Modelling the Australian truck fleet

Technical Appendix to *[report title]*

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Grattan Institute Support

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1 Modelling the Australian truck fleet

Grattan's report *[report name]* includes results from a Grattan model of the Australian truck fleet. This model, referred as the 'Grattan truck model', is designed to estimate the carbon and pollutant emissions from Australian trucks over time. This appendix outlines the assumptions that underpin our model.

The assumptions outlined include inputs to a fleet turnover model (Section 1.1) and assumptions informing carbon and pollutant emission estimates under different policy scenarios (Chapter 2). Cost assumptions which are used as the basis for a cost benefit analysis are also outlined (Chapter 3).

The Grattan truck model is a publicly available and open source R project, and is hosted on GitHub.

1.1 Fleet turnover model

The Grattan truck model includes a fleet turnover model, which we use to estimate the future mix of vehicles that make up the Australian heavy vehicle fleet (including vehicles over 3.5 tonnes).

We estimate the composition and activity of the fleet over time based on sales estimates, estimated vehicle scrappage rates, projected economic activity and estimates of vehicle kilometres travelled (VKTs).

1.1.1 Vehicle attrition rates

Vehicle attrition rates are used to estimate how many heavy vehicles are scrapped each year. We use rates derived from data in the ABS motor vehicle censuses (MVC) between 2013 and 2020.[1] To estimate the proportion of vehicles that survive from one year to the next, we compared the number of vehicles on register between subsequent motor vehicle censuses, by the year of vehicle manufacture.

For example, we compared how many vehicles made in 2000 were on register in the censuses between 2013 and 2020. Over time, the number of registered vehicles made in 2000 decreases as vehicles are progressively scrapped. By comparing across multiple motor vehicle censuses and years of manufacture, we can estimate the rate of vehicle scrappage depending on the vehicles age and type.

We calculated scrappage rates for vehicles up to 50 years old, by averaging rates across all motor vehicle censuses between 2013 and 2020. The resulting data was used to calculate survival curves for each vehicle type. These curves show the proportion of new vehicles that are expected to survive as vehicles age. We assume that any vehicle still remaining more than 50 years after its date of manufacture is scrapped.

Scrappage rates are assumed to remain constant over time throughout the model. Figure 1.1 on the following page illustrates the assumed survival curves used in the model.

1.1.2 Total vehicle sales

We estimate historical heavy vehicles sales numbers from 2013 onward in line with ABS motor vehicle census data. We assume new sales to be the number of new vehicles on register in the MVC.[2]

Although the MVC contains detailed data of new vehicles on register from 2013 onward, data of new vehicle registrations before 2013 are unavailable. To estimate historical vehicle sales before 2013, we

1. ABS (2021).

2. Ibid.

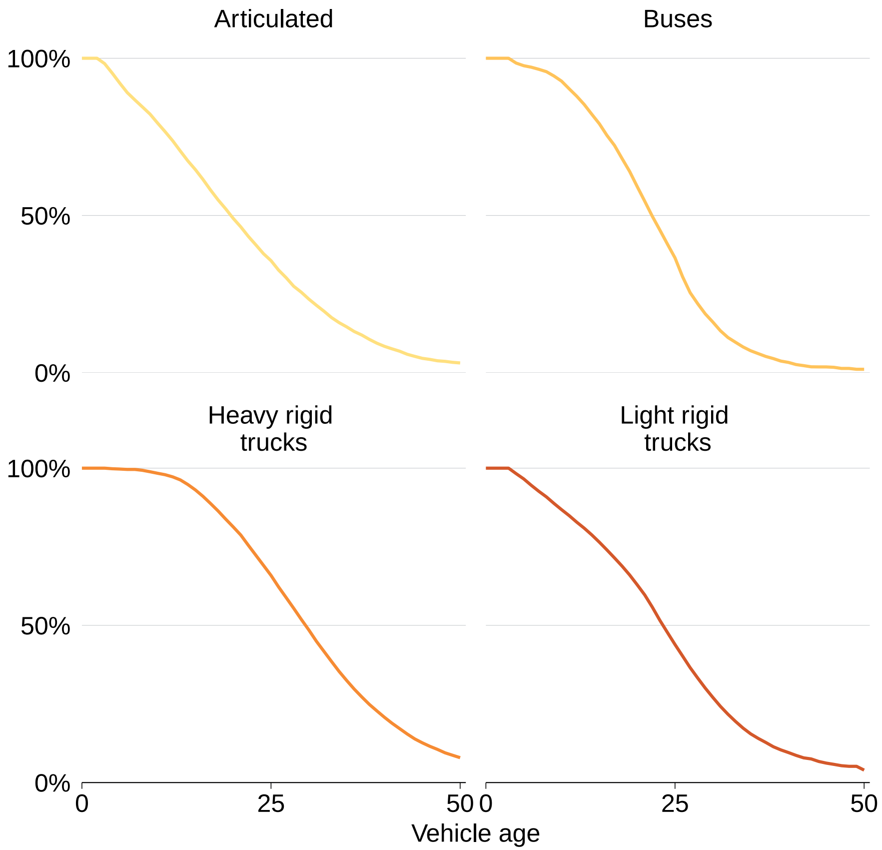
back-calculated from the number of vehicles on register and scrappage rates.

Survival curves provide an estimate of the proportion of vehicles surviving compared to how many were initially purchased. As the MVC includes data on vehicle registration by year of vehicle manufacture, survival curves can be used to back calculate an estimate of how many vehicles, by year of manufacture, were originally sold. We use this method to estimate heavy vehicle sales by vehicle category between 1980 and 2021.

To estimate future vehicle sales, we assume that vehicle sales in each segment grow in line with population growth. We use population growth estimates from the 2021 inter-generational report.[3] As historical sales data is very volatile, 2022 sales levels are assumed to be the average of the past 10 years of vehicle sales.

Historical and future sales estimates are included in Figure 1.3 on the next page.

