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Slow and Steady Wins the Race: How Autonomy Facilitates Long-Haul Truck Electrification

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This paper examines how autonomy affects the competitiveness and operations of battery-electric long-haul trucks. We model fleet operations between Sydney and Melbourne—Australia's busiest long-haul corridor—using a parameterised cost-minimisation framework. By lowering travel-time costs, autonomy leads to slower optimal speeds and reduced energy use. This enables smaller, lighter battery packs or reduces the number of charging stops en route, lowering total costs. Autonomy thus enhances the economic case for battery-electric trucks, improving their cost competitiveness relative to diesel trucks to approximately the same extent as would a AUS$50/kWh reduction in battery pack price.

Keywords

heavy-duty trucks, overland freight, economics, autonomous vehicles, decarbonization

JEL Classification

O33, Q40, Q54, R40

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Slow and steady wins the race: how autonomy facilitates long-haul truck electrification

Anthony Wiskich*

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This paper examines how autonomy affects the competitiveness and operations of battery-electric long-haul trucks. We model fleet operations between Sydney and Melbourne—Australia's busiest long-haul corridor—using a parameterised cost-minimisation framework. By lowering travel-time costs, autonomy leads to slower optimal speeds and reduced energy use. This enables smaller, lighter battery packs or reduces the number of charging stops en route, lowering total costs. Autonomy thus enhances the economic case for battery-electric trucks, improving their cost competitiveness relative to diesel trucks to approximately the same extent as would a AUS$50/kWh reduction in battery pack price.

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1 Introduction

The decarbonisation of long-haul trucking is important for achieving net-zero emissions targets, but remains technically and economically challenging. Battery-electric trucks offer a promising alternative to diesel, yet high upfront costs, long charging times, and payload penalties from battery weight hinder their adoption. At the same time, advances in autonomous driving technology are poised to reshape freight logistics by reducing labour costs and altering optimal operational patterns. While previous literature has pointed to complementarities between autonomous and battery-powered trucks, the economics underlying the interaction between these technologies remains underexplored. This paper addresses this gap by quantifying how autonomy affects the relative competitiveness of battery- versus diesel-powered fleet trucks. We develop a cost-minimising model for Australia's busiest long-haul freight corridor—between Melbourne and Sydney—while drawing broader insights for long-distance freight operations.

Battery-electric trucks are likely to first gain traction on short-haul routes, where frequent returns to base allow for easier recharging and reduce battery capacity needs (AECOM, 2024; Innovation, 2025). In contrast, long-haul trucks require larger batteries, which can reduce payload if the truck is weight-constrained (Liimatainen et al., 2019). Battery capacity can be reduced by charging en route, though this can prolong trips (Cheng & Lin, 2024), or by slowing down (Davis & Figliozzi, 2013; Lee et al., 2013). We consider stationary charging only, excluding highway charging systems such as overhead catenaries. Several studies suggest that battery-electric long-haul trucks will undercut diesel trucks on total cost by 2030–2035, largely due to battery improvements (Innovation, 2025; Ledna et al., 2024; Link et al., 2024; Tanco et al., 2019).

Autonomous driving could shift this landscape further. Autonomy can reduce driver costs, lower energy use via smoother driving, and eliminate rest breaks (Fagnant & Kockelman, 2015; Wadud et al., 2016). Smaller trucks may benefit more if driver wages form a larger cost share (Wadud, 2017), but regulatory and technical constraints may limit autonomous operations to specific corridors (Monios & Bergqvist, 2019). Without a driver, time costs fall—resulting in lower optimal speeds for autonomous trucks (Ghandriz et al., 2020). For example, Bray and

Cebon (2022) find that reducing speeds from 90 km/h to 70 km/h increases costs by 3% for a truck with a driver but reduces costs by 4% for an autonomous truck.

The effect of autonomy on fleet operations, including the adoption of battery-powered trucks, is subject to some uncertainty (Engholm et al., 2025). However, Ghandriz et al. (2020) provide a useful quantitative foundation, finding that autonomy decreases the total cost of ownership for battery-powered tractor-semi trailers more than for diesel-powered ones. For example, on the longest route they consider of 320 km, cost reductions from autonomy are on average 34% for battery trucks and 26% for diesel trucks. They also find that hilliness is important for the competitiveness of battery trucks.

Our study differs by optimising over a continuum of speeds and battery sizes, while abstracting from terrain as we consider the predominantly flat Australian landscape. We present results across a grid of battery pack price and energy density pairs (Wiskich, 2025), providing insight into how the interaction between autonomy and electrification varies with the uncertain future development of battery technology. We also account for payload losses from battery weight (Mauler et al., 2022) and consider optimal recharging for both volume- and weight-constrained trips.

A secondary contribution of our study is an analysis of Australia's trucking sector by trip distance. While most truck emissions are from short-haul trips (Climateworks Centre, 2023), we decompose activity by distance band and major routes, using tonne-kilometres as an emissions proxy. This provides context for assessing the decarbonisation potential of targeted electrification of long-haul trucks.

2 Model

We model the total costs of operating a single depot-to-depot route. There are two types of trip: weight-constrained (where the additional weight from a battery truck reduces the payload) and volume-constrained (where the payload is unchanged and the battery increases the weight of the truck). We consider three cases: *pure weight-constrained* operations, *pure volume-constrained* operations, and a *combination* of both trip types across the year. In the equations below, a bold parameter indicates invariance to the choice variables. Parameter values are in Appendix B.

2.1 Model for a single trip type

For the *pure weight-constrained* and *pure volume-constrained* cases, the truck operator minimises the cost (C) of each standard delivery. For battery trucks, the choice variables are:

- Speed (S): constrained to a maximum of 100 km/h by regulation
- Number of en-route charging stops (n): a non-negative integer
- Battery capacity (Q): in kWh, subject to a minimum threshold Q_{min}

For diesel trucks, only speed is optimized, as we assume sufficient fuel is carried to complete the trip without refuelling. The cost components include energy (C_E), battery (C_Q), truck (C_T), variable mileage (C_X) and time (C_V). If payloads are reduced due to battery weight, from $\mathbf{M}_{f,pay}$ for diesel trucks to M_{pay}, the costs increase to account for this reduction, as shown in equation (1).

$$\text{For battery trucks:} \quad \min_{S,n,Q} C, \; C = (C_E + C_Q + C_T + C_X + C_V) \, \frac{\mathbf{M}_{f,pay}}{M_{pay}} \tag{1}$$

$$\text{For diesel trucks:} \quad \min_{S} C, \; C = (C_E + C_T + C_X + C_V) \tag{2}$$

We now define the truck weights and payloads. Whether the battery truck's payload is limited by the maximum weight allowed by regulations ($\bar{\mathbf{M}}$) is an important consideration in our analysis. The diesel truck weight consists of the empty truck ($\mathbf{M}_{empty}$) and the payload ($\mathbf{M}_{f,pay}$). In a volume-constrained trip, total weight is less than the maximum ($\mathbf{M}_{empty} + \mathbf{M}_{f,pay} < \bar{\mathbf{M}}$), while the truck weighs the maximum level in a weight-constrained trip. The battery truck weight (M) includes the battery weight (M_Q) adjusted for weight savings due to the lack of internal combustion engine (ICE) components ($\mathbf{M}_{ICE}$), the payload (M_{pay}) and the same empty weight. The battery pack's gravimetric energy density is $\boldsymbol{\rho}$. Step functions indicate the configurations: battery ($\boldsymbol{\delta}_Q = 1$) versus diesel ($\boldsymbol{\delta}_Q = 0$) trucks, and driver ($\boldsymbol{\delta}_D = 1$) versus autonomous ($\boldsymbol{\delta}_D = 0$).

