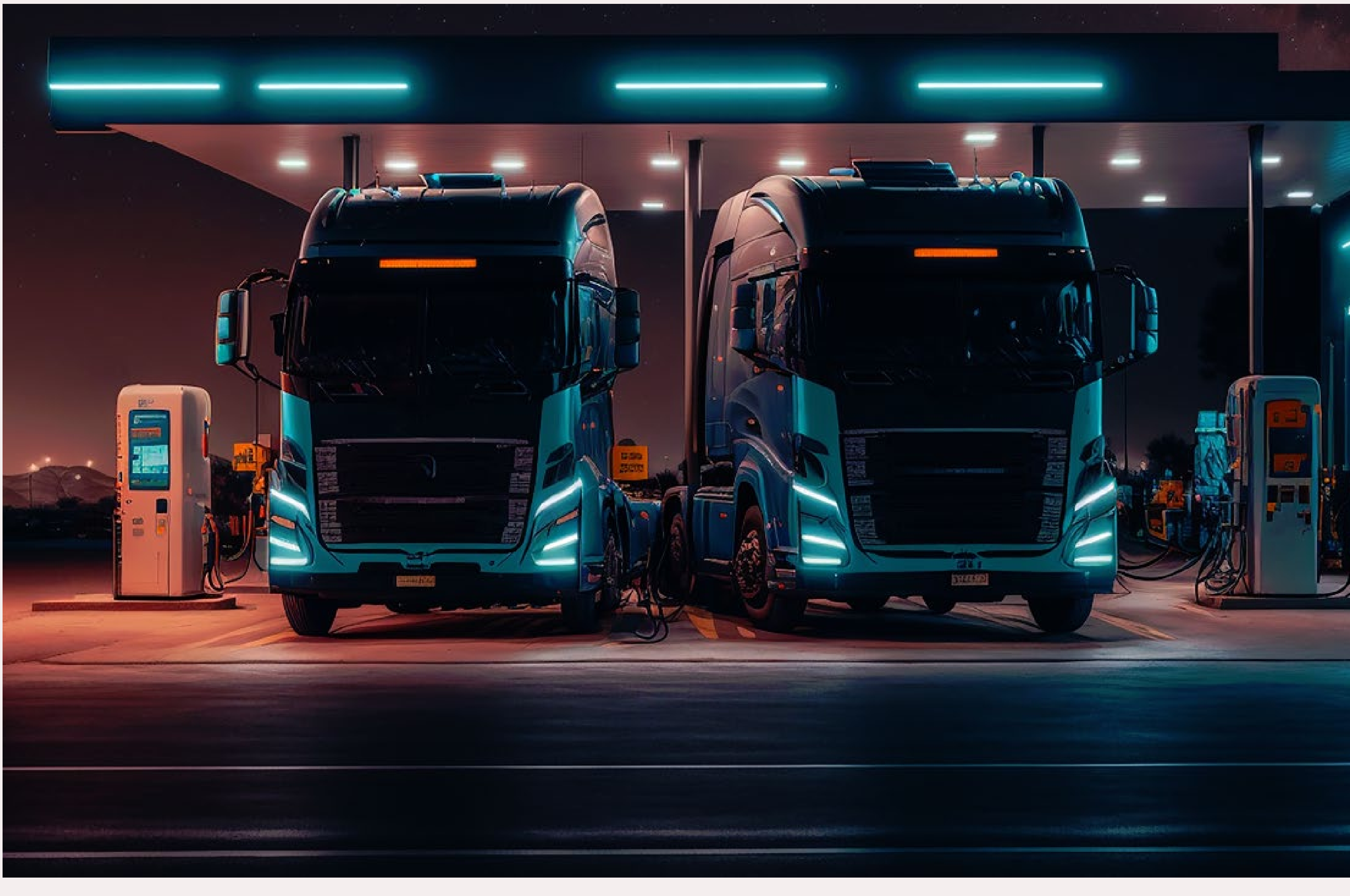
Emissions and economic modelling of road freight in NSW

Final Report

14 December 2023



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Final Report

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Abbreviations

Abbreviation	Description
ART-M	Articulated Truck – Medium
ART-S	Articulated Truck – Small
ART-L	Articulated Truck – Large
BEV	Battery Electric Vehicle
BET	Battery Electric Truck
CAPEX	Capital Expenditure
CE	Choice Experiment
CO_2	Carbon Dioxide
CO_2-e	Carbon Dioxide Equivalent
DCFC	Direct-Current Fast Charger
ERS	Electric Road Systems
FCEV	Fuel Cell Electric Vehicle (Hydrogen)
GCW	Gross Combination Weight
HPV	High Productivity Vehicle
HFCT	Hydrogen Fuel Cell Truck
ICERS	In-road Conductive Electric Road System
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
Kt	Kilo tonnes
LZEV	Low and Zero Emissions Vehicles
LZET	Low and Zero Emissions Truck
Mt	Million tonnes
NO_x	Nitrogen Oxides
OPEX	Operational Expenses
OCERS	Overhead Catenary Electric Road System
PBS	Performance-Based Standards
PHEV	Plug-in Hybrid Electric Vehicle
PHT	Plug-in Hybrid Truck
$PM_{2.5}$	Particulate Matter (2.5 microns or less in diameter)
RIG-M	Rigid Truck - Medium
RIG-S	Rigid Truck – Small
RIG-L	Rigid Truck - Large
TCO	Total Cost of Ownership
VOC	Volatile Organic Compound
WIERS	Wireless Inductive Electric Road System

Executive Summary

Executive Summary

This research modelled the reductions in emissions and economic benefits resulting from targeted policy interventions for decarbonising road freight in NSW. The research focused on key tasks that included:

- A comprehensive literature review that surveyed and interpreted relevant studies to identify the current state of knowledge, opportunities, challenges, and barriers that could influence uptake of low and zero emissions trucks (LZET) in NSW. The review also considered international best practice case studies and identified important insights that were used to inform the research directions.
- Identification and feasibility assessment of targeted policy interventions. Several policy options for the uptake of LZETs were analysed to determine their feasibility in the context of NSW based on a series of qualitative metrics. This helped to develop a good understanding of the expected policy impacts on freight demand and LZET adoption rates over time, which in turn informed the development of modelling scenarios in this study.
- Choice Experiment and modelling of uptake. A Choice Experiment and associated survey was undertaken to collect evidence from fleet operators on the responsiveness of technology uptake to the purchase price and ongoing cost, willingness to pay extra for LZETs, potential impacts of certain non-financial policy interventions, and impacts on decisions of access to charging and refuelling infrastructure. Scenarios on key parameters such as future costs of fuels and vehicles were also established, and the results were then used to determine the demand for LZETs. Models of LZET uptake rates were then developed up to 2061 based on 20 scenarios that included single and various combinations of multiple policy interventions.
- Estimation of emissions and health impacts under policy interventions. An emissions modelling framework was then used that considered VKT by truck type (rigid and articulated), emissions factors for diesel trucks, and LZET uptake rates from the modelling of uptake (drawing on the Choice Experiment results). The output of the emissions model included CO_2-e, NO_x, $PM_{2.5}$ emissions (exhaust and non-exhaust) and monetised health costs for each of the 20 scenarios evaluated in this research.
- Economic assessment of policy interventions. An economic assessment framework which followed cost effectiveness analysis principles was used in this research. The analysis was based on comparing the monetised emissions and air quality impacts associated with the policy interventions, and the likely public sector costs of implementing these interventions.
- Stakeholder consultations. A survey-based stakeholder consultation was conducted in this research to gain insights from freight operators on their perceptions, expectations, and knowledge of LZET technologies. This helped to develop a good understanding of the barriers and challenges faced by the industry and the support they need to improve uptake of LZET fleets.

Key findings

LZET technology acceptance appears high in NSW, providing the basis for incentivising decarbonisation of freight.

