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Title:

Total Cost of Ownership Framework for Trucks in Middle-Mile Logistics

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Abstract

Road freight has expanded steadily over the past two decades. Despite efficiency improvements, trucks remain a major emissions source, accounting for nearly 30 percent of transport-related emissions. Recent advances in vehicle technology and charging infrastructure create a critical window to accelerate electrification and progress toward net-zero freight operations. Upfront purchase costs remain a central barrier, as environmentally friendly trucks are typically more expensive than conventional diesel trucks. The total cost of ownership (TCO), which aggregates capital and operating costs over the vehicle life cycle, provides a more robust basis for comparing financial viability across truck technologies. This study focuses on battery electric trucks (BETs) and proposes a structured framework to evaluate TCO components. We decompose TCO into capital and operating cost categories to assess the influence of key parameters on TCO. The resulting framework enables consistent TCO estimation and comparison for BETs and conventional trucks, informing stakeholders' electrification planning and investment decisions.

1. Introduction

Heavy road vehicles are a major source of noxious transport emissions, despite comprising a small share of the total road fleet. This is especially important in middle-mile logistics, where freight movement relies heavily on diesel trucks. Heavy vehicles represent approximately 4 % of road vehicles, but account for about 8 % of vehicle-kilometers travelled and 23 % of road transport fuel use (Australian Government, 2020). Diesel reliance largely drives this burden, with diesel engines comprising 94 % of the heavy vehicle fleet and 98 % of heavy vehicle vehicle-kilometers travelled, which elevates trucks' contribution to nitrogen oxides (NOx) and particulate emissions. This segment, central to Australia's middle-mile logistics activity, produces approximately 20.4 million tons of carbon dioxide (CO_2) annually (Authority, 2024), and emissions increased by 2.7% over the last financial year (Australian Government, 2024).

However, the central challenge for MML electrification is not only per-vehicle emissions intensity, but the growth of the freight task. In New South Wales, heavy diesel vehicles are the largest source of road-vehicle NOx emissions in the Sydney region, contributing nearly 40 % of total road-vehicle NOx. While NOx emissions intensity from heavy diesel vehicles decreased by 37 % per vehicle-kilometer travelled since 2003, total emissions fell by only 26 %, as rising freight demand and truck travel offset much of the efficiency gain (Australian Government, 2020). This evidence indicates that cleaner engines alone are insufficient to deliver substantial MML emissions reductions under continued freight growth.

Current pathways to electrify middle-mile logistics (MML) primarily involve substituting diesel trucks with battery electric trucks (BETs) or hydrogen fuel cell electric vehicles, both powered by electric motors. BETs are generally better suited to near-term deployment due to higher energy efficiency and lower maintenance complexity. Consequently, BETs are more commercially mature, benefit from rapidly expanding charging infrastructure, and can be integrated more readily into existing freight operations. Accordingly, BETs are the most practical near-term option for MML electrification during the transition period.

Despite these advantages, the adoption of BETs in middle-mile logistics ultimately depends on their financial viability. BETs have higher upfront capital costs (CAPEX) than conventional trucks, which is a major barrier to electrification for many carriers. However, total cost of ownership (TCO) differs from capital cost alone because it also includes operating and maintenance costs, energy costs, and vehicle utilization over time. Therefore, TCO competitiveness between BETs and conventional trucks is a key indicator for fleet switching, especially in the commercial vehicle sector (Basma et al., 2021).

A TCO model provides a robust basis for assessing the economic competitiveness of BETs under real-world MML operating conditions. It captures both CAPEX and lifetime operating expenditure (OPEX) and can incorporate end-of-life outcomes such as resale value or decommissioning costs. Most models adopt a discounted cash flow framework to compare costs incurred at different times on a consistent financial basis. Prior studies typically compute TCO by specifying annual cash flows over the ownership horizon and separating fixed costs from variable, mileage-dependent costs. This structure supports representation of MML-relevant drivers, including vehicle utilization and freight task requirements, while covering major cost categories such as purchase, energy, insurance, maintenance and repair, and taxes and fees (Magnino et al., 2024; Wang et al., 2024).

This study proposes a structured framework for TCO estimation by decomposing costs into CAPEX and OPEX components. CAPEX comprises vehicle acquisition costs, while OPEX includes fuel, insurance, maintenance and repair, taxes, road tolls, and other OPEX incurred over the vehicle life cycle.