Figure 1.1: Vehicle attrition rates – survival curves
Per cent of vehicles surviving from initial sales, by age



3. Treasury (2021).

Figure 1.2: Vehicle sales estimates in the Grattan truck model
Number of vehicles sold

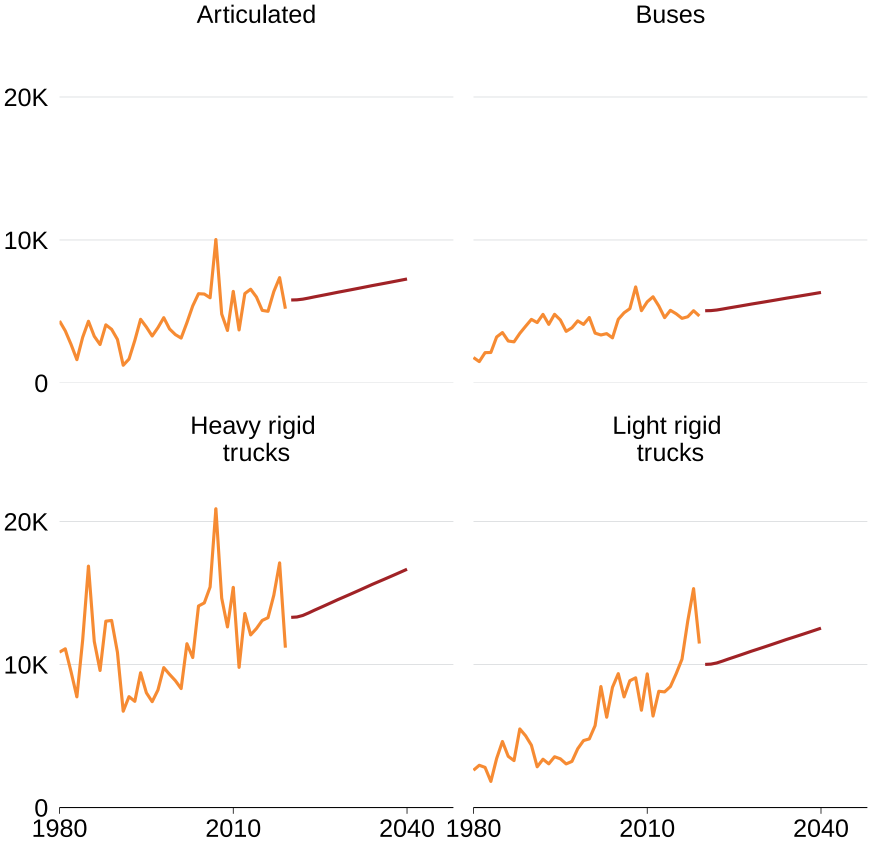
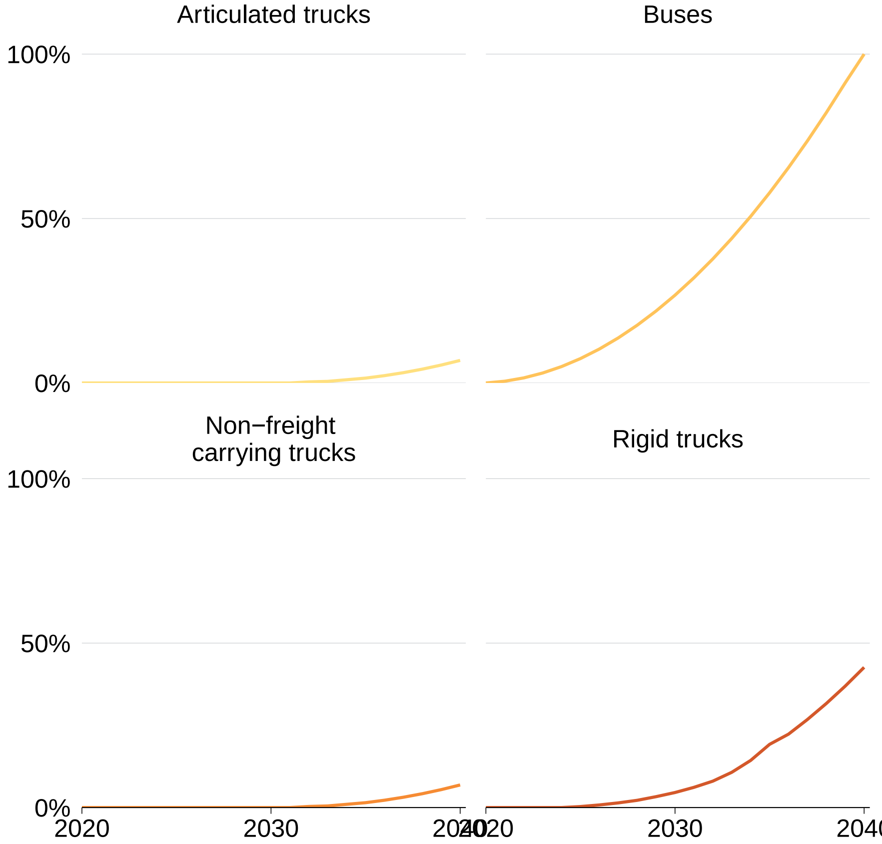


Figure 1.3: Zero-emission sales estimates in the Grattan truck model
Proportion of new sales that are zero-emissions heavy vehicles



1.1.3 Electric and zero emission vehicle sales forecasts

Although the current heavy vehicle fleet has a negligible proportion of zero emissions vehicles in operation as of 2022, this is likely to change over time. Because our modeling extends relatively far into the future, zero emission heavy vehicles needs to be considered to produce a realistic estimate of the fleet.

To estimate Australian zero emissions heavy vehicle uptake, a lagged estimate of European uptake forecasts was used for articulated, rigid and non-freight carrying trucks[4]. A lag of 5 years was assumed. Non-freight carrying trucks were assumed to follow the same trajectory as articulated trucks.

Buses were modeled separately. Zero emission buses are assumed to reach 25% of all new bus sales by 2030, 60% by 2035, and 100% by 2040. The rate of bus zero emission bus uptake is likely to be driven mainly by state government decision making.

For the purposes of estimating emissions from zero emission heavy vehicles, we assume that all zero emission heavy vehicles are electric vehicles. Vehicle energy consumption is assumed to follow upper bound estimates from the ICCT in 2020.[5] Between 2020 and 2030, it is assumed that energy consumption declines by 2.8% per year from the baseline 2022 value, in line with ICCT forecasts for Europe.[6] Energy consumption figures are assumed to remain steady beyond 2030.

4. McKinsey & Company (2017).
5. ICCT (2020).
6. ICCT (2021a).

Table 1.1: Estimated energy consumption of electric heavy vehicles
Energy consumption, kWh/km, by year of vehicle sale

Vehicle type	2020	2025	2030
Articulated trucks	1.9	1.63	1.37
Rigid trucks	1.2	1.03	0.86
Buses	1.02	0.88	0.73
Non-freight carrying vehicles	0.98	0.85	0.71

Notes: ICCT (2020). Values for buses and non-freight carrying vehicles are calculated from rigid truck energy consumption estimates, by scaling in line with current fuel consumption estimates.