The Choice Experiment and econometrics approach helped to understand how freight operators make trade-offs between key parameters when purchasing trucks, and this provided information on how they would respond to policies, and how they assign value and preferences to LZETs. The Choice Experiment estimated respondents' relative valuation of a set of financial and non-financial options in relation to truck operators choosing between diesel and LZET technologies. The results showed a high acceptance of LZETs and preference for these (amongst most participants) when suitable alternatives are available. Specifically, in the largest group of participants (around 65%) there was a statistically significant positive willingness to pay extra for LZETs. Only about a third of respondents were not willing to pay extra for LZETs, but rather this group had a reverse preference in that they had a statistically significant willingness to pay to avoid LZETs (for example by paying penalties or a higher purchase price). The methodology used the equations parameterised by the Choice Experiment, which allowed for calculating the probability of operators choosing one type of vehicle over another in future scenarios. This provided the basis for modelling LZET adoption rates for the period 2023-2061, across a suite of availability scenarios, stipulating which types of trucks that are available for purchase. This was based on ensemble modelling, considering a multitude of scenarios for the possible availability of different vehicle types, aggregated to a single adoption rate for each vehicle type, using Bayes formula. This was used to test and evaluate the impacts on freight decarbonisation resulting from different scenarios that explored a variation of financial and regulatory/policy settings.

This research modelled 20 scenarios (referred to as iMOVE1 to iMOVE20) that include a base scenario (iMOVE1) reflecting the baseline 'Current 2022 Policy", in addition to 19 policy intervention scenarios (**Table ES.1**). The scenarios are based on assumptions related to OPEX and CAPEX financial subsidies, non-financial incentives and considerations such as improved LZET availability, road access to reserved lanes and low emissions zones, discounted loans and phase out year 2035 beyond which ICE trucks would not be available.

Table ES.1: Policy intervention scenarios

OPEX subsidy	$5 rebate on per 100km operating costs -approximately 16.6% rebate
CAPEX subsidy	Percentage of the differential in purchase price between LZET and an ICE equivalent (40% and80%)
Availability	(1) Available (0) Not available A qualitative indicator capturing whether a business can purchase a LZET that matches their needs
Road access	Policy package consisting of road/network access to reserved lanes, low emissions zones, and relaxation of right-time curfews for LZETs
Discounted loan	This a low or zero interest loan offered by the state for the procurement of new LZETs (4% or 6%)
Phase out	Year beyond which Internal Combustion Engine trucks would no longer be available on the Australian market

Scenario	iMOVE 1	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10
OPEX subsidy	0	0	0	0	0	0	0	0	$5	$5
CAPEX subsidy	0	0	0	0	0	0	40%	80%	0	0
Availability	0	0	0	0	0	1	0	0	0	1
Road access	0	0	0	0	1	0	0	0	0	1
Discounted loan	0	0	4%	6%	0	0	0	0	0	6%
Phase out	0	2035	0	0	0	0	0	0	0	2035

Scenario	iMOVE 11	iMOVE 12	iMOVE 13	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19	iMOVE 20
OPEX subsidy	$5	0	0	0	0	5	5	5	0	5
CAPEX subsidy	40%	0	0	40%	80%	0	40%	80%	40%	40%
Availability	1	1	1	1	1	1	1	1	1	1
Road access	1	0	1	0	0	0	0	0	0	0
Discounted loan	0	0	0	0	0	0	0	0	0	0
Phase out	2035	2035	2035	2035	2035	2035	2035	2035	0	0

Financial incentives matter, but regulatory changes have the greatest short to medium term effect.

The modelling results showed improved adoption rates for all proposed policy intervention scenarios compared to the baseline scenario (**Table ES.2**).

Table ES.2: Results of policy intervention scenarios

Scenario	iMOVE 1 (Baseline)	iMOVE 2	iMOVE 6	iMOVE 10	iMOVE 11	iMOVE 18
OPEX subsidy	0	0	0	5	5	5
CAPEX subsidy	0	0	0	0	0.4	0.8
Availability	0	0	1	1	1	1
Road access	0	0	0	1	1	0
Discount	0	0	0	0.06	0	0
Phase out	0	2035	0	2035	2035	2035

Results

Emissions	iMOVE 1 (Baseline)	iMOVE 2	iMOVE 6	iMOVE 10	iMOVE 11	iMOVE 18
CO_2-e (Mt)	177.95	168.39	157.98	149.69	149.80	149.88
NO_x (Kt)	271.98	266.79	254.69	248.94	248.96	248.88
$PM_{2.5}$ exhaust (Kt)	4.62	4.54	4.34	4.24	4.24	4.24
$PM_{2.5}$ non-exhaust (Kt)	19.9	19.90	19.90	19.9	19.90	19.90
$PM_{2.5}$ total (Kt)	24.52	24.44	24.24	24.14	24.15	24.14

Reductions on iMOVE 1	iMOVE 2	iMOVE 6	iMOVE 10	iMOVE 11	iMOVE 18
CO_2-e reductions (Mt)	9.56	19.97	28.26	28.15	28.07
NO_x reductions (Kt)	5.19	17.29	23.04	23.01	23.1
$PM_{2.5}$ exhaust reductions (Kt)	0.09	0.28	0.38	0.38	0.38
$PM_{2.5}$ non-exhaust reductions (Kt)	0.00	0.00	0.00	0.00	0.00
$PM_{2.5}$ total reductions (Kt)	0.09	0.28	0.38	0.38	0.38

Percent Reductions on iMOVE 1	iMOVE 2	iMOVE 6	iMOVE 10	iMOVE 11	iMOVE 18
CO_2-e reductions (%)	5.37%	11.22%	15.88%	15.82%	15.77%
NO_x reductions (%)	1.91%	6.36%	8.47%	8.46%	8.49%
$PM_{2.5}$ exhaust reductions (%)	1.89%	6.11%	8.20%	8.18%	8.20%
$PM_{2.5}$ non-exhaust reductions (%)	0.00%	0.00%	0.00%	0.00%	0.00%
$PM_{2.5}$ total reductions (%)	0.36%	1.15%	1.55%	1.54%	1.55%

In terms of a single policy measure, the greatest CO_2-e emissions reduction impacts were associated with two regulatory options. The iMOVE6 scenario (i.e., truck availability, which assumes a faster than expected availability of trucks for purchase across various freight market segments) had the single largest impact (11.22% reduction on baseline). Currently, freight operators don't have the opportunity to purchase all types of LZETs that they would need for decarbonisation. When such vehicles will be fully available on the Australian market is uncertain, due to a range of factors, including the willingness of manufacturers to bring vehicles into Australia, the uncertainty of technological progress, as well as regulatory barriers, including width and weight requirements in Australia. The iMOVE6 scenario simply assumes earlier availability of LZETs compared with the current expectation, meaning that the regulatory levers to achieve this outcome are also uncertain, indicating an important knowledge gap. IMOVE2 (phase-out 2035) similarly resulted in greater rates of decarbonisation (5.37% reduction in CO_2-e on baseline). Financial incentives (subsidies on purchase costs, interest payment support or fuel rebates) also matter, but their effectiveness is likely downwards biased given the limited choice and availability of LZETs in Australia today.

Comprehensive LZET packages that include both regulatory as well as financial incentives had the largest combined impact on adoption rates. The iMOVE10 (OPEX subsidy, availability, road network access, discounts and phase out by 2035), iMOVE11 (OPEX subsidy, CAPEX subsidy, availability, road network access and phase out by 2035), and iMOVE 18 (OPEX subsidy, CAPEX subsidy, availability and phase out by 2035) policy scenarios provided the largest combined benefits and CO_2-e emissions reductions impacts compared to other scenarios (15.88%, 15.82% and 15.77% reductions on baseline, respectively). These high impact policy scenarios include a combination of OPEX subsidies ($5 rebate per 100 km operating costs), CAPEX subsidies (40% or 80% of the difference in purchase price between a diesel and zero emissions truck), availability of zero emissions trucks that are readily accessible for purchase in the NSW market, provision of road access to special traffic lanes and zero emissions zones, a zero interest loan offered by the state to freight operators to help them with procurement of zero emissions trucks, and finally policy settings for the phase-out of all diesel trucks by 2035.

Modelled policies generate significant decarbonisation and air quality improvements, but more is required to drive emissions towards zero.