2. Total Cost of Ownership Synthesize

As discussed earlier, TCO can be divided into CAPEX and OPEX. In this section, each TCO component is further decomposed into its main cost drivers. In this section whenever we use the term truck, we are referring to both BETs and conventional trucks.

2.1 CAPEX

CAPEX is estimated by multiplying truck component costs (TCC) by the manufacturer or retailer net profit margin. While the net profit margin (NP) varies mainly by truck type and targeted profitability, TCC depends on a set of component-level cost drivers (F1–F11). F1 captures cab-related costs, including cooling modules, chassis quality, and driveline integration. F2 covers essential auxiliaries, including electrical systems, wiring, HVAC, and air brakes. F3 represents the battery pack system, where required energy capacity is the dominant cost driver for electric powertrains. F4 captures the on-board charger, which scales with required charging power. F5 denotes the DC/DC converter for voltage conversion across onboard electrical loads. F6 represents the high-voltage distribution system for routing and protection. F7 captures thermal management for battery and power electronics. F8 represents the electric HVAC system for cabin conditioning without engine-driven auxiliaries. F9 captures the electric drive unit, including the traction motor and drivetrain. F10 represents the electric air brake compressor, and F11 captures the electric steering pump system providing steering assistance without an ICE-driven hydraulic unit.

Trucks are usually purchased using 5–7-year finance terms. The interest rate varies with macroeconomic conditions and borrower risk. In Australia, in early 2026 commercial truck finance rates range between 6% and 10% (Money.com.au, 2020). The final step in calculating OPEX is to estimate the residual value at resale. Residual value depends on vehicle age and cumulative vehicle-kilometers travelled. For further details on residual value estimation, the reader is referred to (Magnino et al., 2024).

In addition to vehicle acquisition costs, BET operation requires charging infrastructure (F12) across the network. This infrastructure cost should be included in the TCO for BET deployment, whereas it is typically excluded for diesel trucks because refuelling stations are already widely available and embedded in existing freight networks (Basma & Rodríguez, 2023).

2.2 OPEX

OPEX, the operational cost of trucks, involves more components than CAPEX. In this subsection, the factors that can impact OPEX are reviewed.

2.2.1 Fuel cost

Trucks' fuel costs are correlated with fuel consumption, which is typically influenced by truck size (FC1), payload (FC2), travel type (FC3), and vehicle quality (FC4). Additionally, using heating and cooling systems (FC5) can increase fuel consumption. Compared to conventional diesel trucks, BETs are generally more energy efficient, which can reduce energy costs per kilometer, depending on electricity prices and charging patterns. Diesel trucks, in contrast, are more exposed to fuel price volatility. On the other hand, BET state of charge is more sensitive to operating conditions, including temperature (FC6), speed (FC7), and driving conditions (FC6).

2.2.2 Maintenance and repair cost

Maintenance and repair costs include ordinary maintenance (MR1), regular inspections (MR2), and major midlife overhaul costs (MR3). Annual inspections are typically required, and midlife overhauls account for partial or full replacement of major propulsion components as they deteriorate. For BETs, midlife costs are primarily driven by battery replacement when usable capacity falls below acceptable levels due to ageing and charge–discharge cycles. Compared to conventional diesel trucks, BETs generally have lower routine maintenance needs due to fewer moving parts but may incur higher midlife costs associated with battery replacement.

2.2.3 Road tolls and CO_2 charges

In Australia, heavy-vehicle road tolls (RTC1) are typically determined by vehicle class, axle configuration, or gross vehicle mass, rather than fuel type. BETs therefore face the same toll schedules as diesel trucks, and toll payments are included as an OPEX in TCO assessments. In Melbourne, tolls may vary by time of day. For the West Gate Tunnel, published heavy commercial vehicle toll caps are $37.20 for travel between 6am and 8pm and $24.80 for travel between 8pm and 6am. East Link’s published schedule lists a heavy commercial vehicle toll cap of $20.58 (Linkt, 2026). Additionally, vehicle registration fees should be included in the TCO as annual ownership charges incurred over the vehicle life cycle (RTC2).