1.1.4 Vehicle kilometres travelled and estimated vehicle activity

As vehicles age, they tend to drive be driven less. For example, an average 25 year old truck is unlikely to cover the same distance each year as an average 5 year old vehicle.

Because of this, estimates of how far different vehicle types are driven each year, and how this value changes based on age, are important to estimate the activity of the heavy vehicle fleet.

There is limited data available to estimate vehicle kilometres travelled (VKTs) for the Australian heavy vehicle fleet. While the ABS motor vehicle use survey includes some high level results of the kilometres travelled by different vehicles types, and vehicles of different ages, these categories are broad.[7] For example, vehicle kilometres based on age are grouped into three categories only; < 5 years old, 5-15 years old, and >15 years old.

7. ABS (2020).

Estimating the total activity of trucks in the Australian heavy vehicle fleet requires estimates of VKTs for trucks of all ages, not just in broad categories. This is particularly important given that the estimates from this model are intended to estimate vehicle pollution; which is very dependent on how old a vehicle is.[8]

Given the lack of available data on the relationship between VKTs and age in an Australian context, we estimate VKTs (for all categories excluding buses) by combining available ABS motor vehicles use survey results with US MOVES model estimates.

The MOVES model contains VMT (vehicle miles travelled) estimates by vehicle age and type, described as functions.[9] We mapped the VMT functions to known Australian data for articulated, rigid, and non-freight carrying trucks. This included minor dilations and translations of the MOVES functions, to ensure consistency with Australian data in the ABS MVUS.

For articulated trucks, the MOVES data is a polynomial function that is only appropriate for trucks aged 0-16 years old. We assume VKTs for articulated trucks older than 16 years follow a linear relationship, calibrated to provide consistent estimates with what is available from the ABS motor vehicle use census data.

Because there is a lack of MOVES data available for buses, they were assumed to follow a piecewise linear relationship. Buses were assumed to travel a constant distance for the first 10 years of operation, before declining linearly between ages of 10 and 30. They are assumed to cease operation at 30 years of operation (an assumption consistent with the attrition curves for buses).

VKTs for all vehicles aged which are 0 years of age (sold during the year in question) are also adjusted. Because vehicles are likely to be sold at roughly an even rate across a year, the average VKT of a new (age 0) vehicle is assumed to be half of that otherwise estimated.

The resulting VKT curves are included in figure Figure 1.4 on the following page

1.1.5 Vehicle activity estimates

Estimates of VKTs and vehicle sales provide a reasonable picture of future heavy vehicle activity. But actual road freight activity is also determined by prevailing economic conditions and freight demand. Because of this, we assume that there is some growth in the activity of the fleet over time, based on forecasts of economic activity.

This is separate (and a smaller share) of freight growth than the freight growth through change in vehicle sales over time. Three scenarios are assumed for growth in fleet activity - a central estimate, lower, and upper bound. The central estimate assumes that future fleet activity grows at a rate of 35% of GDP. When combined with increased fleet growth in line with population growth estimates, this trajectory predicts overall freight activity to increase approximately in line with BITRE estimates.[10]. For the lower bound scenario, we assume that fleet activity grows at 10% of GDP rates, and we assume that freight activity grows at 60% of the rate of forecast GDP growth in the upper bound scenario.

Data for GDP forecast growth was taken from the 2021 inter-generational report.[11]

8. The amount of pollution a vehicle emits is dependent on what pollutant control technologies the vehicle has. As regulations of pollutant control technologies has changed over time, vehicle age can be used as a proxy.
9. EPA (2009).
10. BITRE (2019).
11. Treasury (2021).

Where total yearly vehicle activity estimates for past years differed from historical estimates, we scale activity in line with results from the MVUS and national greenhouse accounts for consistency.

The overall freight growth trajectory is included in Figure 1.5 on the next page. The majority of this growth is driven by increased vehicle sales.

1.1.6 Fuel consumption

Fuel consumption in the road freight sector depends on many variables. Different trucks with different engines, payloads or driving conditions are all likely to consume fuel at different rates. Newer trucks may have more efficient engines than old trucks. However, there is limited detailed data which describes the fuel consumption of the Australian heavy vehicle fleet.

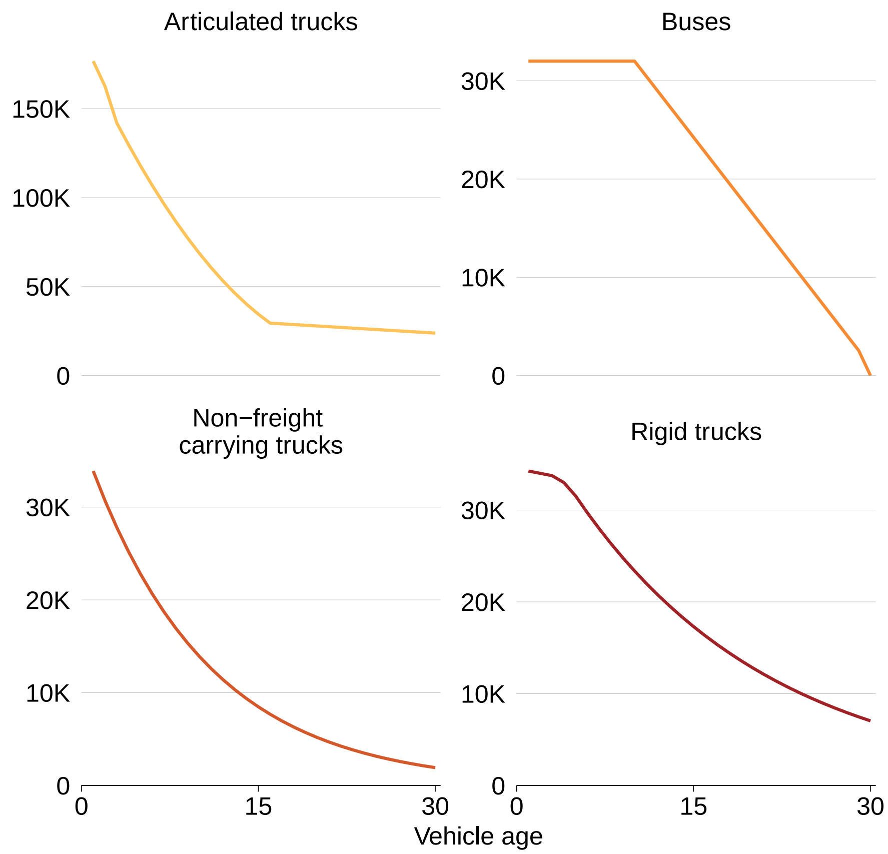
We estimate fuel consumption of heavy vehicles based on data from the ABS MVUS. For articulated trucks sold before 2020, trucks within each ABS age band (<5, 0-15, >15) are ascribed the average fuel consumption rate for each band. For rigid trucks, we assume vehicles sold before 2000 have a constant rate of fuel consumption. Between 2000 and 2020, we assume fuel consumption rates follow a linear relationship determined from the MVUS.[12]