In terms of emissions reductions over the period 2023-2061, the iMOVE10, iMOVE11 and iMOVE 18 scenarios were found to reduce CO_2-e emissions from around 178 million tonnes (Mt) in the baseline scenario to around 150 Mt (around 16% reduction). These scenarios were also found to provide an improvement in NO_x reductions by around 8.5%, $PM_{2.5}$ exhaust reductions by around 8.2% and $PM_{2.5}$ total emissions reduction of around 1.55%, compared to the baseline scenario. Analysis of the emissions produced in the year 2050, however, showed that the CO_2-e emissions produced by the iMOVE scenarios ranged between a maximum of 3.473 million tonnes in 2050 (iMOVE 7) to a minimum of 2.550 million tonnes in 2050 (iMOVE10). These findings suggest that more interventions are needed, beyond truck electrification, to meet net zero targets in the road freight sector. These could include efforts to increase the shift of road to rail freight and wide adoption of high-performance vehicles.

Emissions reductions resulting from a shift of road to rail freight.

In addition to decarbonising the vehicle fleet and shifting from diesel trucks to LZETs, this research also evaluated the emissions reductions that would result from shifting road freight to rail (**Table ES.3**). Although not considered a direct intervention policy, several scenarios were modelled, including a potential shift of 20%, 30% and 40% between 2023-2061. The CO_2-e emissions reductions from these three scenarios were substantial, amounting to 17.1 Mt, 25.70 Mt and 34.20 Mt for the 20%, 30% and 40% shift scenarios, respectively. These reductions are comparable in magnitude or exceed what can be achieved through the iMOVE scenarios relating to a shift towards LZETs. Importantly, the total reductions can reach 45.36 Mt, 53.96 Mt and 62.46 Mt when combining the iMOVE10 with the 20%, 30% and 40% rail shift scenarios, respectively.

Table ES.3: Emissions reductions from a shift of road to rail freight

	iMOVE 10	20% Shift to Rail	30% Shift to Rail	40% Shift to Rail
CO_2-e reductions	28.26 Mt	17.10 Mt	25.70 Mt	34.20 Mt
Combined iMOVE 10 and rail shift reductions		45.36 Mt	53.96 Mt	62.46 Mt
Combined iMOVE 10 and rail shift (% reductions on baseline)		25%	30%	35%

An important consideration for future research is that although the iMOVE 10 scenario combined with shifting road freight to rail represent significant reductions from the baseline scenario, they still fall short of meeting 2050 net zero emissions targets. This still leaves a large gap in emissions that cannot be met through these interventions and policy settings. To address this, these measures would need to be considered holistically as part of a comprehensive transport decarbonisation strategy that includes demand management, optimisation of freight distribution networks, establishment of freight consolidation centres, and similar freight and transport improvement and innovation projects.

Emissions reductions resulting from a shift to high performance vehicles.

A key challenge in rapid decarbonisation of freight is the absence of current technological availability, particularly in larger truck classes (articulated trucks). Modern High Productivity Vehicles (HPV), particularly Performance Base Standards (PBS) vehicles, provide emissions reductions potential, and represent an intermediate transition opportunity with emissions reduction potential until LZET technology becomes available.

HPVs are novel heavy road freight transport solutions that can carry a greater payload than general access vehicles, which is achieved through optimised vehicle designs and configurations for specific freight tasks. Their key advantage is that by travelling fewer kilometres and using generally newer vehicles, they require smaller amounts of fossil fuels to complete the same freight tasks compared to their conventional counterpart trucks. Their emissions reductions benefits have been documented in several studies.

A study by the Industrial Logistics Institute (ILI, 2017) examined several scenarios for deployment of HPVs in Australia. The findings showed that under a moderate growth scenario, HPVs will save 8,860 million kilometres by 2034. This will result in reducing fuel consumption by around 3.2 billion litres, saving at least 8.7 million tonnes of CO_2 in addition to operational savings of at least $17.2 billion in all sectors of the economy. The study also found that just for the year 2016, PBS vehicles were estimated to have reduced fuel consumption by 94 million litres.

A subsequent study by the National Heavy Vehicle Regulator (NHVR, 2019) showed that since the introduction of PBS, and as of March 2019, the PBS fleet had provided annual reductions of 200 million litres of fuel and 486,000 tonnes of carbon dioxide emissions. These savings would continue to increase as the PBS fleet size grows.

A study by the International Transport Forum (ITF, 2019) also showed that HPVs require less energy per unit of transported cargo and thus offer reduced emissions and less impact on the climate.

Similarly, a 2020 study undertaken jointly by the National Heavy Vehicle Regulator (NHVR) and the Australian Road Transport Suppliers Association Institute (ARTSA-I) showed that the improved productivity of PBS combinations was estimated to have reduced the heavy vehicle road transport task by over 2 billion kilometres since they were introduced (NHVR, 2020).

NSW DPE modelling of potential emissions reductions resulting from replacing existing medium articulated trucks with high productivity large articulated trucks.

Four scenarios were modelled representing the potential replacement of 10%, 20%, 30% and 40% of existing ART-M trucks (that are more than 10 years old) with HPV ART-L trucks. In this simplified analysis, it was assumed that two ART-M trucks would be replaced by an ART-L HPV each year. The results (**Table ES.4**) show these shifts will reduce emissions by around 4.9 Mt, 8.4 Mt, 12.3 Mt and 15.6 Mt for the 10%, 20%, 30% and 40% scenarios, respectively, compared to the baseline iMOVE1 scenario.

Table ES.4: Emissions reductions from a shift of ART-M trucks to HPV ART-L

	iMOVE 1	10% Shift to HPV	20% Shift to HPV	30% Shift to HPV	40% Shift to HPV
Articulated trucks - cumulative total CO_2-e emissions (Mt) (2023-2061)	108.5	103.6	100.1	96.2	92.83
Articulated trucks – cumulative CO_2-e reductions (Mt) (2023-2061)		4.9	8.4	12.3	15.6
Percent reduction on iMOVE1 (%)		4%	8%	11%	14%

In future work, it is recommended that these truck types are included in the modelling as a separate category to diesel trucks. While freight optimisation and reduction in VKT are sources of GHG emissions reductions, the magnitude of any reductions remain more uncertain given limited data on their GHG emissions profile. Future studies should also look to undertake field studies and operational performance to establish their emissions profiles.

Financial incentives should be carefully designed to enhance the economic impact of public expenditure.

The societal and public sector costs and benefits associated with the policy options varied substantially. The benefits are primarily determined by the degree of decarbonisation and air quality improvements (reduction in externalities) as well as reduction in real resource use associated with fuel consumption by truck operators. To compare the economic impact of policy options against the baseline decarbonisation assumption, most cost categories can be set aside. However, faster rates of decarbonisation will likely be associated with additional road wear (LZEV vehicle technology is typically heavier than diesel trucks) and additional infrastructure requirements, at least until battery technology improves and LZETs become lighter over time.

As with the impact on emissions themselves, the net social benefit of regulatory options such as iMOVE2 (phase-out 2035) and iMOVE6 (availability) exceeded other single policy options. These two options also generated the greatest net societal benefit per dollar of public expenditure (**Table ES.5**). A key reason for this finding is that they are primarily regulatory in nature, with little additional costs beyond road wear and tear (public cost) or infrastructure (either public or private). These two policy options are modelled to generate $203m and $1bn in net social benefit (2023-2061), respectively. Comprehensive policy packages combining several initiatives, including subsidies, do generate higher social benefits, but also come at greater social costs.

Table ES.5: Societal benefits analysis

Scenario	iMOVE 2	iMOVE 6	iMOVE 8	iMOVE 10	iMOVE 11
Societal analysis	**Phase-out 2023**	**Availability**	**Capex 80 %**	**Comprehensive**	**Comprehensive**
NPV Total Benefits (million, $)	$1,108m	$2,731m	$101m	$4,090m	$3,720m
NPV Total Costs (million, $)	$905m	$1,697m	$126m	$2,779m	$2,589m
NPV Net Benefits (million, $)	$203m	$1,034m	-$26m	$1,311m	$1,131m
Ratio analysis					
Societal B/C	1.22	1.61	0.80	1.47	1.44

This study also found that financial incentives are comparatively less effective in reducing emissions, i.e., promoting decarbonisation. Consequently, they generate lower net social benefits and add considerably to public sector expenditure. For example, iMOVE8 (80% subsidy on price differential between ICE and LZEV alternatives) illustrates the comparatively higher cost. These results must be seen in relation to the currently very limited availability of LZET options in Australia in 2023. Insights from behavioural finance show that reduction in upfront costs can be important to reduce barriers to large capital expenditure outlays. However, financial incentives are also expensive because even at a time of relatively high baseline demand for LZETs, they can be poorly targeted. The reason for this is that, a priori, it is difficult to establish which LZET purchases are the result of any specific financial incentive, and which would have taken place anyway. As a result, each purchase potentially requires/obtains a subsidy payment. Thus, while iMOVE8 has a total cost of $126 million (low efficacy), the cost under iMOVE10 and iMOVE11 is inflated due to poorer targeting.

