourable scenarios. Under the O_T scenario, the plan exceeds interim and long-term targets, achieving 58% operational emissions reduction by 2031/32 and 90% by 2049/50, largely driven by bus electrification and grid decarbonisation. An example of the plan’s sensitivity is that a 7-11% decrease in bus funding from the O_T may lead to AT missing the 2031/32 target regardless of the movements of the other modes.

Ferries remain a critical weakness, delivering only 22% reduction by 2031/32 even in the best case. D_T and HH_T scenarios fall significantly short of the 2031/32 target, achieving only 12% reduction, and risk locking in high emissions from diesel ferries and limited electrification for decades endangering potential emissions reductions in 2049/50. While the initial decarbonisation of ferries does not contribute significantly to the 2031/32 goal in a D_T scenario for tarins and ferries, early O_T uptake of ferries can make the difference such that the 90% target is met in 2049/50. These findings highlight the sensitivity of AT’s transition plan to funding, policy ambition, and technology adoption.

Aside from meeting its emissions targets the funding analyses for buses showed both the O_T and D_T provided significant social cost savings in the form of GHG and pollutant emissions. However, per $m invested DT buses provide the highest amount of carbon reduction when normalised against HH_T. Based on these insights, AT can begin to strategise on the best way to mitigate the risks posed. Options may include to accelerate ferry decarbonisation by securing dedicated funding streams through central government grants, green bonds, and public-private partnerships, and prioritise early procurement.

AT may enhance scenario-based planning by incorporating adaptive pathways and contingency measures for bus and ferry electrification under constrained funding scenarios and regularly update assumptions on technology costs and grid emissions factors using MBIE EDGS projections. Finally, AT could improve life-cycle emissions accounting by commissioning Environmental Product Declarations (EPDs) for local vessel types and expanding embodied emissions modelling to include infrastructure upgrades and depot electrification.

Opportunities for improvement of this analysis include addressing data gaps caused by reliance on scaled LCA data for ferries, refining modelling assumptions to incorporate demand elasticity and modal shift impacts, and exploring alternative financing models such as leasing and “charging-as-a-service” to reduce upfront capital barriers. Limitations to consider include uncertainty in future technology costs, static service demand assumptions that may not hold under severe climate or economic shocks, and exclusion of upstream supply chain emissions, which could underestimate total life-cycle impacts. Severe limitations in the funding analysis for ferries also limit its comparability with the bus funding analysis to identify trade-offs.

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