$$M = M_{pay} + \mathbf{M}_{empty} + M_Q - \boldsymbol{\delta}_Q \mathbf{M}_{ICE}, \tag{3}$$

$$M_Q = \frac{Q}{\boldsymbol{\rho}} \tag{4}$$

$$M_{pay} = \min\left(\mathbf{M}_{f,pay}, \bar{\mathbf{M}} - \mathbf{M}_{empty} - (M_Q - \boldsymbol{\delta}_{\boldsymbol{Q}} \mathbf{M}_{ICE})\right) \tag{5}$$

Truck costs include capital costs ($\mathbf{K}_T$) adjusted for the savings from eliminating ICE components for battery trucks ($\mathbf{K}_{ICE}$), converted to an equivalent annualised cost (using rate $\mathbf{i}_T$), and additional yearly fixed costs per truck ($\mathbf{F}_T$). Over a year, the truck spends a constant proportion of time on the road ($\mathbf{U}$). The time moving on the road is the trip distance ($\mathbf{X}$) over speed. The time spent stopped on the road (t_{stop}) is the charging time, subject to a minimum ($t_{min\ stop}$) for driver rest stops, consisting of a base rest time ($\mathbf{R}_0$) and an additional rest time ($\mathbf{R}_\Delta$) per hour above a threshold ($\mathbf{t}_0$). The charging time is the number of stops (n) times a connection time ($\mathbf{t}_{connect}$), plus total charging time - a constant charge rate ($\boldsymbol{\Gamma}$) times the total capacity charged (e_2).

$$C_T = ((\mathbf{K}_T - \delta_Q \mathbf{K}_{ICE})\mathbf{i}_T + \mathbf{F}_T + (1 - \boldsymbol{\delta}_D)\mathbf{K}_{aut})\frac{t}{365(24)\mathbf{U}}, \tag{6}$$

$$t = t_{moving} + t_{stop} \tag{7}$$

$$t_{moving} = \frac{\mathbf{X}}{S}, \quad t_{stop} = \max(n\mathbf{t}_{connect} + \boldsymbol{\Gamma} e_2, t_{min\ stop}) \tag{8}$$

$$t_{min\ stop} = \boldsymbol{\delta}_D(\mathbf{R}_0 + \max(0, t_{moving} - \mathbf{t}_0)\mathbf{R}_\Delta) \tag{9}$$

The energy costs are either for fuel (C_f) or electricity (C_e). The power needed by the truck (P) is the sum of an aerodynamics term (P_{aero}), a cubic function of speed (S), and a rolling term (P_{roll}) proportional to speed and mass. Fuel is converted to useful power by $\boldsymbol{\lambda}$ litres per kWh and the price is $\mathbf{p}_f$. The price of electricity at a depot (p_1) is a base level $\mathbf{p}_{base}$ plus an uplift, dependent on battery capacity by factor $\mathbf{p}_\Delta$, while the price at en route charging stations is $\mathbf{p}_2$. Some battery capacity ($\mathbf{Q}_{res}$) is held in reserve, leaving usable capacity Q_0, and charging the battery has efficiency $\boldsymbol{\eta}$. We assume that the battery truck leaves the depot fully charged.

$$C_E = (1-\boldsymbol{\delta}_Q)C_f + \boldsymbol{\delta}_Q C_e, \tag{10}$$

$$C_f = \mathbf{p}_f f, \quad f = \boldsymbol{\lambda} P t_{moving}, \quad P = P_{aero} + P_{roll} \tag{11}$$

$$P_{aero} = \boldsymbol{\alpha}\left(\frac{S}{3.6}\right)^3, \quad P_{roll} = \frac{\boldsymbol{\beta} SM}{3.6} \tag{12}$$

$$C_e = \frac{p_1 E_1 + \mathbf{p}_2 E_2}{\boldsymbol{\eta}}, \quad p_1 = \mathbf{p}_{base} + \mathbf{p}_{\Delta} Q \tag{13}$$

$$E_1 = \min(Q_0, E), \quad E_2 = E - E_1 \tag{14}$$

$$Q_0 = \boldsymbol{\delta}_Q(Q - \mathbf{Q}_{res}), \quad E = t_{moving} P \tag{15}$$

The equivalent annualised cost of the battery (C_Q) depends on pack price ($\mathbf{p}_Q$), capacity, financial interest rate ($\mathbf{i}_Q$), lifetime in cycles (τ) and cycles per year (θ).

$$C_Q = \frac{tc_Q}{365(24)\mathbf{U}}, \tag{16}$$

$$c_Q = \mathbf{p}_Q Q \mathbf{i}_Q \frac{(1+\mathbf{i}_Q)^{\tau/\theta}}{(1+\mathbf{i}_Q)^{\tau/\theta} - 1}, \quad \theta = \frac{E365(24)\mathbf{U}}{Qt} \tag{17}$$

Variable mileage costs (C_X) are set relative to tyre maintenance costs ($\mathbf{m}_{tyre}$) and other maintenance ($\mathbf{m}_f$ for diesel, $\mathbf{m}_Q$ for battery) costs for a truck at maximum weight, with elasticities $\boldsymbol{\sigma}_{tyre}$ and $\boldsymbol{\sigma}_o$.

$$C_X = \mathbf{X}\left(\mathbf{m}_{tyre}\left(\frac{M}{\bar{\mathbf{M}}}\right)^{\boldsymbol{\sigma}_{tyre}} + \left((1-\boldsymbol{\delta}_Q)\,\mathbf{m}_f + \boldsymbol{\delta}_Q \mathbf{m}_Q\right)\left(\frac{M}{\bar{\mathbf{M}}}\right)^{\boldsymbol{\sigma}_o}\right) \tag{18}$$

Driver costs per hour are $\mathbf{W}_D$ and a variable time cost $\mathbf{W}_{aut}$ applies to an autonomous truck. Other time costs ($\mathbf{W}_t$) include consideration of delivery time.

$$C_V = (\boldsymbol{\delta}_D \mathbf{W}_D + (1-\boldsymbol{\delta}_D)\mathbf{W}_{aut} + \mathbf{W}_t)t \tag{19}$$

2.2 Model for a *combination* of trip types

To combine the weight-constrained and volume-constrained trip types denoted by subscripts w and v, the combined costs are minimised based on a fixed proportion (ϕ) of weight-constrained trips. We allow different speeds and number of stops for the two trip types, but enforce a single battery capacity.

$$\text{For battery trucks: } \min_{S_w, S_v, n_w, n_v, Q} \boldsymbol{\phi} C_w + (1 - \boldsymbol{\phi}) C_v \tag{20}$$