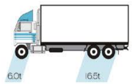
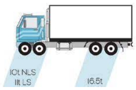
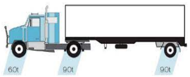
Importantly, financial incentives can nevertheless generate important signalling effects that work on buyers (in terms of commitment to uptake) and producers (in terms of assessing Australia's market potential and viability).

A key determinant of decarbonisation in the modelling and economic assessment is the rate with which existing vehicles are retired (the vehicle retirement rate was fixed in the modelling). We recommend that future research should consider how financial incentives could be targeted by subsidising the removal of older trucks and more polluting trucks. Financial rates could also be differentiated by age and emissions to ensure that the removal of lower-polluting trucks is not subsidised to the same extent as higher-polluting trucks.

Disaggregation of emissions impacts by freight vehicle subclass can help identify the priority intervention of fleet segments while considering LZET availability.

The emissions impact for each truck subclass (e.g., rigid small, rigid medium, articulated large etc) was evaluated in this research as a function of how polluting each subclass typically is, and how many kilometres trucks in each subclass typically travel (**Table ES.6**). This analysis, however, is limited in that it does not consider payload and total tonne-kilometres of travel per truck subclass (i.e., that larger trucks can move more cargo per trip). A strategy to address the lack of technological availability, particularly for large articulated trucks, is the greater utilisation of HPVs. While their emissions profile remains uncertain, their associated VKT reductions provide the potential for some GHG emissions savings. HPVs offer potential payload efficiencies compared to their traditional counterparts, which means that they can move goods more productively (in terms of tonne-kilometres). The use of more HPVs to move freight across the network would reduce emissions per tonne-kilometres because fewer vehicles would be required to perform the same task.

Table ES.6: Emissions and social cost according to truck subclass

Vehicle Type		Number of Trucks	Avg VKT per truck	CO_2-e (tonnes) per average truck	Total CO_2-e (tonnes)	Social cost per average truck
Rigid Truck (Small)		71,330	23,561	8.6	613,438	$1,127
Rigid Truck (Small-Medium)		19,160	21,113	8.3	159,028	$1,080
Rigid Truck (Medium)		29,220	20,957	12.6	368,172	$1,649
Rigid Truck (Medium-Large)		17,167	21,899	14.0	240,338	$1,833
Rigid Truck (Large)		23,816	23,591	22.1	526,334	$2,892
Articulated Truck (Small)		4,697	73,561	105.8	496,943	$13,825
Articulated Truck (Medium)		28,243	60,899	79.9	2,256,616	$10,435
Articulated Truck (Large)		10,868	66,670	110.2	1,197,654	$14,395

Independent pilot studies, field testing and knowledge sharing of the capabilities and limitations of LZETs could support operators with informed decision making.

The stakeholder consultation survey provided insights into the perceptions, expectations, and levels of knowledge of fleet operators about LZETs. Analysis of survey responses showed low and varying level of zero emission truck knowledge, and a high level of uncertainty about LZET technical features (e.g., range, payload, and reliability). These factors, if not addressed, could impact decision making and delay the fleet operators' adoption of LZETs. Independent pilot studies and testing of different LZET technologies in the context of Australian urban and regional settings would help to provide guidance on most appropriate use cases for each technology solution. Furthermore, vehicle performance evaluation is important to reduce new product introduction for heavy vehicle manufacturers, particularly to build trust among users about the technology and its benefits.

Introduction

1. Introduction

The Government of New South Wales, represented by Transport for NSW (TfNSW) has commissioned Swinburne University of Technology and The University of Queensland (UQ), through the iMOVE CRC Project Agreement, to work on the emissions and economic modelling for road and rail freight in NSW. This report represents the final deliverable of the project which combines each of the tasks and activities undertaken – including the literature review of the different pathways to road freight decarbonisation, assessments of policy interventions and their potential uptake, emission and economic modelling and stakeholder consultations.

It is important to note this report primarily focuses on road freight. While some literature had been reviewed from other freight sectors, road freight is the primary consideration here due to this being the most mature and highest impact LZET market. A comprehensive list of freight transport measures to reduce and eliminate carbon emissions have been included in this research based on evidence from the literature review. However, the scope of the project in terms of **rail is just looking at mode shift**; and this report will mainly focus on strategies to reduce road freight emissions by supporting a **switch to lower and zero emission fuel / technology** in road freight vehicles.

When considering the road freight fleet, it should be recognised that this represents a wide range of vehicles, including small vans, rigid trucks, and articulated trucks. The international studies and papers reviewed in this report, divide the road freight trucks into different broad categories. However, it is important to note that the overall focus and scope of this project is limited to vehicles with a GVWR of **4.5t and above**.

1.1 Purpose of study

Decarbonisation of road freight has seen less attention than passenger transport**.** The International Transport Forum (ITF) reports that decarbonising road freight must move higher in the overall decarbonising policy agenda to support efforts to achieve net zero emissions by 2050 (ITF, 2018). The International Energy Agency (IEA) has also recently reported that focusing solely on the electricity sector will not be sufficient to achieve global climate targets (IEA, 2020). NSW's current truck fleet is primarily reliant on imported diesel fuel for operations. It will be challenging to achieve the NSW Government's net-zero emissions target by 2050 without decarbonising the road freight fleet.

Exploring opportunities to transition to low and zero emission fuel / technologies is important not only for achieving environmental targets, but in the process can also deliver a range of co-benefits including reduced local air pollution, lower fleet operating costs and freight costs, increased energy efficiency, reduced reliance on foreign fuel, and utilisation of locally produced, renewable energy. These goals are in line with the NSW Government's existing renewable energy, electric vehicle, and hydrogen policies, as well as other related strategies currently under development.

These goals are also important given:

- Vehicles are one of the primary sources of local air pollution, with vehicle emissions being responsible for approximately 40% more premature deaths each year, compared to road accidents. In 2017, Melbourne University's Energy Institute estimated that 1715 Australians died because of vehicle pollution while 1224 deaths were attributable to vehicle accidents (Jafari, 2019).

- Heavy vehicles contribute approximately a quarter of all transport greenhouse gas emissions in NSW and are a key sector to decarbonise to achieve net-zero emissions by 2050.
- Increasing fluctuations in global oil markets lead to both national energy security risks, and freight cost uncertainties. By prioritising both energy efficiency and a shift away from foreign oil to domestic energy production, freight costs can be stabilised, in addition to achieving greater transport energy independence.

This research will provide evidence-based insights at the state level in NSW and inform similar efforts in other states. The findings will be valuable for achieving Australia's goal of reducing emissions by 43% by 2030 by learning from the experiences of countries with more advanced decarbonisation in the freight sector. This will provide insight into the challenges and opportunities of decarbonising transport and freight. The role of proactive policy should not be underestimated, given Australia continue to fall behind comparable international partners in the transition to low and zero emission technologies.

1.2 Report structure

This report is divided into the following sections.

Section 1: Introduction
This section presents the purpose of the study, scope, research aims and objectives.

Section 2: Background
This section presents background international and national literature covering the landscape of global and national emissions from the road freight sector, trends in road freight distribution, net zero emissions commitments, freight decarbonisation scenarios, barriers to uptake of low and zero emissions vehicles, pathways to road freight decarbonisation, and summary of high impact global policies and case studies on freight decarbonisation.