We adopt a similar approach for buses, and assume a constant value for buses made before 2005. We assume fuel consumption improves linearly for vehicles sold between 2005 and 2020. For non-freight carrying trucks sold before 2020, we assume a constant rate of fuel consumption.

In all vehicle categories, we assume that fuel consumption declines by 0.5% year-on-year for new vehicles sold after 2020. This follows assumptions made in the national GHG accounts.[13]

12. ABS (2020).
13. DISER (2021).

Figure 1.4: Estimated vehicle kilometres travelled (VKT) in the Grattan truck model
Annual kilometres travelled, by vehicle age and category



1.2 Estimating carbon and pollutant emissions from the Australian heavy vehicle fleet

1.2.1 Estimating carbon emissions

We estimate carbon emissions from the heavy vehicle fleet through fuel and electricity use.

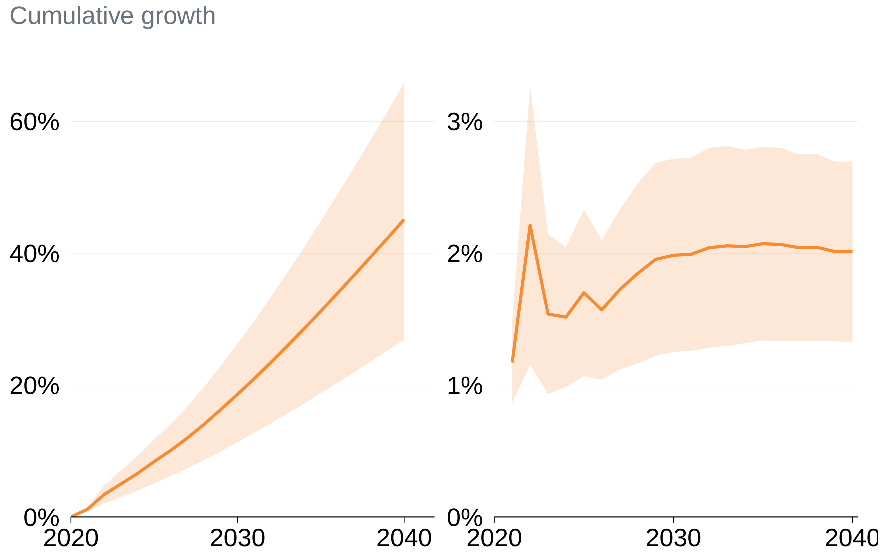
For combustion engine vehicles, carbon emissions are estimated based on total fuel consumption estimates. A conversion ratio between fuel consumption and CO2 production is assumed in line with the National Transport Commission/Department of Climate Change.[14]

For electric vehicles, carbon emissions are estimated based on estimated electricity use, and the carbon intensity of the electricity grid. We assume all vehicles are charged using energy from the electricity grid. Estimates for the carbon intensity of the grid between 2020 and 2040 follow the AEMO 'step change' scenario for the national electricity market (NEM).[15] Beyond 2040, it is assumed the grid linearly decarbonises to zero emissions by 2050, and stays at zero emissions beyond 2050.

Forecast carbon emissions under a business as usual (BAU) scenario are included in Figure 1.6 on the following page.

Figure 1.5: Estimated freight growth scenario in the Grattan truck model

Per cent growth in total freight kilometres travelled



Notes: Includes growth from increased vehicle sales and change in vehicle activity.

14. National Transport Commission (2021, p. 10).
15. AEMO (2021).

1.2.2 Estimating pollutant emissions

As well as carbon dioxide, heavy vehicles produce numerous other pollutants. Many of these pollutants have been found to be damaging to human health. We estimate heavy vehicle pollutant emissions for key pollutant categories, including nitrogen oxides (NOx), particulate matter (PM10 and PM2.5), sulfur oxides (SOx) and volatile organic compounds (VOCs).

For exhaust emissions, such as diesel particulates, we calculate pollutant emissions based on fuel consumption. 'Emissions factors' for various pollutants and vehicle types (reported as gram of pollutant per litre of fuel burned) are used for this calculation. Pollutant emissions factors were provided by BITRE[16], categorised by vehicle age, vehicle type, and fuel type.

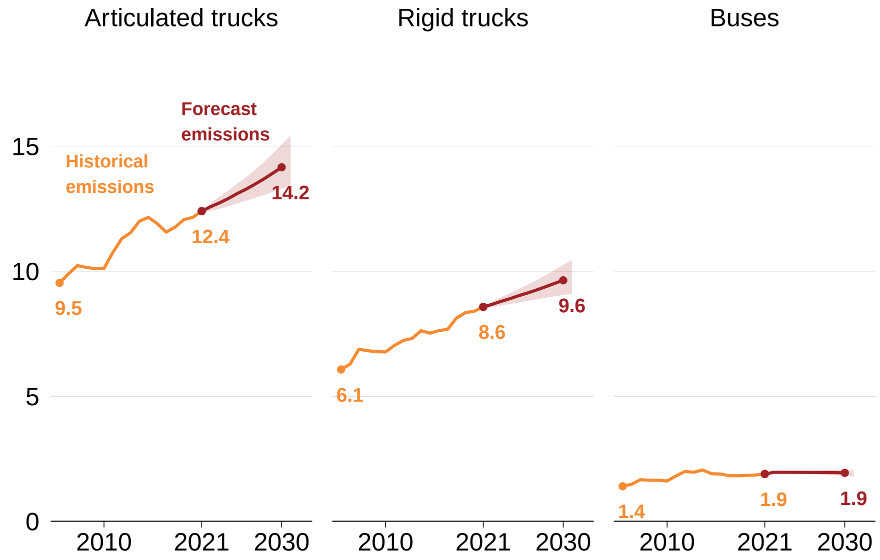
For exhaust particulates, we assume that 92% of PM10[17] by mass are PM2.5[18] and the remaining 8% fraction is PM2.5-10.[19]

For non-exhaust emissions, such as tyre and brake wear, we calculate emissions based on vehicle kilometres travelled. Values for tyre and brake wear per kilometre are assumed to follow assumptions in the US EPA MOVES model.[20] Particulate matter from road wear and re-entrained road dust is not included in this analysis.