CO_2 road charges (RTC3) for trucks are designed to internalize the external cost of freight-related emissions, typically by linking road pricing to vehicle emission performance or CO_2 intensity. In Europe, for example, the Euro vignette Directive enables Member States to apply CO_2-differentiated road charges for heavy goods vehicles, with rates based on emission class and exemptions or reductions for zero-emission trucks (Basma & Rodríguez, 2023). In contrast, Australia does not currently implement a dedicated CO_2-based road charge for trucks. Heavy vehicle charges are primarily recovered through fuel exercise and road user charging mechanisms rather than an explicit carbon pricing instrument for road freight.

2.2.4 Other costs: taxes, insurance, labor

In Australia, both BETs and conventional trucks face material taxes and charges through ownership and operation (OC1), but the main concessions differ. Conventional heavy vehicles can benefit from the Fuel Tax Credit, which reduces the effective cost of diesel for eligible activities.

Moreover, insurance (OC2) rates can vary based on geographical location and the level of coverage selected. A reasonable estimation of the insurance rate is a fixed percentage of the vehicle’s residual value per year, which is commonly assumed in TCO modelling to reflect asset depreciation and risk exposure over time.

Driver labor costs (OC3) are modelled using representative industry-average hourly rates that include gross wages, employer social security contributions, and travel allowances. As driver requirements are assumed to be technology-neutral, the same labor cost parameters are applied across all vehicle technologies in the TCO assessment (Basma & Rodríguez, 2023). In Australia, truck driver wages range between 28.09 Australian Dollar (AUD) and AUD 30.12 per hour (Australian Government, 2026).

2.3 Discount initiatives

While many studies reported that BETs' TCO can be reasonably close to conventional trucks', many carriers are reluctant to transition to these green trucks. One way to promote road freight decarbonisation is to introduce targeted discount initiatives and regulatory support, such as purchase tax credits (DI1), emissions performance standards (DI2), and direct purchase subsidies (DI3). Examples include the US Commercial Clean Vehicle Credit, which provides up to USD 40,000 for qualified heavy-duty vehicles, the EU's CO_2 emissions performance standards, which require a 45% reduction by 2030 for new heavy-duty vehicles, and China's NEV purchase subsidy program, which previously offered support of up to CNY 500,000 for certain heavy-duty zero-emission trucks (IRS, 2025). In Australia, heavy-truck-specific tax concessions for BETs are less common, and support is more often delivered via targeted programs, such as the CEFC–Volvo package that offers an interest-rate discount (up to 0.5%) and residual value support to reduce operating lease costs for medium and heavy electric trucks, alongside charging infrastructure (Australian Government, 2025).

Figure 1 shows the connections between the TCO components. Although CAPEX is higher than OPEX in absolute terms, operational costs account for the largest share of total TCO. Comparing CAPEX and operating components indicates that upfront purchase cost remains the primary adoption barrier, while OPEXs drive long-term cost performance. CAPEX are largely fixed at acquisition and tend to decline with technological learning. In contrast, OPEXs, particularly energy and maintenance, compound over the vehicle life and are highly sensitive to utilization, energy prices, and road charging or carbon-related policies. Consequently, relatively small changes in annual mileage or energy price assumptions can dominate upfront cost differences, suggesting that CAPEX reductions alone are unlikely to achieve cost parity without concurrent improvements in operating conditions.

3. Case Study and TCO Calculations

This section estimates the five-year TCO for two truck brands that offer both diesel trucks and BETs. The analysis is conducted for the Melbourne case study. Four truck models are considered: Volvo FH16-Diesel, Volvo FH Aero-BET, Isuzu F-Series-Diesel, and BYD 8TT-BET. The Volvo trucks represent the articulated heavy-duty category, while the Isuzu and BYD trucks represent the rigid medium-duty category. The assumptions and parameter values used in the analysis are summarized in Table 1.