Section 3: Road Freight Low Emission Technologies and Energy Systems
This section presents global developments in low and zero emissions trucks focusing on battery electric trucks, hydrogen fuel cell trucks, advanced biofuel trucks and plug-in hybrid trucks. A comparative evaluation of their advantages and limitations is provided. This section also provides the energy systems' requirements to support deployment of these types of trucks particularly the need to transition these energy systems to renewable sources to support decarbonisation efforts. This section also presents high performance vehicles and the role they play in decarbonising road freight through their capacity to carry higher payloads and reduce the number of trips needed to carry cargo between origins and destinations, thus leading to a reduction in total vehicle-kilometres of travel, lower fossil fuel usage and reduced emissions.

Section 4: Freight Emissions and Economic Modelling Framework
This section presents the road freight emissions and economic modelling methodology used in this research which relied on the NSW GHG emissions and health cost modelling framework. The section also presents the application of these models to a baseline scenario

reflecting current policy settings to estimate emissions and health burdens and impacts up to 2061.

Section 5: Assessment of Emissions Reduction interventions for NSW

The section presents a range of interventions that highlighting their advantages and benefits, and an assessment of these levers is provided. This section also presents how packages of policies that combine different interventions would be required to encourage adoption.

Section 6: Estimation of LZET Uptake Resulting from Policy Interventions

This section of the report presents the research tasks undertaken to estimate potential uptake of LZET resulting from the proposed policy interventions. This covers primary data exploration including the Drives Data that describes all the vehicles that are currently in the Fleet Stock, as well as Choice Experiment Data to establish parameters that feed into the models that will be used to estimate decisions to adopt zero/low emissions vehicles. It also discusses the setup of a simulation framework that utilises adoption equations to estimate adoption of different vehicle types (Diesel, BEV, PHEV and Hydrogen Fuel Cell trucks) over time. This section also describes the survey and Choice Experiment as well as the experimental setup of policy settings that were evaluated in this research.

Section 7: Emissions Under Policy Interventions

This section presents the application of adoption curves developed in this study to estimate the emissions reduction under each of the proposed policy interventions. The impacts of these scenarios on reducing emissions are presented for four types of emissions (CO_2-e, NO_x, $PM_{2.5}$ exhaust and $PM_{2.5}$ non-exhaust emissions). The emissions were estimated using emissions intensity factors for diesel trucks and expected Vehicle Kilometres Travelled (VKT) per truck type (rigid and articulated) over the period 2023-2061. This section also presents potential emissions reductions that would result from shifting road freight to rail assuming total shifts of 20%, 30% and 40% over the period 2023-2061.

Section 8: Economic Assessment of Policy Interventions

This section presents the development of an economic assessment framework that was used to calculate and compare the economic impacts for each of the policy intervention scenarios evaluated in this study. The focus in the economic assessment was on difference in economic benefits and costs relative to a baseline scenario reflecting the Department of Environment and Planning (DPE) decarbonisation-baseline, and modelling of zero emissions trucks and characteristics up to 2061.

Section 9: Disaggregate Analysis of Emissions and Economic Costs by Truck Class

This section presents analyses on the emissions contributions of each of the 8 subclass trucks (e.g., rigid small versus rigid medium) as well as the social cost associated with each truck subclass. These analyses were performed using indicators that included total number of trucks in each subclass category as well as their total VKT.

Section 10: Stakeholder Consultations

This section presents findings from an online survey that solicited inputs from truck operators about their perceptions of LZET and their preferences to the type of truck technology and any barriers they thought must be overcome to allow them to procure LZET in the future.

Section 11: Summary and Recommendations for Future Research

The final section of the report provides a summary of the research findings and outlines several recommendations to extend this research work in the future.

2. Background

To adequately assess what LZET policy options are most suitable for NSW, it is first necessary to gain an understanding of the required transformational change across the entire transport sector in less than 30 years, and how this major task fits within the broader decarbonisation agenda. The following section of this report sets out the current road freight emissions situation globally and outlines scenarios of what a future transport system will need to look like to achieve global climate targets.

2.1 Global road freight transport GHG emissions

The global transportation sector is a major contributor to GHG emissions, accounting for around one quarter of energy-related carbon dioxide (CO_2) emissions globally in 2019, as shown in **Figure 1** (International Energy Agency, 2020). Passenger travel is responsible for approximately 60% of CO_2 emissions from transportation, with freight accounting for the other 40%.

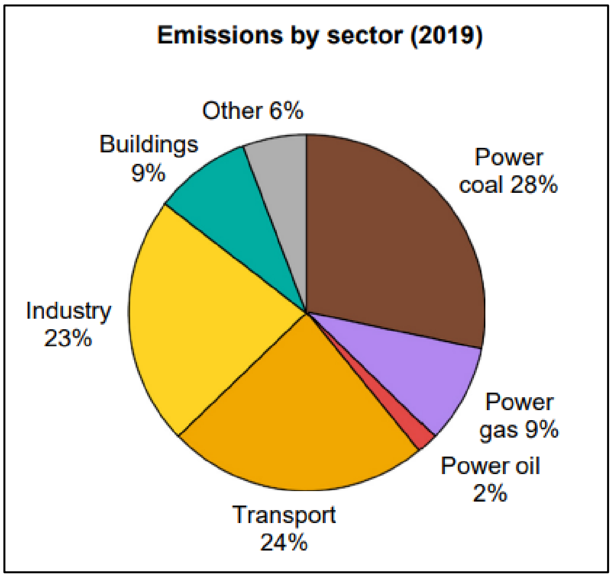


Figure 1: Global GHG emissions by sector (2019)

Road freight is the most visible and most flexible part of the global supply chain; with around 3 million companies responsible for transporting almost 22 trillion tonne-kilometres of cargo each year, this sector accounts for about **9% of global GHG emissions** (Shell International, 2021). There are some 217 million vans, trucks, and buses in the global fleet and around 63 million of those are medium duty trucks (MDT) and heavy duty trucks (HDT), which together account for around 60% of global road freight CO_2 emissions, shown in **Figure 2** (Shell International, 2021). Approximately 1.2 billion metric tons of CO_2 emissions is produced worldwide by 27 million heavy-duty trucks (HDTs). This accounts for 41% of global road freight emissions. In comparison, the fleet of 144 million Light Commercial Vehicles (LCVs) produced roughly half the emissions of HDTs.

According to the Organisation for Economic Co-operation and Development (OECD) 2021 projections, as population and economic activity grow, demand for all forms of transport is expected to rise in the future, and it is set to double before 2050 (ClimateWorks Australia, 2020). The road freight sector contributes greatly to GHG emissions and decarbonisation of this sector would create a cleaner, healthier, and more affordable future for everyone.

	Light Commercial Vehicles (LCVs)	Medium-Duty Trucks (MDTs)	Heavy-Duty Trucks (HDTs)	Buses and coaches	
Max. tonnage[1]	<3.5 tonnes	3.5–15 tonnes	>15 tonnes	variable	Σ (M)
Europe[2]	28	2	4	1	35
US[3]	20	5	3	1	29
China	21	4	7	3	35
India	5	3	2	1	11
Rest of World	70	22	11	4	108
Total	144	36	27	10	217
Road freight emission (Mt CO_2)[4]	596 (21%)	587 (21%)	1,183 (41%)	495 (17%)	2,861 Mt CO_2

MDTs & HDTs

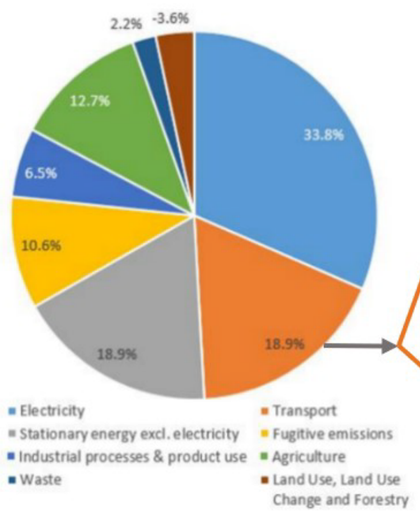
63 million trucks account for 62% of global road freight emissions

Figure 2: Global GHG emissions from medium and heavy-duty trucks

2.2 Road freight transport emissions in Australia

In Australia, transport emissions have been rising every year since 1990 except for 2020, which saw a temporary drop due to COVID-19 restrictions (Australian Government: Climate Change Authority, 2020). It is also a sector that is highly dependent on fossil fuels and imposes a high cost for society, in terms of health, atmospheric pollution, noise and crashes, congestion and damage caused to the environment. The transport sector is the second largest source of emissions in Australia with transport emissions responsible for around 19% of Australia's GHG emissions in 2020 (Australian Government: Department of Industry, Science, Energy and Resources, 2021). Most transport emissions come from road vehicles, with freight vehicles accounting for 38% (ClimateWorks Australia, 2020). Government projections indicate that emissions from road freight, specifically articulated and rigid trucks will increase in the next decade, producing 22 MT CO_2-e by 2030. This is a 6 MT CO_2-e increase from 2005 levels (ClimateWorks Australia, 2020) (Electric Vehicle Council and Australian Trucking Association, 2022). **Figure 3** shows emissions from different Australian transport subsectors in 2020 and also the projected changes from 2020 to 2030 (ClimateWorks Australia and Monash University, 2020) (Department of Environment and Energy, 2019).

