Net Environmental Impact of Mixed-Mode Transport in the Melbourne Metropolitan Area: A Breakeven Analysis of Cyclist-Induced Traffic Disruption

Abstract

This study investigates the net environmental impact of mixed-mode transport — specifically the interaction between bicycles and motor vehicles — within the Melbourne Metropolitan Area. While cycling is widely recognised as a zero-emission mode of transport, its integration into shared road infrastructure may produce secondary emission effects by disrupting the flow of motor vehicle traffic. This research develops a simplified breakeven model to estimate the number of motor vehicles, and the duration of delay, required to negate the carbon dioxide (CO2) savings achieved by a single cyclist replacing a car trip. Scenario-based analyses reveal that relatively modest traffic disruptions — as few as 10 vehicles delayed for 5 minutes — can offset the emission savings of a typical 5 km cycling trip. These findings underscore the need for infrastructure design that maximises the environmental co-benefits of active and motorised transport modes.

Keywords: mixed-mode transport, carbon emissions, cycling infrastructure, traffic flow disruption, urban transport policy, Melbourne

1. Introduction

Urban transport systems are significant contributors to greenhouse gas emissions globally, and the promotion of active transport modes — particularly cycling — has become a central pillar of urban sustainability policy (Pucher & Buehler, 2017). In the Australian context, state and local governments have invested substantially in cycling infrastructure, guided by the assumption that modal shifts from private motor vehicles to bicycles yield direct environmental benefits through reduced per-trip emissions (Austroads, 2020).

However, the environmental calculus of mixed-mode transport is not straightforward. In urban settings where dedicated cycling infrastructure is absent or incomplete, cyclists frequently share road space with motor vehicles. This coexistence can generate secondary environmental effects: slower-moving cyclists in shared lanes may impede traffic flow, inducing stop-start driving patterns, increased idling, and elevated fuel consumption among trailing motor vehicles (Gosse & Clarens, 2013). The net environmental outcome therefore depends not only on the emissions avoided by the cyclist but also on the additional emissions imposed on surrounding traffic.

Despite the policy relevance of this question, quantitative assessments of the breakeven point — that is, the threshold at which cyclist-induced traffic disruption negates the emission savings of cycling — remain scarce in the literature, particularly for Australian urban conditions.

This study addresses this gap by developing a simplified analytical model to estimate the breakeven point for mixed-mode transport scenarios in the Melbourne Metropolitan Area. The specific research questions are:

1. What is the magnitude of CO2 savings attributable to a single cyclist replacing a car trip of a given distance?
2. How many motor vehicles, delayed for a given duration, are required to offset those savings through increased idling and stop-start emissions?
3. Under what plausible traffic conditions does the net environmental impact of a shared-lane cyclist become negative?

The remainder of this report is structured as follows: Section 2 describes the data sources and analytical methodology; Section 3 presents the scenario-based findings; Section 4 discusses the implications of the results; and Section 5 concludes with recommendations for future research and policy.

---

2. Methodology

2.1 Research Design

This study employs a scenario-based analytical modelling approach. A breakeven emissions model was developed to compare the CO2 savings achieved by a cyclist (through the displacement of a motor vehicle trip) against the additional CO2 emissions generated by motor vehicles delayed in shared-lane conditions. The model was implemented as a Python script (`emissions_model.py`) and executed under a range of parameter configurations.

2.2 Data Sources

Data requirements for the model encompass three principal domains: traffic flow and speed, bicycle activity, and vehicle emission factors.

Traffic and Bicycle Activity Data. The following open data sources were identified for the Melbourne Metropolitan Area:

- *City of Melbourne Open Data Portal* — "Transport Activity Counts" (granular traffic counts by mode) and "Traffic Count Vehicle Classification" (vehicle composition by type) (City of Melbourne, 2024).
- *Transport Victoria Open Data Portal (DTP/VicRoads)* — "Bluetooth Travel Time" (link-level travel time and congestion metrics), "Traffic Signal Volume Data" (intersection-level traffic volumes), and "Bicycle Volume and Speed" (bicycle counts and average speeds) (Transport Victoria, 2024).

Due to programmatic access constraints encountered during data retrieval (HTTP 403 responses on automated fetches; API access requiring institutional registration), empirical data were substituted with simulated datasets for the purposes of this preliminary analysis. This constitutes a recognised limitation, discussed further in Section 4.

Emission Factors. Vehicle emission parameters were derived from Australian transport and energy literature:

- *Idling emission rate:* A fleet-average value of **3,500 g CO_2/hour** per vehicle was adopted, consistent with estimates ranging from 2,400 to 4,500 g CO_2/hour across vehicle classes reported in Australian motoring sources (Drive.com.au, 2023).
- *Free-flow urban emission rate:* A value of **190 g CO_2/km** was used, aligned with the national average for passenger vehicles reported by the National Transport Commission (NTC, 2023) and the Australian Energy Council (AEC, 2023).
- *Stop-start emission multiplier:* A factor of **1.25** (representing a 25% increase over free-flow emissions) was identified from the literature on real-world driving cycles. In the current simplified model, this factor was not applied directly; instead, delay-related emissions were modelled as idling-equivalent emissions for the duration of the delay.