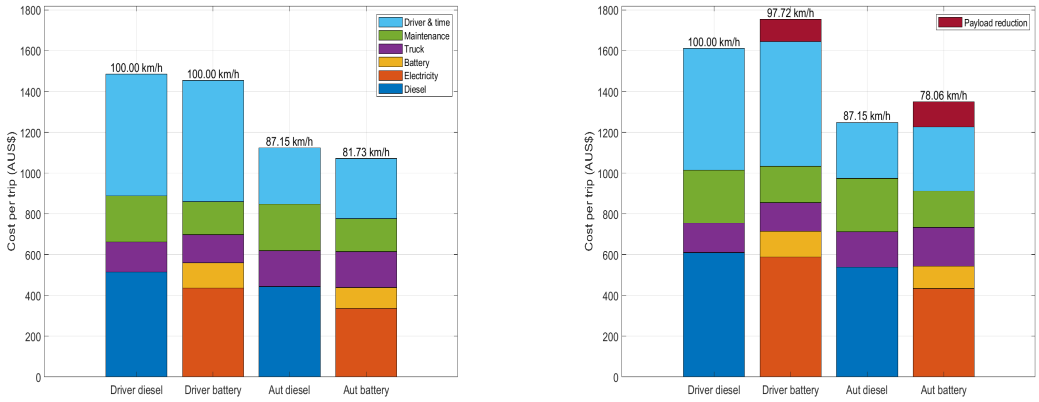
$$\text{For diesel trucks: } \min_{S_w, S_v} \boldsymbol{\phi} C_w + (1 - \boldsymbol{\phi}) C_v \tag{21}$$

3 Results

This section presents results across a range of scenarios that vary the truck's propulsion method (diesel or battery) and autonomy status (with driver or autonomous). We evaluate three cases: *pure weight-constrained*, *pure volume-constrained*, and a *combination*. Section 3.1 presents cost breakdowns, Section 3.2 discusses optimal battery and charging strategies for different cases, and Section 3.3 explores competitiveness thresholds focussing on the *combination* case.

3.1 Cost breakdown comparison

We begin by decomposing total costs using a single battery pack price-density pair to illustrate cost structures and operation under different payload constraints. Figure 1 compares the costs for a diesel truck and a battery truck with a price-density pair of AUS\$150/kWh and 200 Wh/kg. The battery truck includes a cost for payload reduction that occurs in a weight-constrained trip. Optimal speeds for the diesel truck with a driver are the maximum limit of 100 km/h, reducing to 87 km/h for an autonomous truck with lower variable time costs. Consequently, emissions from the autonomous truck are 12% and 14% lower for the *pure weight-* and *pure volume-constrained* cases, respectively. The optimal speeds for an autonomous diesel truck are identical between the two cases, as the first derivative of cost with respect to speed is independent of mass (derivation in the following equation block). Intuitively, truck capital, time, and aerodynamic costs are independent of mass, while mileage and rolling resistance costs (over a given distance) are independent of speed.



A: *Pure volume-constrained* **B:** *Pure weight-constrained*

Figure 1: Optimal costs and speeds for diesel and battery trucks with a price-density pair of AUS$150/kWh and 200 Wh/kg.

$$\begin{aligned}\frac{\partial^2 C}{\partial M \partial S} &= \frac{\partial^2 C_f}{\partial M \partial S} + \frac{\partial}{\partial S}\left(\cancel{\frac{\partial C_T}{\partial M}}\right) + \frac{\partial}{\partial M}\left(\cancel{\frac{\partial C_X}{\partial S}}\right) + \frac{\partial}{\partial S}\left(\cancel{\frac{\partial C_V}{\partial M}}\right) \\ &= \mathbf{p}_f \boldsymbol{\lambda}\left(\frac{\partial}{\partial S}\left(\cancel{\frac{\partial t_{moving} P_{aero}}{\partial M}}\right) + \frac{\partial}{\partial M}\left(\frac{\partial t_{moving} P_{roll}}{\partial S}\right)\right) \\ &= \mathbf{p}_f \boldsymbol{\lambda} \frac{\boldsymbol{\beta X}}{3.6} \frac{\partial}{\partial M}\left(\cancel{\frac{\partial M}{\partial S}}\right) \\ &= 0\end{aligned} \tag{22}$$

3.2 Optimal battery capacities and competitiveness by operational case

This section discusses how the optimal choice variables for battery trucks differ over a grid of pack price-density pairs, and by operational case. Figure 2 shows optimal battery capacities. For the best visibility of the surfaces, the price axis is inverted, so as the price falls and density rises, their combination moves towards the far (top right) corner of the surface. We also draw a solid "cost parity" line on the surface, beyond which the costs of the battery-powered truck are lower than the diesel truck. Unlike the surface, this line is calculated in price increments of single $ per kWh. We include contour dashed lines, and each surface point is annotated with the average number of charging stops for that price–density pair. As weight-constrained trips may involve an extra charge stop, this average may not be an integer in the *combination* case. For example, a value of 0.3 implies no stops for a volume-constrained trip (70%) and one stop for a weight-constrained trip (30%). The first column corresponds to a truck with a driver, and the second to an autonomous truck. The first and second rows correspond to *pure volume-constrained* and *pure weight-constrained* cases, respectively, and the third row to a *combination*.

Panel A shows very high optimal capacities exceeding 1.3 MWh for the best battery pack technology (low-cost, high-density pair). Such capacities are sufficient to cover the entire trip without the need to charge en route. This is optimal because the higher electricity price on the road dominates the financial and weight cost burden of a large battery (there would be no time penalty for one or two charge stops due to compulsory driver rest stops). However, at lower pack densities and higher prices, optimal capacities fall and the truck makes a charging stop, and generally travels at a slower speed. Speeds vary from 95 km/h to 100 km/h from the worst to the best price-density pairs (see Appendix A for the equivalent figure for speeds). Diesel out-competes batteries if battery prices exceed AUS$207/kWh, but at sufficiently low prices, batteries can out-compete diesel at any density we consider.

Panel C shows much reduced capacities for the *pure weight-constrained* case, where the battery weight reduces the payload. The truck now stops between 1 and 4 times to charge, and speeds vary between 90 km/h and 100 km/h. The cost parity line is pushed back, highlighting how payload penalties from battery weight reduce battery truck competitiveness. Panel E shows the varying capacities for the *combination* case, where the number of charging stops is between 0 and 4 and, naturally, the cost parity line lies between those for Panels A and C.

Panels B, D, and F show that lower optimal speeds in autonomous trucks (under 86 km/h) reduce energy needs, enabling smaller battery capacities when no charging stops occur. The lines marking equal costs between battery and diesel trucks are brought forward, as autonomy boosts the competitiveness of batteries relative to diesel. We discuss this key result further in Section 3.3, where we focus on the *combination* of trip types.

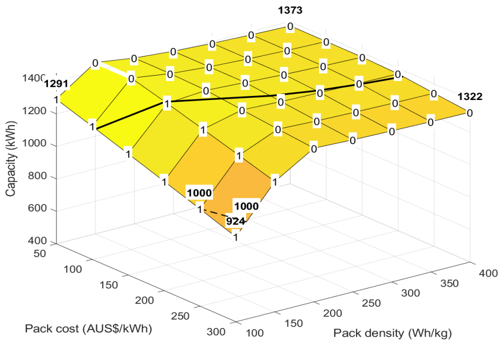
3.3 Results for a *combination* of trip types

We now focus on the *combination* case to reflect typical truck operations. Figure 3 shows the optimal number of charging stops. For a given battery pack price-density pair, autonomous trucks tend to stop fewer times than trucks with a driver, relating to lower energy needs due to reduced speeds, as discussed above. For some pairs, the number of stops is the same for weight- and volume-constrained trips, but in others the weight-constrained trips require an additional stop, reflecting the higher energy requirements of a heavier truck.