The American Council for an Energy-Efficient Economy (ACEEE) rates the world's 25 largest energy users for sectors including transportation, as shown in **Figure 4** (American Council for an Energy-Efficient Economy, 2022). The scoring methodology included a combination of policy and performance metrics relating to energy efficiency in transportation. In 2022, Australia ranked 18th overall and **23rd in the transportation category**, scoring less than a quarter of the 25 available points on nine different criteria that cover passenger and freight transport. There are no light-duty or heavy-duty fuel economy standards in Australia, and the country does not have a national smart freight program, and freight movement within the country is relatively energy intensive. Use of public transit within the country is also limited.



Subsector	2020 Mt CO2e	Change 2020 to 2030
Passenger vehicles	44	-2%
Light commercial vehicles	17	+1%
Articulated trucks	13	+14%
Rigid trucks	9	+14%
Domestic aviation	9	+31%
Railways	4	+13%
Buses	3	+1%
Domestic shipping	2	+26%
Other transportation[1]	1	+30%
	102	+7%

Figure 3: GHG emissions from different Australian transport subsectors 2020/2030

Country	Total score	2025 LD fuel economy standard	Average light-duty (LD) on-road fuel economy	Electric vehicle (EV) sales share	VMT per capita	Heavy-duty (HD) fuel economy standard	Ton-mile per $ of GDP	Smart freight programs	Ratio of rail to road investments	% of passenger travel by transit
Max. score	25	4	3	3	3	3	2	1	3	3
France	18	4	3	2	1	1	1.5	1	3	1.5
U.K.	17	4	3	2	1	0	2	1	3	1
Italy	16	4	3	1	1	1	1.5	1	2	1.5
Netherlands	16	4	3	3	1.5	1	1.5	1	0	1
Spain	15	4	3	1	1.5	1	1	0	2	1.5
China	14.5	3	1	1	2.5	2	0	1	1	3
Germany	14	4	2	2	0.5	1	1	1	1	1.5
Poland	12	4	2	0	1.5	1	0.5	0	1	2
Japan	11.5	2	2	0	1.5	1	2	1	0	2
South Korea	10.5	3	2	1	0	0	1.5	1	0	2
Taiwan	10.5	2	2	0	2.5	0	1.5	0	1	1.5
India	10	2	3	0	3	0	0	0	0	2
Canada	9	3	0	1	0	3	0.5	1	0	0.5
Turkey	9	0	3	0	2	0	1	0	1	2
Mexico	8.5	1	1	0	1.5	0	1	1	2	1
U.S.	8.5	2	0	1	0	3	1	1	0	0.5
Brazil	6.5	1	1	0	2	0	0.5	0	0	2
Egypt	6.5	0	0	0	2.5	0	0	0	2	2
Indonesia	6	0	0	0	3	0	0	0	0	3
Russia	5	0	0	0	2	0	0	0	1	2
South Africa	3.5	0	1	0	2.5	0	0	0	0	0
Thailand	3	0	1	0	2	0	0	0	0	0
Australia	2.5	0	0	0	0.5	0	0.5	0	1	0.5
Saudi Arabia	2	1	0	0	1	0	0	0	0	0
U.A.E.	2	0	1	0	1	0	0	0	0	0

Figure 4: Transport energy efficiency of 25 largest energy users 2022
Source: (American Council for an Energy-Efficient Economy, 2022)

Due to a lack of strategic transport emissions policy in Australia, on current trends, emissions from the sector are expected to continue to increase out to 2030, and potentially beyond (ClimateWorks Australia, 2020).

2.3 Road freight transport in NSW

In NSW, the transport sector is the second largest GHG producer in the state, behind electricity generation, and transport emissions was responsible for approximately 20% of emissions in 2021, shown in **Figure 5**. Road transport was responsible for 88% of the emissions, split between cars and light commercial vehicles accounting for 65% and heavy-duty vehicles accounting for 23% (NSW Environmental Protection Agency, 2022). The transport sector is also highly dependent on fossil fuels and imposes a prohibitive cost for society, from the point of view of health, atmospheric pollution, noise and accidents, congestion and damage caused to the environment. Road freight is a key enabler of NSW's economy while also a significant emitter of GHG and air pollution. The volume of freight moved on the NSW transport network, in 2021, was estimated at approximately 472 million tonnes, up from 409 million tonnes in 2011 (NSW Department of Planning and Environment, 2022). In 2021, eCommerce experienced an increase of around 50% in NSW, resulting in a 27% growth in parcel deliveries for Australia Post. The amount of commodity freight is predicted to rise by 34% in NSW and 56% in Greater Sydney by the year 2061 (Transport for NSW, 2022) .

It will be challenging to achieve the NSW Government's net-zero emissions target by 2050 without decarbonising the freight fleet. As a result, it is important to identify technologies and measures that can rapidly decarbonise road freight fleets and set out strategic steps by which this could be done.

In addition to this, the heavy vehicle fleets in Australia and New Zealand are among the oldest in the OECD with an average age of 15 and 18 years respectively, as shown in **Figure 6** (Austroads, 2021). Older trucks tend to be more inefficient, consuming more fuel and affects the community and the environment and results in higher emissions produced by the sector. The average truck age in Australia is significantly older than the average age of trucks in Austria (6.4 years), France (9.3 years), Germany (9.5 years) and the Netherlands (9.6 years). Governments in other countries have enacted measures to reduce the operation of aged trucks in their jurisdictions. There are many government strategies and policy actions underway in Australia for heavy vehicles, but most do not address the issue of aged trucks.

With population growth and increased urbanisation, there is increasing demand for the delivery of goods in urban areas. Around 70% of all rigid truck kilometres travelled in NSW are in urban areas (**Figure 7**) and thus creates an opportunity to transition at least some of those trucks to LZETs (QTLC, 2022). Although most articulated trucks operate in regional areas, in NSW, around 40% operate within urban areas.