We estimate secondary PM2.5 pollution from SOx and NOx using offset conversion factors. An offset factor of 1:100 is assumed for NOx, and 1:40 for SOx – meaning that for each gram of NOx formed, 0.01g of secondary PM2.5 is assumed to form, and for 1g of SOx emissions, 0.025 grams of PM2.5 is formed. This approach is consistent with US

Figure 1.6: Business as usual emissions forecasts from the Grattan truck model

Historical and forecast CO2 emissions from heavy vehicles



Notes: Confidence intervals represent different VKT growth trajectories. Forecast emissions are from the grattan truck model. Historical emissions from DISER..

Source: DISER (add source).

16. Pers comm
17. Particulate matter smaller than 10um in aerodynamic diameter.
18. Particulate matter smaller than 2.5um in aerdynamic diameter.
19. EPA (2014a).
20. EPA (2014b, pp. 16, 24).

NACAA (National association of clean air agencies) methodology for estimating secondary pollutant emissions. The ratios assumed are ratios used for the west coast of the US.[21]

Estimates of business as usual pollution are included in Figure 1.7.

1.3 Pollutant health costs

We estimate the health cost from pollution using a damage cost approach. This approach assigns a cost to pollutant emissions based on mass, for example, as a cost per tonne of pollutant emitted. Damage costs are typically calculated from more detailed impact pathway approaches.

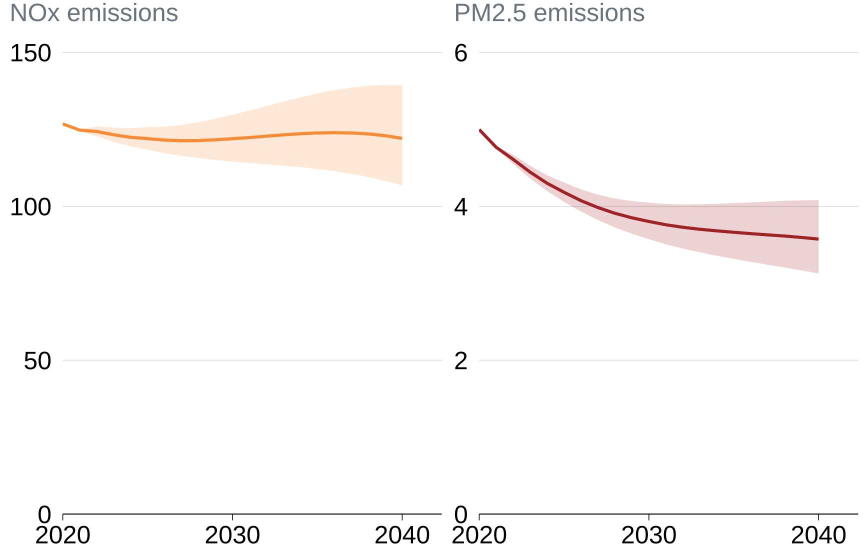
By multiplying the emissions of the heavy vehicle fleet by damage costs, an estimate of total health costs under various policy scenarios can be forecast. We assume damage costs as provided by BITRE[22]. These estimates are developed from impact pathway modeling conducted by Jacob Marsden Ass. (2016), which was part of a broader review into fuel quality and vehicle emissions.[23]

While health costs are inherently uncertain, these costs are comparable with the range of other costs estimated in the literature.[24]

Pollutant emissions are particularly harmful to human health in densely populated, urban areas, because more people are exposed to the pollution. To account for this, damage costs are separated into rural and urban costs to account for the differences in population exposure. We calculate the share of pollution in urban and rural areas by assigning a proportion of vehicle kilometres travelled to each, based

Figure 1.7: Business as usual pollutant forecasts from the Grattan truck model

Annual emissions from Australian heavy vehicles (000' tonnes)



21. NACAA (2011, p. 18).
22. Pers comm.
23. Jacob Marsden Associates (2016).
24. For example in the US: Gilmore et al (2018)

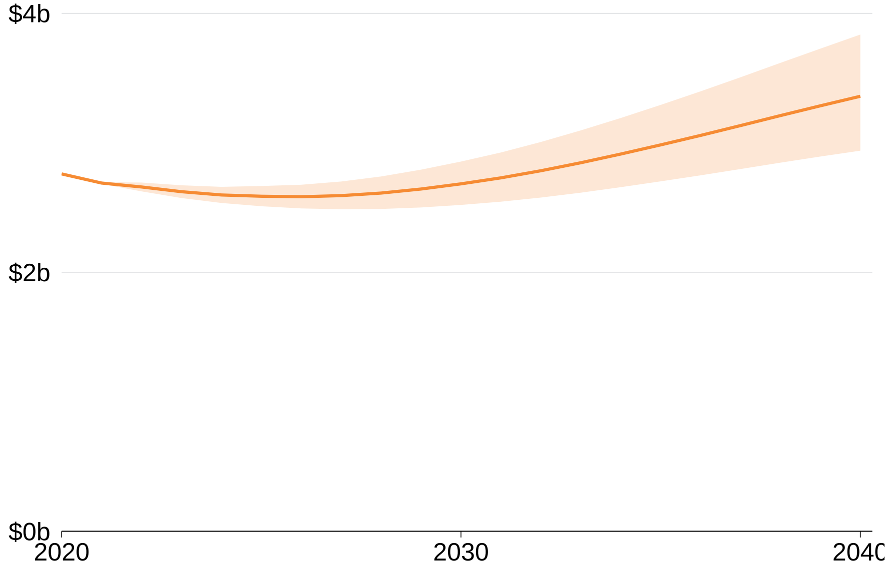
on data from the ABC MVUS. This share is assumed to be constant with vehicle age and over time.

For zero-emission trucks, health costs for pollutants from large scale power generaion are also estimated. We use the Australian Academy of Technological Sciences and Engineering (ATSE) externality estimates are used for health costs for different generation fuels. The make-up of total costs is weighted by the power generation share in the NEM.[25] Costs are assumed to decrease in line with the decrease in emissions intensity of the grid.