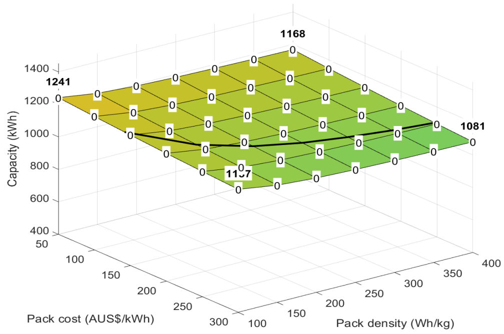
Figure 4 shows the cost parity lines for battery and diesel trucks, for our main scenario and sensitivities. We label the average number of charge stops at each data point. We also show historical and projected 2030 data points for these battery pack price-density pairs for vehicles (BloombergNEF, 2024a, 2024b). Panel A highlights the more favourable economics for autonomous battery trucks, along with the reduced number of charge stops.

The other panels indicate some sensitivities of interest, and more sensitivities are shown in Appendix A. Panel B highlights the importance of lower speeds in autonomous trucks. We show the cost parity line for a sensitivity where autonomous truck speeds are held at the optimal levels for non-autonomous operations, separately for diesel and battery trucks. For diesel trucks, holding the autonomous speed at 100km/h only increases costs by 1%. For battery trucks, there is up to a 14% increase in costs from holding autonomous speeds at the optimal levels with a driver. Thus, slower speeds are essential to autonomy's competitive advantage for battery trucks—without speed optimization, the improvement in competitiveness is almost eliminated.

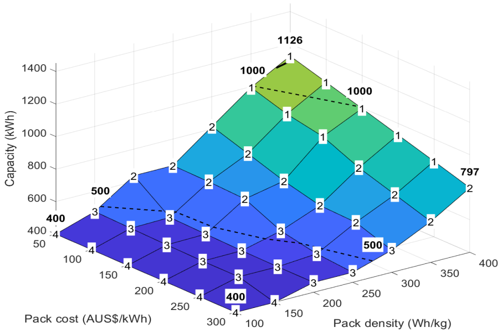
The competitiveness of battery trucks is highly dependent on electricity prices. Panel C reveals that the increase in competitiveness of battery trucks under a lower on-road electricity price depends on the number of charge stops. Thus, the effect is less pronounced for (i) autonomous trucks and (ii) as pack densities



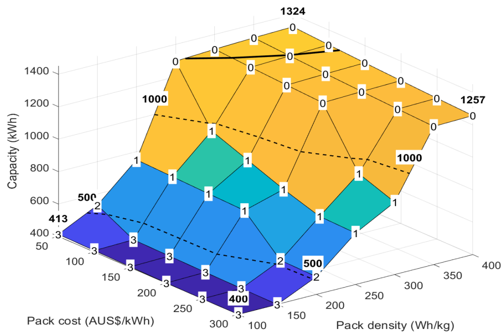
A: Driver, *pure volume-constrained*



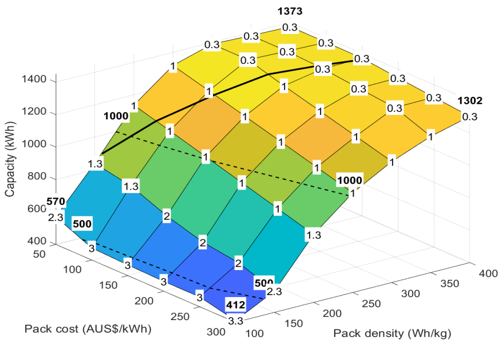
B: Autonomous, *pure volume-constrained*



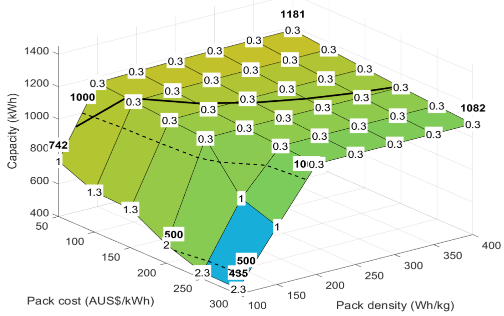
C: Driver, *pure weight-constrained*



D: Autonomous, *pure weight-constrained*

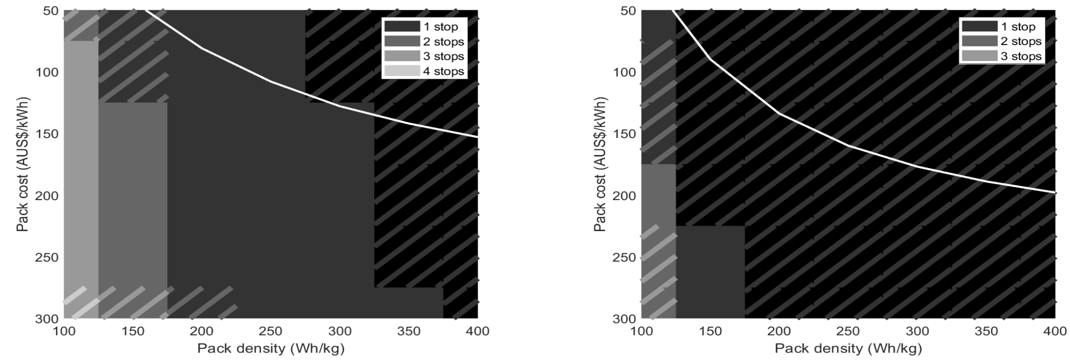


E: Driver, *combination*



F: Autonomous, *combination*

Figure 2: Optimal battery capacities for battery trucks, by pack price and density. The first column corresponds to a truck with a driver and the second to an autonomous truck. The first and second rows correspond to *pure volume-constrained* and *pure weight-constrained* cases, respectively; the third row corresponds to a *combination*. The solid black line indicates equal costs between diesel and battery trucks and the average number of charging stops are labelled at each data point.

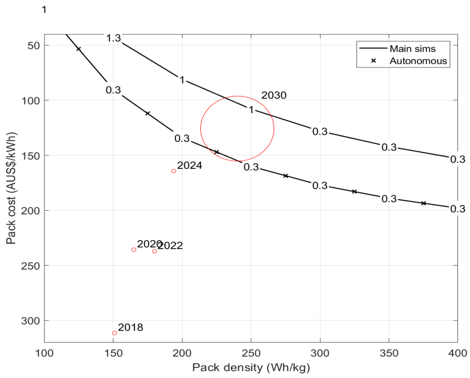


A: Driver, *combination* **B:** Autonomous, *combination*

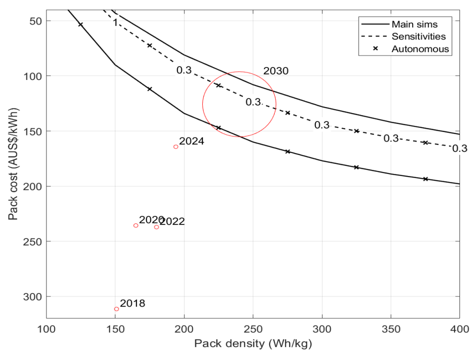
Figure 3: Optimal charging stops for battery trucks, by pack price and density. The first panel corresponds to a truck with a driver and the second to an autonomous truck. Hatched areas indicate where weight-constrained trips require an additional stop over volume-constrained trips. The white line indicates equal costs between diesel and battery trucks.

increase. Panel D shows the high dependence on the base price of electricity, with a reduction leading to roughly equal battery competitiveness gains in autonomous and non-autonomous trucks.