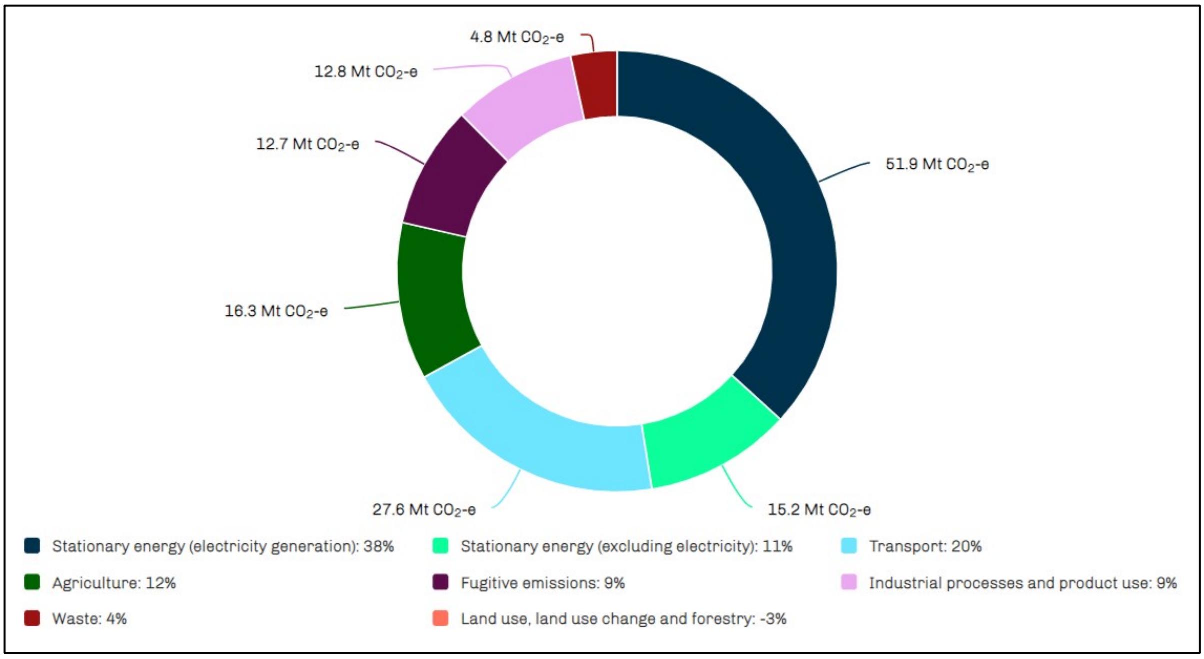


Figure 5: Greenhouse gas emissions from different key sectors in NSW

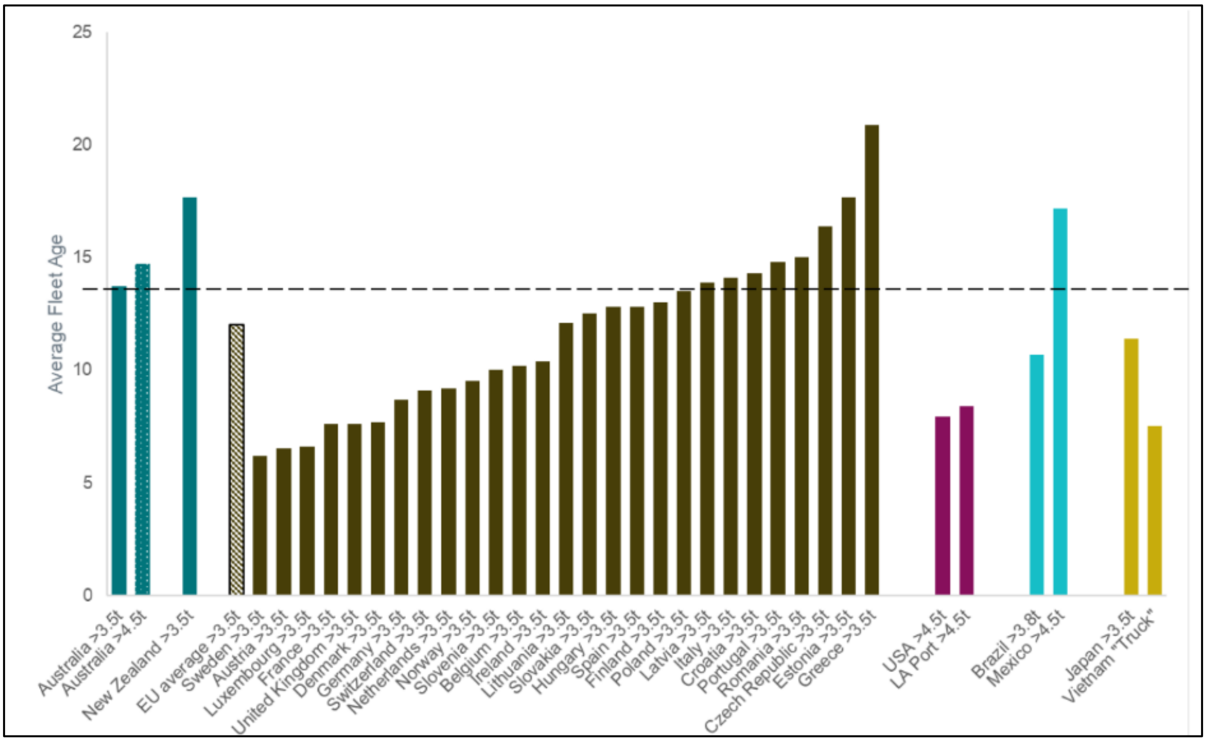


Figure 6: International comparison of average age of trucks

Source: (Austroads, 2021)

The Australian Bureau of Statistics (ABS) data also shows that the average daily kilometres travelled by a rigid truck in Australia is 60–84 km per day, while articulated trucks on average travel 240-336 km per day (Australian Bureau of Statistics, 2020). As shown in **Figure 8**, for most of the heavy-duty BETs, the driving range is around 250 km, with a few in the 500-750 km range.

Figure 7: Proportion of road freight kilometres by area of operation and truck type
Source: (QTLC, 2022)

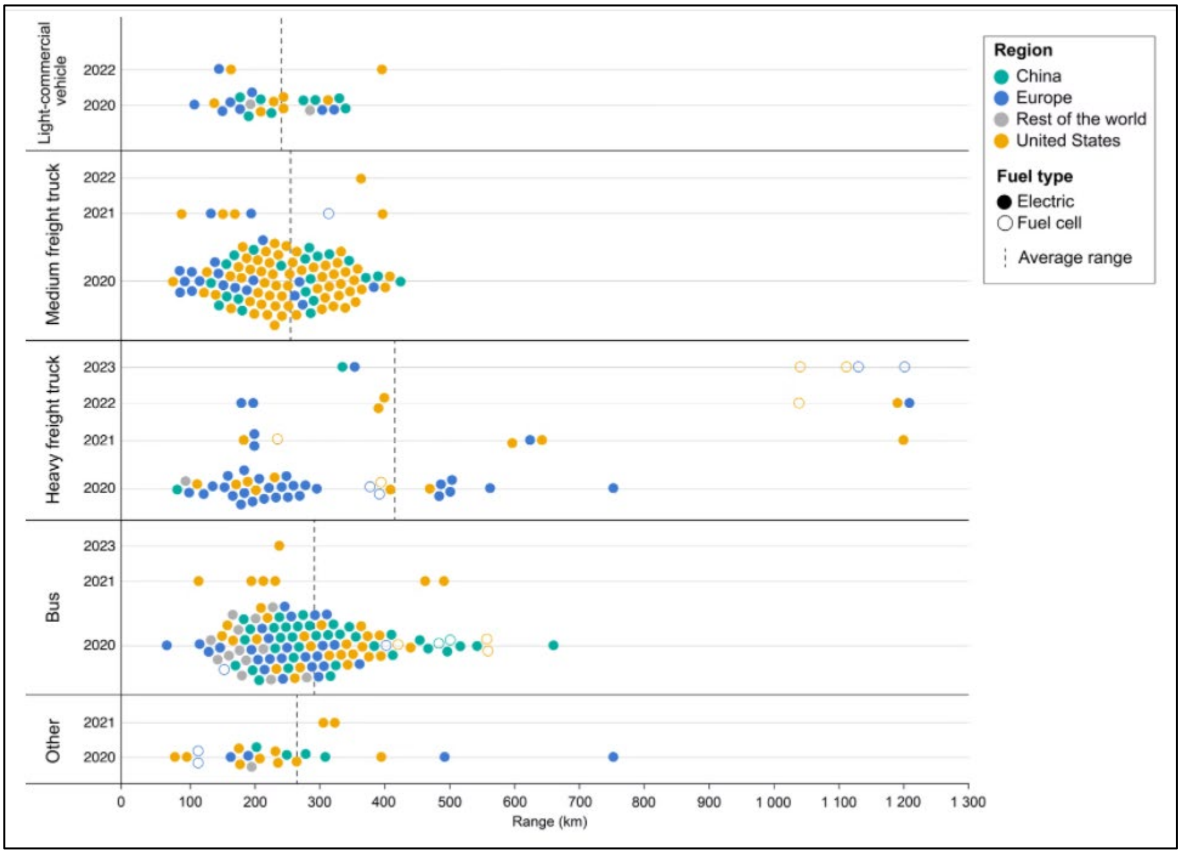


Figure 8: Zero-emission heavy vehicle models by class, country, and range
Source: (IEA, 2021)

There are also models planned in the near-future at up to 1,200 km. Heavy duty Hydrogen Fuel Cell Trucks (HFCT) models currently have a range of around 400 km, with models planned in the near-future at up to 1,200 km. Finally, in terms of medium duty trucks, the average BET driving range is around 200 km, with some models available at up to 400 km and for HFCTs it is around 300 km (IEA, 2021).