The COPERT Australia model (Emisia, 2024; DCCEEW, 2023) was noted as a more sophisticated alternative for future emission factor estimation.

2.3 Breakeven Model Specification

The breakeven model operates on the following logic:

Carbon savings from cycling (S):

$$S = d\_cyclist \times EF\_free\text{-}flow$$

where *d_cyclist* is the distance of the trip replaced by cycling (km) and *EF_free-flow* is the free-flow emission rate of the displaced motor vehicle (g CO_2/km).

Additional emissions from delayed vehicles (E):

$$E = n\_cars \times (t\_stuck / 60) \times EF\_idle$$

where *n_cars* is the number of vehicles delayed, *t_stuck* is the delay duration per vehicle (minutes), and *EF_idle* is the idling emission rate (g CO_2/hour).

Breakeven condition:

The net environmental impact is zero when S = E. The model solves for either *n_cars* (given fixed *t_stuck*) or *t_stuck* (given fixed *n_cars*) at the breakeven point.

2.4 Scenario Parameters

Four scenarios were defined to illustrate the sensitivity of the breakeven point to key input parameters:

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Replaced trip distance (km)	5	5	10	10
Number of delayed vehicles	3	10	1	Variable (solved)
Delay per vehicle (min)	2	5	Variable (solved)	2

2.5 Limitations of the Methodology

Several limitations should be noted at the outset:

1. The use of simulated rather than empirical traffic data restricts the external validity of the numerical results.
2. The idling-equivalent assumption for delay-related emissions is a simplification; real-world stop-start driving involves a complex pattern of acceleration, deceleration, and idling with non-linear emission profiles.
3. The model does not account for spatial heterogeneity (e.g., gradient, intersection density), temporal variation (e.g., peak versus off-peak), or fleet composition effects.
4. Behavioural responses such as route diversion, overtaking, or induced demand are not modelled.

---

3. Results

The breakeven model was executed across the four defined scenarios. Results are summarised in Table 1 and described below.

Table 1. Scenario results for the cyclist-vehicle emissions breakeven analysis.

Scenario	Cyclist CO2 Saving (g)	Additional Vehicle CO2 (g)	Breakeven Status
1	950.00	350.00	Not reached — net benefit retained
2	950.00	2,916.67	Exceeded — net disbenefit
3	1,900.00	Solved: 1,900.00	Breakeven at 32.57 min delay
4	1,900.00	Solved: 1,900.00	Breakeven at 16.29 vehicles

3.1 Scenario 1: Short Delay, Few Vehicles, 5 km Trip

A cyclist replacing a 5 km car trip was estimated to save 950.00 g CO2. With 3 trailing vehicles each delayed by 2 minutes, the additional emissions totalled 350.00 g CO2. The cyclist's trip produced a net environmental benefit, with savings exceeding induced emissions by approximately 600 g CO2.

3.2 Scenario 2: Longer Delay, More Vehicles, 5 km Trip

Under identical trip distance assumptions but with 10 delayed vehicles each experiencing a 5-minute delay, additional emissions rose to 2,916.67 g CO2 — more than three times the cyclist's savings of 950.00 g CO2. Under these conditions, the net environmental impact of the cycling trip was negative.

3.3 Scenario 3: Single-Vehicle Breakeven Duration for a 10 km Trip

For a cyclist replacing a 10 km trip (saving 1,900.00 g CO2), the model estimated that a single trailing vehicle would need to be delayed for approximately **32.57 minutes** at idling-equivalent emission rates to fully offset the cyclist's carbon saving.

3.4 Scenario 4: Multi-Vehicle Breakeven Count for a 10 km Trip

With a fixed delay of 2 minutes per vehicle, approximately **16.29 vehicles** (effectively 17 vehicles) would need to be delayed behind a cyclist to offset the 1,900.00 g CO2 saved by a 10 km cycling trip.

---

4. Discussion

4.1 Interpretation of Findings

The results indicate that the environmental breakeven point for mixed-mode transport in shared-lane conditions can be reached under plausible urban traffic scenarios. Although a single cyclist replacing a car trip generates meaningful CO2 savings (on the order of 1–2 kg per trip), these savings are vulnerable to erosion when multiple vehicles experience even modest delays.

Scenario 2 is particularly instructive: 10 vehicles delayed for 5 minutes — a situation that is not uncommon on arterial roads during peak periods — was sufficient to produce a net environmental disbenefit approximately three times the magnitude of the cyclist's savings. This finding challenges the implicit assumption in much transport policy that every kilometre cycled represents a net environmental gain, regardless of the infrastructure context.