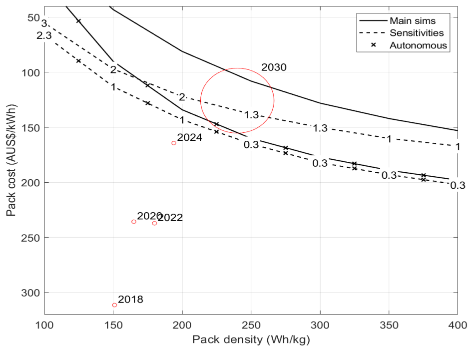
Panel E shows a high sensitivity to battery life, particularly for higher pack densities - the competitiveness gain from autonomy also increases, due to a larger battery and, thus, higher related cost share. Panel F shows that even a modest increase in distance from 800 km to 1000 km markedly reduces the competitiveness of battery trucks, with a slightly lower boost from autonomy. According to Australian regulations, drivers are limited to 10 hours work time in any 11 hour period before a night rest break must be taken, which our model does not consider (NHVR, 2025b). Thus, 1000 km would be close to the maximum distance a driver could undertake in a day.



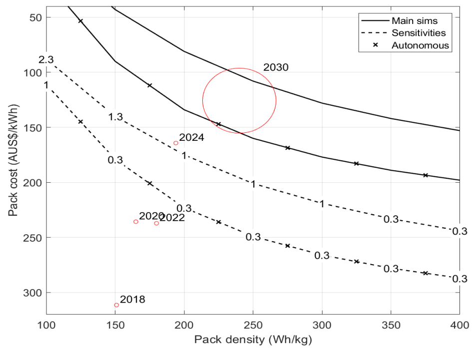
A: Main



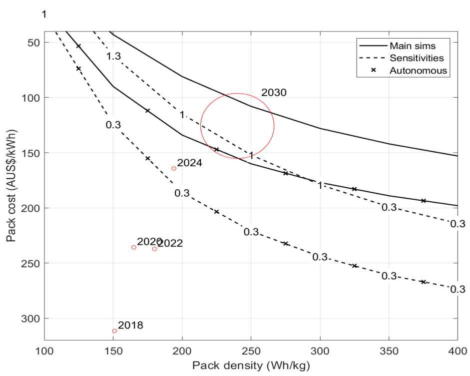
B: Autonomous speed same as driven



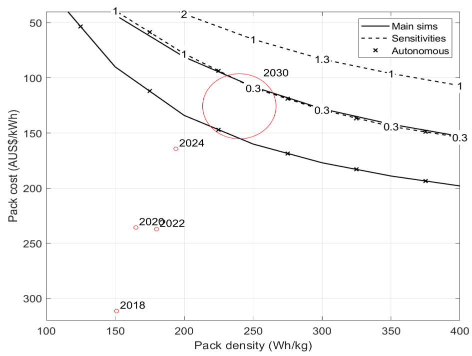
C: Base electricity price of \$0.17/kWh, from \$0.22/kWh



D: On-road electricity price uplift of \$0.15/kWh, from \$0.2/kWh



E: Battery life of 3000 cycles, from 2000



F: Trip of 1000 km, from 800 km

Figure 4: Battery and diesel truck cost parity lines for different pack price-density pairs, for the main scenario and sensitivities (*combination* of trip types). In AUS\$.

4 Discussion

Our results highlight a key finding: autonomy substantially boosts the competitiveness of battery-electric long-haul trucks, yielding cost reductions roughly equivalent to a AUS\$50/kWh decline in battery pack prices. This section contextualises these findings within Australia's freight sector and outlines limitations and directions for future work.

4.1 Context for Australia

If autonomy helps make battery-powered trips between Sydney and Melbourne (and similar or shorter distance trips) competitive, what kind of impact on long-haul emissions, or aggregate truck emissions, could this have? To assess this, we analyze 2014 truck activity data by trip distance (Australian Bureau of Statistics, 2016). Note that long-distance road travel in Australia is typically 20% to 25% longer than the geodesic (straight-line) distance due to road routing. Figure 5 shows a histogram of tonne-kilometres—a proxy for emissions—travelled by all trucks against geodesic distance. A description of the construction is in Appendix A. Trips under 500 km geodesic distance (corresponding to 600-625 km of actual driving) account for 59% of tonne-kilometres and thus dominate aggregate emissions. Data for the main intra-metro trips are shown in coloured areas in the first truncated column.

Trips between geodesic distances of 500 km and 1000 km make up 23% of the total, while distances beyond 1000km make up 18%. For a given truck size and speed, a more accurate emissions measure would combine tonne-kilometres (a proxy for rolling resistance) and distance (a proxy for aerodynamic resistance). The equivalent figure for the latter measure is in Appendix A and has a greater skew towards shorter-distance trips (79% $<$ 500km, 14% between 500 km and 1000 km, 7% $>$ 1000 km). Further, intra-urban trips with variable speeds likely have higher emissions per tonne-kilometre than long-haul trips, and road trains used on remote, extreme long-haul trips would have relatively low emissions per tonne-kilometre. These factors suggest that using tonne-kilometres as a proxy likely overstates the emission share of very long-haul trips ($>$1000 km).

The top 15 region pairs for trips exceeding 500 km (geodesic) are coloured in the figure. The Sydney–Melbourne corridor alone represents a significant share of long-haul freight. Included in the same column are the Brisbane-Sydney and Adelaide-Melbourne pairs. These routes could be good candidates for initial truck autonomy from an emission-reduction perspective. As revealed in Figure 4, longer trips become harder to electrify, but this result would be sensitive to electricity prices en route. For example, having low prices at a depot in Fitzroy could increase the competitiveness of the longer route between Brisbane and Cairns.

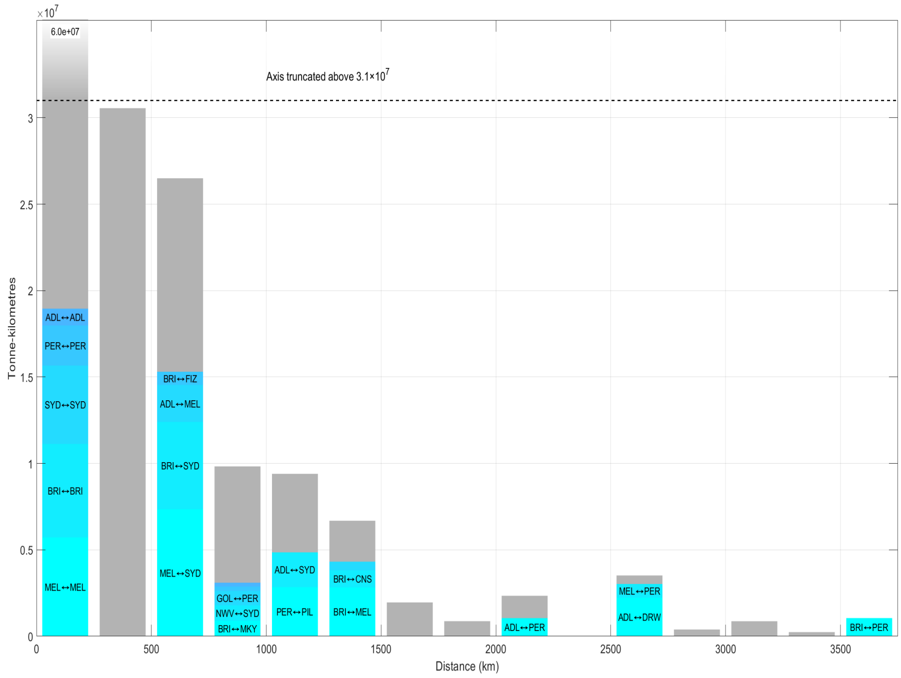


Figure 5: Histogram of truck tonne-kilometres in Australia by the geodesic trip distance, in 2014. SYD=Sydney, MEL=Melbourne, BRI=Brisbane, PER=Perth, ADL=Adelaide, FIZ=Fitzroy, GOL=Goldfields, NWV=North West Vic, MKY=Mackay, PIL=Pilbara, CNS=Cairns, DRW=Darwin

4.2 Limitations and future work

A critical assumption underpinning our result—that autonomy brings a relative cost advantage for battery trucks equivalent to a AUS\$50/kWh battery price drop—is that depot electricity remains significantly cheaper than en route charging. Charging at depots can be more flexible and less time critical, leading to greater utilisation of charging infrastructure and lower infrastructure costs per unit of electricity delivered. Further, on-road charging providers may set a higher price to account for site rental, profit margins, and greater operational risks (NREL, 2024a; Qmerit, 2025).