Figure 1.8 shows the estimated health costs under a business as usual scenario.

Figure 1.8: Business as usual health cost forecasts from the Grattan truck model

Estimated health costs from vehicle pollution



25. Technological Sciences and Engineering (2009); and Australian Energy Regulator (2022).

2 Policy scenarios modelled

2.1 Policies to reduce carbon emissions

Technology standards

We used the Grattan truck model to estimate what effect implementing technology standards would have on carbon emissions from the Australian heavy vehicle fleet.

Technology standards would give targets to heavy vehicle manufacturers, mandating improves to the efficiency of certain technologies in new vehicles. This would most effectively be targeted at engines and tyres, as international evidence has suggested they are cost effective paths for reducing vehicle emissions.[26] Engine standards would require manufacturers to meet target improvements to engine efficiency on average across the vehicles they sell. Tyre mandates could be imposed in a similar way – requiring tyres on new vehicles to, on average, meet targeted rolling resistance improvements annually.

Based on international evidence of what technology standards could achieve, we assume carbon emissions reductions of 3% per year would be met through engine standards, and of 1.5% per year would be met through tyre standards.[27] Both are assumed relative to a 2022-era Euro V baseline vehicle, and assumed to be in place from 2024 to 2030.

We assume targets would cover rigid and articulated trucks, and that manufacturers would meet, but not overshoot, the targets each year.

Zero emission targets

Targets for the sale of zero emissions trucks are becoming common globally. We modelled the expected effect of zero-emission targets on carbon emissions from the heavy vehicle fleet.

The assumed target trajectories are shown in Figure 2.1 on the next page. Targets are assumed to be enforced beginning in 2024, and are applied to articulated and rigid trucks only. We assume all zero emissions vehicles are electric vehicles. Figure 2.2 on the following page shows the expected carbon emissions under technology standard and zero emission target scenarios.

26. ICCT (2017); and ICCT (2016).
27. ICCT (2017); ICCT (2016); ICCT (2021b); and ICCT (2018).

Figure 2.1: Proposed zero-emissions sales targets for articulated and rigid trucks
Zero emission sales targets as a proportion of new sales

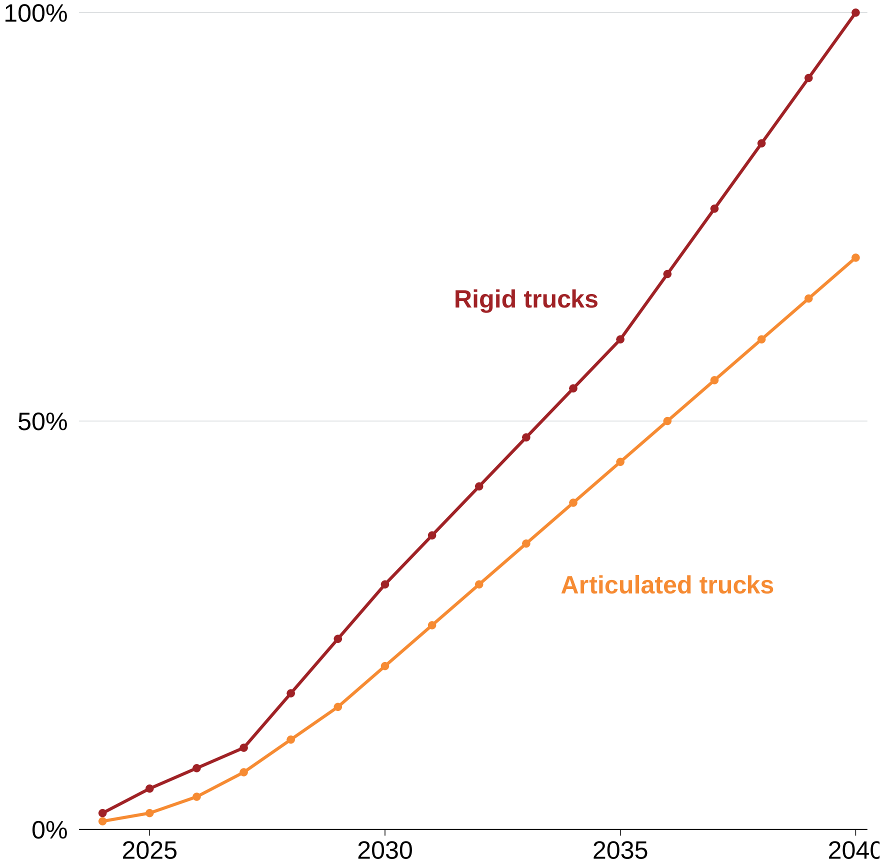
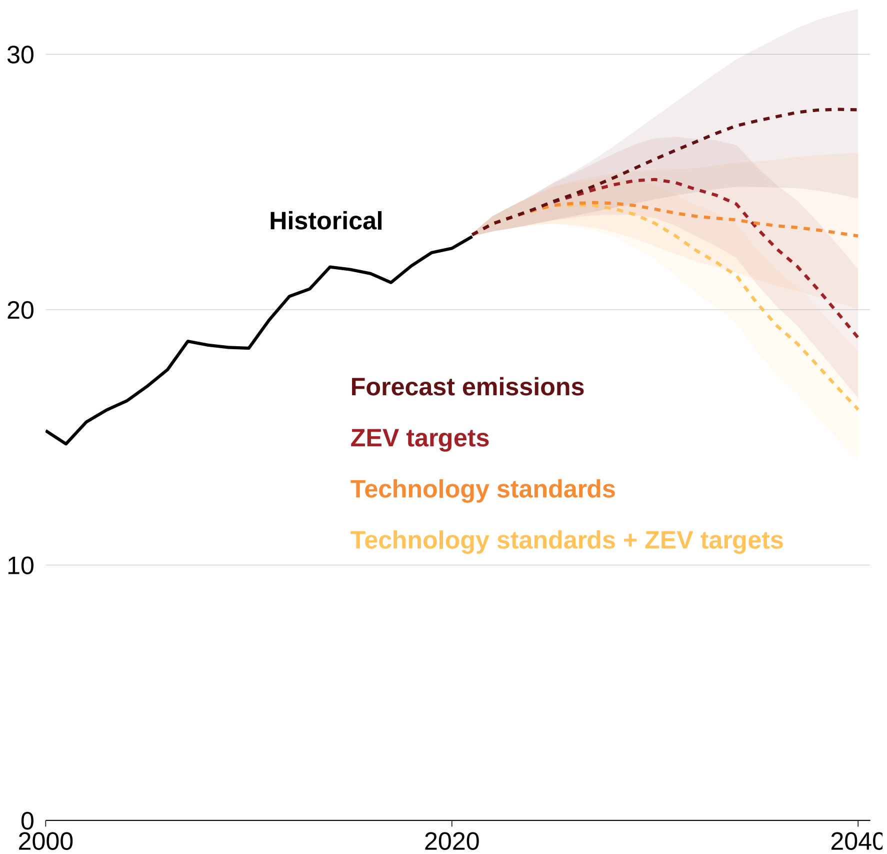