4.2 Contextual Considerations

It is important to interpret these findings within their appropriate context. The model represents a deliberately simplified, worst-case framing. Several real-world factors would moderate the results:

- **Overtaking behaviour:** On multi-lane roads or where overtaking is feasible, the effective delay per vehicle may be substantially shorter than modelled.

- **Infrastructure provision:** Dedicated cycling lanes, physically separated from motor traffic, would eliminate the shared-lane interaction entirely, rendering the breakeven question moot.
- **Induced demand and mode shift:** Over longer time horizons, cycling infrastructure may reduce overall motor vehicle volumes, producing system-level emission reductions that are not captured in the per-trip model.
- **Fleet electrification:** As the motor vehicle fleet transitions toward electric vehicles, the idling and stop-start emission penalties will diminish, shifting the breakeven point in favour of cycling.

4.3 Policy Implications

Notwithstanding these caveats, the analysis highlights the importance of infrastructure design in determining the net environmental impact of cycling promotion. Shared-lane configurations on high-volume roads may produce perverse environmental outcomes. Investment in separated cycling infrastructure not only improves cyclist safety but also preserves the emission reduction benefits of modal shift by eliminating adverse traffic flow interactions.

---

5. Conclusion

This study developed a simplified breakeven model to assess the net environmental impact of mixed-mode transport in the Melbourne Metropolitan Area. The analysis demonstrates that, under shared-lane conditions, the CO2 savings from cycling can be offset by relatively modest disruptions to motor vehicle traffic flow. Specifically, as few as 10 vehicles delayed for 5 minutes can negate the emission savings of a typical 5 km cycling trip.

These findings do not argue against the promotion of cycling as a sustainable transport mode. Rather, they underscore the critical role of infrastructure design in realising the environmental benefits of active transport. Separated cycling infrastructure, by decoupling bicycle and motor vehicle traffic flows, ensures that the emission savings from modal shift are not eroded by secondary traffic disruption effects.

5.1 Directions for Future Research

Several avenues for future research are recommended:

1. **Empirical data integration:** Subsequent iterations of this model should incorporate real traffic flow, speed, and bicycle activity data from the City of Melbourne and Transport Victoria open data platforms.
2. **Advanced emission modelling:** Integration of the COPERT Australia model or equivalent tools would permit more accurate estimation of stop-start emission profiles, including acceleration and deceleration effects.

3. **Spatiotemporal analysis:** Coupling the model with geographic information systems (GIS) data on cycling infrastructure networks would enable corridor-level and time-of-day analysis.
4. **Sensitivity and uncertainty analysis:** A systematic sensitivity analysis across key parameters (idling rate, stop-start multiplier, fleet composition, delay duration) is needed to characterise the robustness of the breakeven estimates.
5. **Fleet composition effects:** Incorporating vehicle classification data would allow weighted emission rates that reflect the actual on-road fleet mix.
6. **Lifecycle and system-level modelling:** Extending the analysis to account for lifecycle emissions (vehicle manufacturing, infrastructure construction) and system-level dynamics (induced demand, long-term mode shift) would provide a more comprehensive environmental assessment.

References

Australian Energy Council. (2023). *Vehicle emissions and fuel efficiency data.* AEC. https://www.energycouncil.com.au

Austroads. (2020). *Guide to traffic management: Part 4 — Network management.* Austroads Ltd.

City of Melbourne. (2024). *Open data platform: Transport activity counts; Traffic count vehicle classification* [Data set]. City of Melbourne. https://data.melbourne.vic.gov.au

Department of Climate Change, Energy, the Environment and Water (DCCEEW). (2023). *National greenhouse accounts factors.* Australian Government. https://www.dcceew.gov.au

Drive.com.au. (2023). *How much fuel does idling use?* Drive Media. https://www.drive.com.au

Emisia. (2024). *COPERT Australia: Road transport emission estimation tool.* Emisia SA. https://www.emisia.com

Gosse, C. A., & Clarens, A. F. (2013). Quantifying the total cost of infrastructure to enable environmentally preferable decisions: The case of urban roadway design. *Environmental Research Letters*, 8(1), 015028.

National Transport Commission (NTC). (2023). *Carbon dioxide emissions intensity for new Australian light vehicles.* NTC. https://www.ntc.gov.au

Pucher, J., & Buehler, R. (2017). Cycling towards a more sustainable transport future. *Transport Reviews*, 37(6), 689–694.

Transport Victoria. (2024). *Open data: Bluetooth travel time; Traffic signal volume data; Bicycle volume and speed* [Data set]. Department of Transport and

Planning. https://transport.vic.gov.au/data-and-research/open-data

---

Report prepared as part of a preliminary investigation into mixed-mode transport emissions dynamics in the Melbourne Metropolitan Area.