Many studies and industry sources corroborate a substantial cost difference between depot (or home-base) charging and public fast charging, in various regions. In Australia, public fast charging typically costs AUS$0.40-0.60/kWh compared to AUS$0.20–0.30/kWh for business grid electricity (Revcharge, 2025), with similar patterns in the US (NREL, 2024a; Qmerit, 2025), Europe (Octopus, 2025) and the UK (Flexible Power Systems, 2025). Academic studies also reflect this differential: Börjesson and Proost (2025) assume depot costs of €0.16/kWh versus €0.41/kWh en route, while Ledna et al. (2024) project US$0.18 versus US$0.28 in 2030. These sources suggest our assumed differential of AUS$0.12–0.18/kWh (see Appendix B) is conservative.

Electricity's temporal price variability—unlike diesel's—offers benefits from operational flexibility. For example, the average difference between low daytime prices (due to solar) and the evening peak in 2024 was around $0.3 per kWh (Beard, 2024). If truck operators are exposed to such price variation, they could adjust their operations to reduce the average price of electricity they pay. However, our model does not endogenise load shifting or arbitrage strategies. While we could proxy the benefits of electricity price variation by considering excess battery capacity (Börjesson & Proost, 2025; Greaker et al., 2022), we are not convinced of the merits of this approach without a more detailed logistical framework that explicitly accounts for trip scheduling and depot operations.

We do not consider the safety consequences of speed reductions for autonomous trucks. Heavy vehicles were limited to 80 km/h until the mid-1980s in Australia. Due to safety concerns (related to overtaking) of speed limit differentials between light and heavy vehicles, they were then increased (Mitchell, 2010). However, these risks may differ for multi-lane roads, such as the major highway between Sydney and Melbourne, and single-lane roads.

Our model is limited in its consideration of driver rest stops and could be extended to consider trips across the Nullabor, for example. Our simple single-trip approach omits insights that could be gained with a more complex logistical model. Such future work could draw out insights into interactions between charging infrastructure demands, the role of battery storage at depots, variable electricity prices, and optimal battery sizing for trips of various lengths. In-motion charging on the road could be explored, as well as the effects of uncertainty of future technology developments.

5 Conclusion

This paper explores how vehicle autonomy affects the competitiveness of battery-electric versus diesel-powered long-haul trucks. We find that autonomy significantly enhances the economic case for battery-electric trucks, with gains equivalent to a battery pack price reduction of approximately AUS$50 per kWh. This effect is consistent across a wide range of parameter choices, though it depends on a sustained cost premium for en-route versus depot electricity.

The primary mechanism behind this result is the lower optimal driving speed of autonomous trucks, which reduces energy consumption. This allows for smaller and lighter battery packs and typically fewer charging stops. These operational efficiencies suggest that enabling autonomous long-haul trucking could substantially accelerate fleet electrification, supporting decarbonisation goals.

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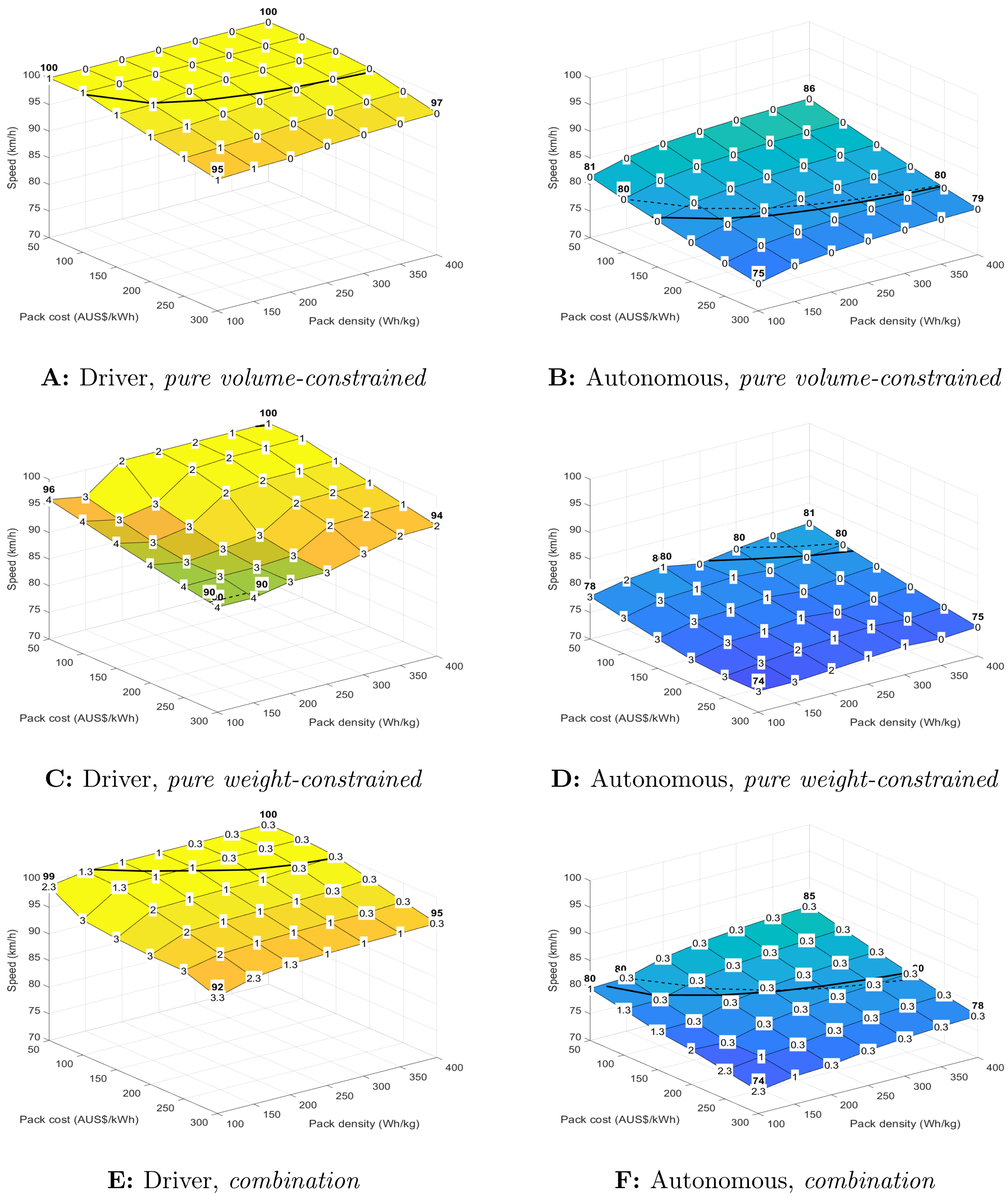
A Additional figures

Figure A.1 shows optimal speeds for battery-powered trucks, given different pack costs and densities. Speeds tend to reduce as the truck weight increases, for autonomous trips, and as battery pack prices increase.