The TCO calculation includes CAPEX, registration, insurance, maintenance and service, energy cost, and financing cost over a five-year analysis period. All trucks are assumed to operate 78,300 km per year (Statistics, 2020). The CAPEX for the diesel trucks was obtained from historical market listings and then adjusted to 2026 price levels to ensure comparability with current electric truck prices. The reported purchase prices of AUD 373,497 for the Volvo FH16-Diesel and AUD 225,004 for the Isuzu F-Series-Diesel correspond to 2016 market prices (Australian Transport Assessment and Planning, 2016). To reflect present-day vehicle costs, these values were adjusted using an inflation-based price index, assuming approximately 33% cumulative inflation between 2016 and 2026. This adjustment reflects the general increase in heavy vehicle prices observed in Australia over the last decade. After inflation adjustment, the estimated 2026 purchase prices are AUD 497,000 for the Volvo FH16-Diesel and AUD 299,000 for the Isuzu F-Series-Diesel. For the BETs, the CAPEX are based on recent manufacturer or fleet procurement estimates. The purchase price is assumed to be AUD 600,000 for the Volvo FH Aero-BET and AUD 390,000 for the BYD 8TT-BET, which are consistent with current electric heavy-truck price estimates reported by manufacturers and industry sources. Moreover, annual vehicle registration is assumed to be AUD 1,200 per truck. Insurance costs are assumed to equal 3% of the vehicle CAPEX per year.

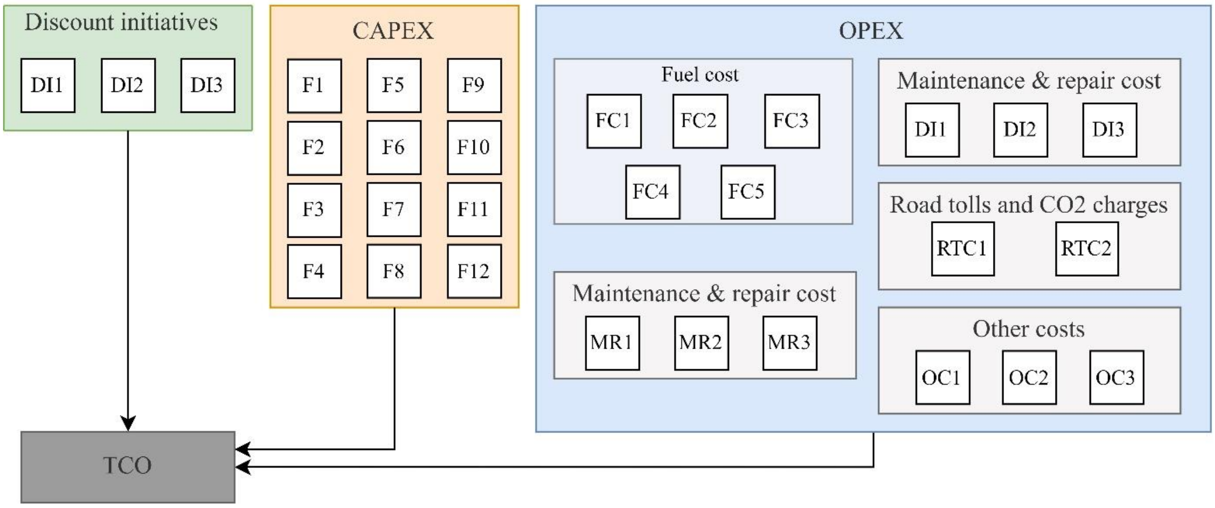

Figure 1. TCO cost components, including CAPEX, operational, and discount initiatives.

Maintenance and service costs are estimated using cost-per-kilometer values derived from vehicle OPEX parameters. The maintenance cost for the articulated diesel truck is assumed to be 22.8 cents per km, while the rigid diesel truck maintenance cost is assumed to be 7.1 cents per km (Australian Transport Assessment and Planning, 2016). BET maintenance costs are assumed to be 40% lower than diesel trucks (Edenred, 2026), reflecting reduced mechanical complexity and fewer serviceable components. Consequently, maintenance costs are assumed to be 13.68 cents per km for the Volvo FH Aero-BET and 4.26 cents per km for the BYD 8TT-BET.

Energy consumption assumptions are based on typical vehicle specifications. The Volvo FH16-Diesel consumes 35 L/100 km, while the Isuzu F-Series-Diesel consumes 25 L/100 km. The

Volvo FH Aero-BET consumes 140 kWh/100 km, and the BYD 8TT-BET consumes 120 kWh/100 km. The diesel price is assumed to be AUD 1.70 per liter, while the electricity price is assumed to be AUD 0.50 per kWh. Financing costs are incorporated using interest rates of 6.5% for diesel trucks and 6.0% for BETs (Volvo, 2025).