Figure 2.2: Forecast CO2 emissions under Grattan's proposed policy scenarios
Estimated annual CO2 emissions (Mt)



Notes:

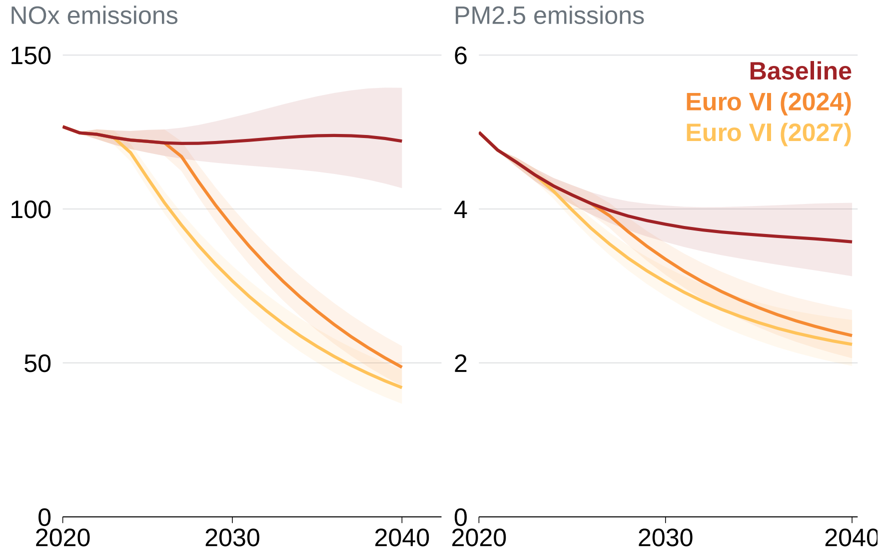
2.2 Euro VI pollution standards

Euro VI pollutant standards for heavy vehicles are common globally and have been proposed repeatedly for Australia. The following charts illustrate the estimated affect of Euro VI regulations on pollutant emissions from the heavy vehicle fleet.

We assume that a Euro VI vehicle produces 80% less NOx emissions and 66% less PM emissions compared to an equivalent Euro V vehicle, in line with test requirement figures.[28] In practice, actual NOx and PM reductions are likely to exceed these estimates.

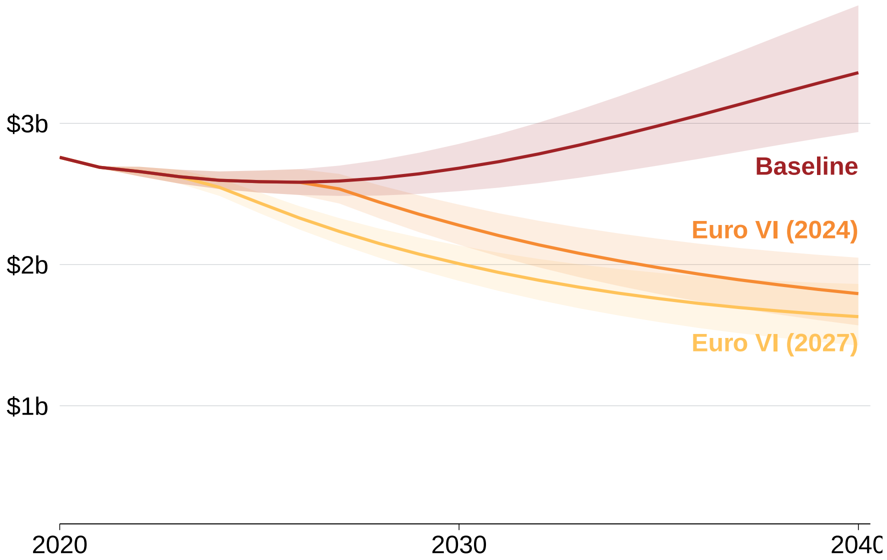
Estimates of vehicle pollution (Figure 2.3) and health costs are included (Figure 2.4 on the following page).

Figure 2.3: Euro VI regulations are will drive down pollution
Annual emissions from Australian heavy vehicles (000' tonnes)



28. These alues are the upper limits of the transient and stationary test cycles: DITRDC (2020)

Figure 2.4: Euro VI regulations can significantly reduce health costs from vehicle pollution ($ 2022)
Estimated annual health cost from heavy vehicle pollution



3 Zero emissions targets: cost benefit analysis

As well as estimating the resulting carbon emissions under a zero emissions target scenario, we used the Grattan truck model as the basis for a cost benefit analysis (CBA). This cost benefit analysis compares the costs and benefits of mandating zero emissions vehicle targets for heavy vehicles, compared to a business as usual scenario.

We assume targets only apply to rigid and articulated trucks.

The framework for the CBA includes the costs and benefits Table 3.1.

Although there may be other benefits (and costs), such as reduced noise pollution and safety improvements, these are not quantified by the modelling.

The evaluation period for the CBA is from 2022 to 2040, with residual values beyond 2040 included in the analysis. Discount rates of 7% and 4% are applied.

3.1 Cost assumptions used

Diesel and electricity prices

We assume that diesel and electricity prices remain constant over the evaluation period. Diesel is assumed to cost 1.33$/L[29] for truck operators, and electricity at $0.15/kWh. These assumptions are in line with estimates from Australian Trucking Association.[30]

29. This price does not include the fuel excise tax because the vast majority of heavy vehicles receive a rebate on fuel excise tax.
30. EVC & ATA (2021, p. 8).