Figure A.2 presents additional sensitivity analyses that highlight the robustness and conditions of the competitiveness advantage from autonomy. The key insights are:

- Panel A: Lowering the driver's wage from AUS$50/h to AUS$40/h has only a modest effect on the competitiveness differential, since labour cost savings remain substantial.
- Panel B: Increasing the autonomous truck's variable time cost from AUS$10/h to AUS$20/h reduces the competitiveness boost from autonomy.
- Panel C: Raising the proportion of weight-constrained trips reduces the competitiveness of driven and autonomous battery trucks by a similar degree.
- Panel D: Lowering battery truck maintenance costs enhances the boost from autonomy, as time-related costs make up a higher share.
- Panel E: Reducing the truck utilisation weakens the autonomy boost, due to a higher fixed cost share.
- Panel F: Reducing the truck weight further improves the autonomy boost, as energy needs of lighter trucks are more sensitive to aerodynamic savings from slower speeds.
- Panel G: Lowering rolling resistance makes battery trucks more competitive and marginally improves the boost from autonomy.
- Panel H: Lowering aerodynamic resistance weakens the autonomy boost, as the benefits of slower speeds are reduced.
- Panel I: Increasing the price of diesel provides a similar boost in competitiveness to driven and autonomous battery trucks.

Additional sensitivities with a low on-road charge rate of 2 MW (from 3 MW), and a high autonomy capital cost of AUS$100k (from AUS$50k), make little difference to competitiveness and are not shown.



A: Driver, *pure volume-constrained*

B: Autonomous, *pure volume-constrained*

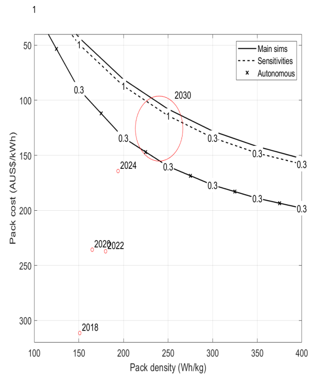
C: Driver, *pure weight-constrained*

D: Autonomous, *pure weight-constrained*

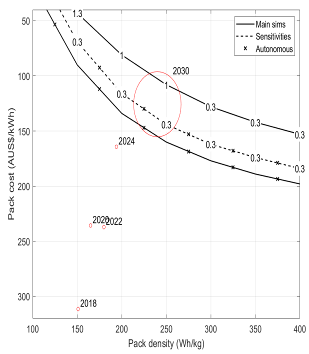
E: Driver, *combination*

F: Autonomous, *combination*

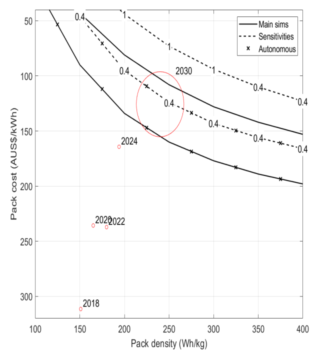
Figure A.1: Optimal speeds for battery trucks, by pack price and density. The first column corresponds to a truck with a driver and the second to an autonomous truck. The first and second rows correspond to *pure volume-constrained* and *pure weight-constrained* cases, respectively; the third row corresponds to a *combination*. The solid black line indicates equal costs between diesel and battery trucks and the average number of charging stops are labelled at each data point.



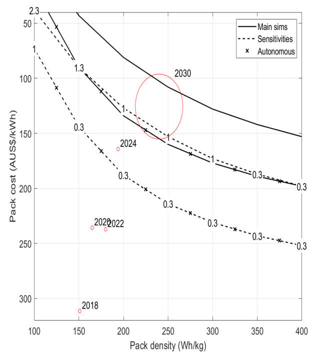
A: Driver wage of $40/h, from $50/h



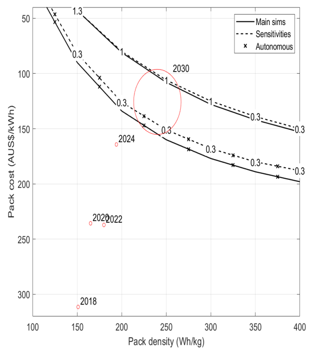
B: Autonomous "wage" of $20/h, from $10/h



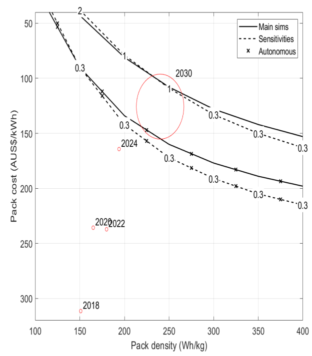
C: 40% weight-constrained trips, from 30%



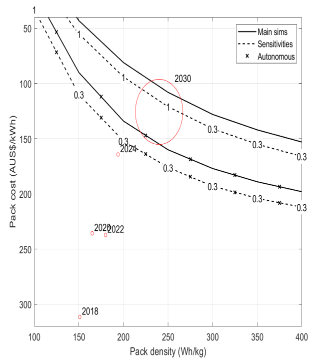
D: Elec truck maintenance of $0.1/km, from $0.15/km



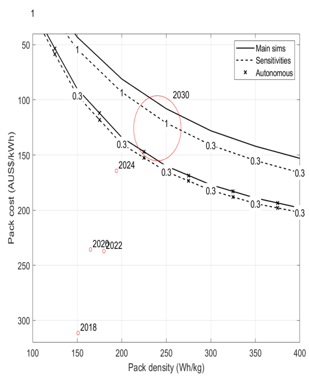
E: Truck utilisation of 50%, from 60%



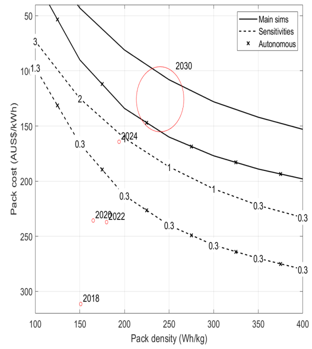
F: Lighter truck by 20% (empty, payload & max)



G: 10% lower rolling resistance



H: 10% lower aerodynamics resistance



I: $1.8/L diesel price, from $1.6/L

Figure A.2: Battery and diesel truck cost parity lines for different pack price-density pairs, for the main scenario and sensitivities (*combination* of trip types). In AUS$.

Figure A.3 replicates the analysis from Figure 5, but uses cumulative kilometres travelled rather than tonne-kilometres. This provides an alternative emissions proxy, emphasizing the dominance of short-haul trips even further. Both figures are constructed using SA3 trip data and shapefiles to calculate geodesic distances. Most of the labels in the figures combine to SA4 or city regions.