The TCO over the analysis period is calculated as presented in equation (1).

$$TCO = C_{cap} + \sum_{t=1}^{T} (C_{reg} + C_{ins} + C_{maint} + C_{energy} + C_{fin}) \tag{1}$$

where C_{cap} is the vehicle purchase cost, C_{reg} is the annual registration cost, C_{ins} represents the annual insurance cost, C_{maint} is the maintenance and service cost, the fuel or electricity cost is shown by C_{energy}, C_{fin} represents the financing cost, and T is the analysis period (five years).

Using the assumptions described above, the five-year TCO of the Volvo FH16-Diesel is estimated at approximately AUD 899,755, while the Volvo FH Aero-BET has a five-year TCO of approximately AUD 1,023,607. For the medium-duty truck category, the Isuzu F-Series-Diesel has an estimated five-year TCO of AUD 544,084, whereas the BYD 8TT-BET has a five-year TCO of AUD 706,078. These results indicate that, under the assumed purchase prices, energy prices, annual mileage, and maintenance costs, diesel trucks remain less expensive than BETs over a five-year ownership period, although the difference is smaller for articulated trucks than for rigid trucks.

Table 1. Parameters used in the TCO analysis and results.

Truck Model	Volvo FH16-Diesel	Volvo FH Aero-BET	Isuzu F series-Diesel	BYD 8TT-BET
Max payload	30 tons	25 tons	20 tons	20 tons
CAPEX	\$497,000	\$600,000	\$299,000	\$390,000
Registration	\$1200	\$1200	\$1200	\$1200
Maintenance	22.8 cents per km	13.68 cents per km	7.1 cents per km	4.26 cents per km
Insurance	3% of CAPEX	3% of CAPEX	3% of CAPEX	3% of CAPEX
Fuel efficiency	35 L / 100 km	140 kWh / 100 km	25 L / 100 km	120 kWh / 100 km
Fuel cost	1.7 / liter	\$0.50 / kWh	1.7 / liter	\$0.50 / kWh
Interest rate	6.5%	6.0%	6.5%	6.0%
5-year TCO (AUD)	899,755	1,023,607	544,084	706,078

4. Conclusion

This study proposed a structured framework for estimating the TCO of diesel and BETs in MML by decomposing costs into CAPEX and operational components. The framework enables consistent comparison between conventional and zero-emission truck technologies under realistic freight operating conditions.

The case study results indicate that diesel trucks currently retain a lower total ownership cost over the five-year horizon primarily because of their lower upfront purchase prices. Although BETs benefit from lower routine maintenance requirements and comparable energy costs, these operational advantages are not yet sufficient to fully offset the higher capital investment required for electric vehicles. Consequently, the upfront purchase cost remains the primary barrier to the adoption of BETs in middle-mile logistics.

At the same time, the analysis highlights the importance of operational factors in shaping long-term cost competitiveness. Because operating expenses accumulate with vehicle utilization, parameters such as annual mileage and electricity price significantly influence total ownership cost. Under high-utilization freight operations, the OPEX advantages of BETs can progressively narrow the cost gap with diesel alternatives.

These findings suggest that strategies targeting both CAPEX and operational components could accelerate the transition toward electric freight transport. In particular, policies that reduce upfront investment costs, stabilize electricity prices for freight operators, and prioritize high-utilization routes can significantly improve the economic viability of BETs in middle-mile logistics.

Future research should further refine the TCO estimation by incorporating more detailed cost components and real-world operational data. The current analysis relies on representative parameter values and simplifying assumptions, such as constant annual mileage, stable energy prices, and fixed maintenance cost differences between diesel and BETs. These assumptions represent limitations that may influence the accuracy of the results, as operational conditions can vary across routes, vehicle utilization levels, and charging infrastructure availability. Future studies should therefore conduct sensitivity analyses to evaluate how variations in operational conditions and policy incentives affect TCO outcomes. In particular, examining factors such as annual vehicle kilometers traveled, electricity price volatility, and discount initiatives, including purchase subsidies, low-interest financing, or tax incentives, would provide deeper insights into the economic conditions under which BETs can become competitive with diesel vehicles and support the broader electrification of road freight.

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