Table 3.1: Costs and benefits quantified in the CBA

Benefits	Costs
Reduced running costs	Additional upfront vehicle costs
Reduced maintenance costs	Additional charging infrastructure costs
Avoided health costs	Time and weight penalties
Avoided carbon emissions	

Upfront vehicle costs

The upfront costs of zero emission and diesel vehicles is assumed in line with CSRIO estimates between 2020 and 2050, using the 'long range' vehicle cost estimates for electric vehicles.[31] The additional upfront cost of a zero emissions vehicle is assumed to be the difference between the cost of an electric vehicle and diesel vehicle.

As CSIRO only provides data at five yearly intervals, we estimate costs of all years through linearly interpolation.

Charging infrastructure costs

We assume that charging infrastructure costs follow ICCT estimates (Table 3.2 on the following page).[32] Cost are estimated per zero emissions vehicle sold. We assume that 'low volume' cost estimates apply between 2020 and 2030, medium volume cost estimates apply between 2030-2035, and high volume costs apply after 2035. These assumptions assume a 5 year lag behind US charging cost rates.

31. Graham and Havas (2021, p. 24).
32. ICCT (2019).

Table 3.2: Charging infrastructure costs

Vehicle type	Volume	Cost per vehicle
Articulated trucks	Low volume	$255,600
Articulated trucks	Medium volume	$160,460
Articulated trucks	High volume	$99,400
Rigid trucks	Low volume	$116,440
Rigid trucks	Medium volume	$56,800
Rigid trucks	High volume	$38,340

Notes: Rigid truck cost estimates are also assumed to apply to buses and non-freight carrying vehicles.

Maintenance and Adblue costs

Maintenance costs are assumed to follow ATAP estimates for Australian vehicles by type.[33] In line with ICCT estimates, we assume electric vehicle maintenance costs are 30% lower than for diesel vehicle costs.[34]

Oil and lubricant costs are assumed to follow ICCT estimates for diesel vehicles.[35]

Adblue is assumed to cost $0.55/L, and adblue consumption rates are assumed to be 5% of fuel consumption rates where used.[36]

Time and weight penalties for electric vehicles

As electric heavy vehicles tend to have large, heavy batteries, they typically weigh more than their diesel equivalent. This reduces the payload that can be carried by the vehicle. To account for this, we assume that 3% more electric vehicles are required to perform the same freight task as diesel vehicles.

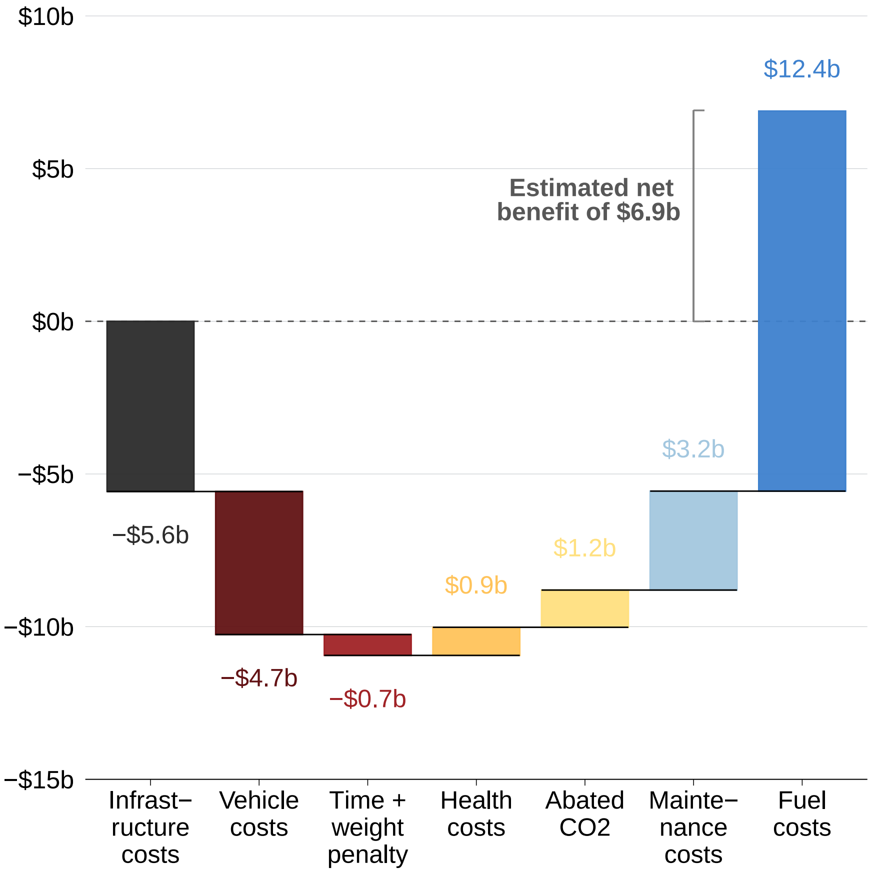
Electric vehicles also must be charged, which can take longer than refuelling a diesel vehicle. To account for this time penalty, we assume that an additional 1.5% more electric vehicles are required to perform the same freight task as diesel equivalents.

Both assumptions are in line with ICCT estimates, and apply to all costs – including the requirement for more chargers to support the additional vehicles.[37]

33. Australian Transport Assessment and Planning (2013).
34. ICCT (2019).
35. Ibid.
36. Yara (2022).
37. ICCT (2019).

3.2 CBA results

Figure 3.1: Zero emissions targets are likely have a net benefit
Costs and benefits of ZE-HDV targets under baseline scenario



Notes: A discount rate of 7% is used.

Table 3.3: Sensitivity testing of CBA results

Scenario	Discount rate	Net benefit	BCR
Baseline	7%	$6.9b	1.63
Baseline	4%	$15.2b	2.00
Upper bound freight growth	7%	$9.4b	1.85
Upper bound freight growth	4%	$19.7	2.29
Lower bound freight growth	7%	$4.7b	1.43
Lower bound freight growth	4%	$11.3	1.75
High diesel cost	7%	$8.3b	1.76
High diesel cost	4%	$17.6	2.16
High electricity cost	7%	$4.7	1.43
High electricity cost	4%	$11.5	2.00
Low diesel cost	7%	$5.5b	1.50
Low diesel cost	4%	$12.8b	1.84
Low electricity cost	7%	$9.1b	1.84
Low electricity cost	4%	$18.9b	2.26

Notes: High diesel cost is assumed to be $1.43/L. Low diesel cost is assumed to be $1.23/L. High electricity cost is assumed to be $0.20/kWh. Low electricity cost is assumed to be $0.10/kWh.

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