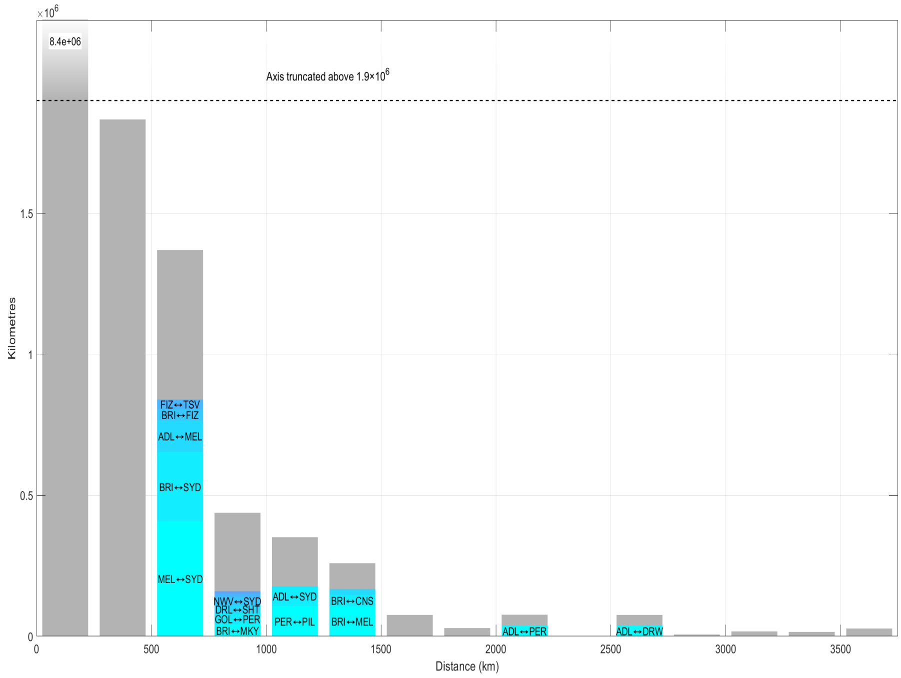


Figure A.3: Histogram of total truck kilometres in Australia by the geodesic trip distance, in 2014. SYD=Sydney, MEL=Melbourne, BRI=Brisbane, PER=Perth, ADL=Adelaide, FIZ=Fitzroy, TSV=Townsville, GOL=Goldfields, NWV=North West Vic, DRL=Darling Downs - Maranoa, SHT = Shepparton, MKY=Mackay, PIL=Pilbara, CNS=Cairns, DRW=Darwin

B Parameters

Table B.1: Parameter Values

Description	Parameter	Main [sensitivity]	Note
Trip distance (km)	$\mathbf{X}$	800 [1000]	Melbourne - Sydney
Maximum truck weight (kg)	$\bar{\mathbf{M}}$	60k [48k]	represents B-double truck (BITRE, 2024; NHVR, 2025a)
Truck empty weight (kg)	$\mathbf{M}_{empty}$	18k [14.4k]	Ghandriz et al. (2020) use 24.5t for a truck with 60t GCM
Volume-constrained diesel payload (kg)	$\mathbf{M}_{f,pay}$	24k [19.2k]	BITRE (2011) report an average payload for a B-double of 24t
Net weight saved without ICE (kg)	$\mathbf{M}_{ICE}$	900	890kg for battery (SAE Media Group, 2023), about 1800kg for ICE including gearbox (AJK Engines, 2025; Diesel Store, 2025)
Weight-constrained % for a *combination* of trip types	$\boldsymbol{\phi}$	30 [40]	Empty trips included in volume-constrained proportion
Minimum battery capacity (kWh)	Q_{min}	400	
Diesel truck capital cost ($)	$\mathbf{K}_T$	300k	Sharpe and Basma (2022) use US$175k, Ghandriz et al. (2020) use €186k for 60t GCM excluding ICE
Cost saving from electric motor & components versus ICE ($)	$\mathbf{K}_{ICE}$	25k	Ghandriz et al. (2020)
Equivalent annualised cost for all trucks	$\mathbf{i}_T$	20%	ICCT (2021)
Other fixed costs per truck ($)	$\mathbf{F}_T$	30k	ICCT (2021)
Autonomy hardware & software capital cost ($)	$\mathbf{K}_{aut}$	50k [100k]	Ghandriz et al. (2020) use €30k
Utilisation rate of trucks	$\mathbf{U}$	60% [50%]	Rates of 40% to 60% typically assumed (Ghandriz et al., 2020)
Connect time to charger (hrs)	$\mathbf{t}_{connect}$	5/60	
On-road charge power (kW)	$\boldsymbol{\Gamma}$	3000 [2000]	The Megawatt charging system standard is for up to 3.75 MW (NREL, 2024b)
Driver minimum rest time base (hrs)	$\mathbf{R}_0$	15/60	NHVR (2025b)
Driver min rest time delta threshold (hrs)	$\mathbf{t}_0$	5.5	NHVR (2025b)
Driver min rest time delta (hrs/hrs driven)	$\mathbf{R}_\Delta$	0.1	NHVR (2025b)
Diesel price ($/L)	$\mathbf{p}_f$	1.6 [1.8]	
Diesel specific fuel consumption (L/kWh)	$\boldsymbol{\lambda}$	0.25	Ghandriz et al. (2020)
Base electricity price ($/kWh)	$\mathbf{p}_{base}$	0.22 [0.2]	Ghandriz et al. (2020) use €0.1/kWh
Depot electricity price uplift factor ($/kWh/kWh)	$\mathbf{p}_\Delta$	0.05/1000	Larger truck batteries need more depot charging infrastructure, Ledna et al. (2024) use US$0.18 for depot charging in 2030
On-road electricity price ($/kWh)	$\mathbf{p}_2$	$\mathbf{p}_{base} + 0.2$ [$\mathbf{p}_{base} + 0.15$]	Börjesson and Proost (2025) use an uplift of €0.25/kWh, Ledna et al. (2024) use US$0.1 over depot costs in 2030
Aerodynamic resistance	$\boldsymbol{\alpha}$	$1.2(0.5 \times 1.2 \times 0.6 \times 10)$ [-10%]	Ghandriz et al. (2020), Reynard et al. (2016) use 0.4 rather than 0.6, uplift of 1.2 for terrain/weather
Rolling resistance	$\boldsymbol{\beta}$	$1.2(0.005 \times 9.81)$	Ghandriz et al. (2020) with uplift of 1.2 for terrain/weather
Battery efficiency	$\boldsymbol{\eta}$	90%	
Battery capacity in reserve (kWh)	$\mathbf{Q}_{res}$	50	
Financial interest rate	$\mathbf{i}_Q$	10%	Ghandriz et al. (2020) use 5%
Battery cycles life	$\boldsymbol{\tau}$	2k [3k]	No residual value at end of life, Ghandriz et al. (2020) use 2400 for energy-optimised packs
Maintenance cost of diesel trucks for a weight-constrained trip ($/km)	$\mathbf{m}_f$	0.25	Link et al. (2024) use €0.147 for all maintenance, Victoria Government (2024) report $0.26/km
Maintenance cost of battery trucks for a weight-constrained trip ($/km)	$\mathbf{m}_Q$	0.15 [0.1]	Link et al. (2024) use €0.098, Ghandriz et al. (2020) assume half diesel costs, both for all maintenance
Elasticity of maintenance costs with weight	$\boldsymbol{\sigma}_o$	0.3	
Weight-constrained tyre costs ($/km)	$\mathbf{m}_{tyre}$	0.075	Victoria Government (2024) report $0.12/km for forestry
Elasticity of tyre costs with weight	$\boldsymbol{\sigma}_{tyre}$	0.6	
Driver cost ($/h)	$\mathbf{W}_D$	50 [40]	Bray and Cebon (2022) use £15.4/h, Ghandriz et al. (2020) use €25/h, Cheng and Lin (2024) use US$30/h, Victoria Government (2024) report $44/h
Autonomous variable cost per truck ($/h)	$\mathbf{W}_{aut}$	10 [20]	Bray and Cebon (2022) and Ghandriz et al. (2020) use no cost
Other variable time costs ($/h)	$\mathbf{W}_t$	20	

All $ values are in AUS$.