2.4 Trends in road freight transport

In the coming decades, economic development and increasing demand for e-commerce will drive further growth in road freight volumes (Bureau of Infrastructure, 2019). Demand for freight is growing at a faster rate than population growth because Australian consumers are purchasing more and increasingly expecting goods to be delivered quickly and directly to their door, leading to an increase in Australia's road freight transport emissions. There are several primary pathways by which the decarbonisation of road freight transport can be achieved:

- Approaches that reduce the total distance that freight vehicles must travel, for instance, through reducing the demand for freight transport activity by reorganising supply chains and altering the location of facilities between which goods are moved.
- Shifting goods transport to less carbon-intensive freight modes (e.g., from road to rail).
- Improving the efficiency of existing freight transport operations (by increasing the quantity of goods carried in each vehicle movement, reducing empty vehicle journeys, or enabling access for innovative vehicles that improve productivity).
- Using the most energy efficient conventionally fuelled freight vehicles that make use of recent advances in engine technology and vehicle design.
- Shifting to the alternatively fuelled freight vehicles, i.e., LZETs.

There is a limit to the extent of further emission reduction achieved with improvements to diesel engines and efficient supply chain logistics planning. Although in some regions, modal shift to waterways and rail, digitally enabled route, and network optimisation, and, in the longer term, autonomous technologies might slow the growth rate of GHG emissions, the net effect will almost certainly be more trucks on the road leading to increased emissions (**Table 1**).

The IEA estimates that to meet the targets set by the Paris Agreement, absolute emissions from road freight will need to decline almost 60% by 2050, despite a possible doubling of road freight volume over the same period (International Energy Agency, 2020) (IEA, 2020). Therefore, the sector will need to realise an emission intensity reduction of over 80% in less than 30 years. More pressingly, the sector's emission intensity must decline by around 31% before 2030. Trucks continue to rely primarily on diesel; the share of diesel in overall oil-based road fuel consumption rose from 38% in 2000 to nearly 45% in 2019, largely due to greater road freight activity (IEA, 2020). As a result, in the longer term, switching to low-carbon alternative fuels and powertrains will be needed to decouple rising activity and energy use from CO_2 emissions.

The objective of this project is to review and analyse the main measures, sustainable road freight options or combinations of options of policies, practices, technologies, etc., that are possible to avoid, reduce and eliminate GHG emissions from the road freight sector in NSW. In the following sections, we will analyse the instruments of pricing, regulations (efficiency standards) and financial incentives as well as practices to transition to low and zero emission alternatives in the road freight sector. This will mainly consist of presenting the best practices implemented internationally to mitigate the impacts of freight transport and to analyse the advantages and limitations of these options. This analysis will help us develop a strategic roadmap to clearly define the steps necessary to reduce CO_2 emissions from freight transport in NSW and to understand the actions that need to be taken by individual companies, public and private sectors, governments, and society.

Table 1: Trends impacting GHG emissions from road freight

Trends in road freight transport	Impact on road freight emissions
Modal shift	
Global population and economic growth **(Bureau of Infrastructure, 2019)**	
Efficient supply chain logistics with route and network optimisation	
Growth in eCommerce and changing consumer habits **(Bureau of Infrastructure, 2019)**	
NET IMPACT	

2.5 Net zero emissions commitments

Globally, several countries and regions are committing to achieving net zero emissions by 2050 and taking steps to support the transition of their transport sectors to low and zero emission technologies. As of late 2020, countries responsible for around 60% of global energy-related CO_2 emissions have announced net zero emissions targets (IEA, 2020). NSW will need to significantly increase its efforts on both renewable energy adoption and carbon pollution reduction to achieve its goal of net zero emissions by 2050.

Under the NSW Climate Change Policy Framework 2016 (NSW Government, 2016), the NSW Government has set objectives to achieve net zero emissions by 2050. The **Net Zero Plan Stage 1: 2020–2030**, released in March 2020, is the foundation for NSW's action to reduce emissions, reach targets of a 50% emissions reduction on 2005 levels by 2030 and to achieve net zero emissions by 2050 (NSW Government: Department of Planning, Industry and Environment, 2020). More specifically, the initiatives under this plan include:

- NSW Electricity Infrastructure Roadmap to modernise the energy system and increase the use of renewable energy, reducing NSW electricity emissions by 90 million tonnes by 2030.
- NSW Net Zero Industry and Innovation Program to reduce emissions in the industrial sector and invest in clean technologies.
- NSW Electric Vehicle Strategy to accelerate the adoption of electric vehicles.
- NSW Hydrogen Strategy to support the growth of the hydrogen industry.

- NSW Waste and Sustainable Materials Strategy to reduce emissions through better waste and materials management.
- NSW Primary Industries Productivity and Abatement Program to drive sustainable land management and boost productivity while reducing emissions.

2.6 Global net zero emissions scenarios

Several organisations have developed different future scenarios to explore what transformations will be required across the global economy, including transport, over the coming decades to achieve climate targets. While these scenarios do not predict what will happen in the future, they are useful for gaining an appreciation of the scale and pace of change required to achieve these targets. Comparison of these scenarios is also useful for understanding the potential implications of different policy choices by governments. The primary scenarios reviewed here include:

- The International Energy Agency's (IEA's) Sustainable Development Scenario (SDS)
- IEA's Net Zero Emissions by 2050 (NZE2050) scenario, and
- The Energy Transitions Commission's (ETC's) Zero Emissions Scenarios (ZES)

2.6.1 IEA sustainable development scenario

IEA's SDS outlines the economy-wide transformation required to achieve the energy-related components of the United Nation's Sustainable Development Goals (SDGs) (i.e., SDG 7 - achieve universal access to energy; SDG 3 - reduce the severe health impacts of air pollution; and SDG 13 - tackle climate change), while simultaneously aligning with the Paris Agreement. SDS is not aligned with a global net zero emissions target of 2050, but instead a later net zero emissions target of around 2070 (IEA, 2021).

The IEA state that if the SDS was achieved, it would limit global warming to less than 1.8°C with a 66% probability without reliance on global net negative emissions technologies. This is claimed to be equivalent to limiting global warming to 1.65°C with a 50% probability. The IEA claim that if SDS relied on a level of net negative emissions lower than the average assumed in most IPCC scenarios, it would achieve 50% probability of limiting global warming to 1.5°C, consistent with the IPCC's recommended target (IEA, 2021).

2.6.2 IEA net zero emissions by 2050 scenario

Given the serious concerns surrounding the feasibility of negative emissions technologies, it is important to understand a scenario that achieves a 50% chance of limiting global warming to 1.5°C without any reliance on net negative emissions. In line with the IPCC's findings, the IEA agree that this requires achieving net zero emissions globally by around 2050. This highlights why some governments have significantly increased their policy ambitions to align with this target (IEA, 2021).

The IEA has recently released its NZE2050 scenario to align with this increased ambition, recalling that the IEA's SDS aligns with achieving net zero emissions by around 2070. The IEA modelling comparing SDS and NZE2050 highlights that decisions up to 2030 will play a critical role in determining the transition pathway to 2050, and further emphasises the need for immediate action (IEA, 2021).

2.6.3 Energy Transitions Commission (ETC) zero emissions scenario

The ETC has recently released its ZES, which focuses on supply-side decarbonisation, and the addition of energy productivity improvements. Both variations are aligned with achieving net zero emissions by 2050, and the ambition of limiting global warming to 1.5°C. ZES is therefore like IEA's NZE2050 scenario. The consideration of energy productivity improvements was included by ETC to highlight the impact these measures can have on reducing energy demand, and in turn, reducing the magnitude of transformation required – at least in terms of additional renewable energy generation capacity (Energy Transitions Commission, 2020).

Unlike SDS and NZE2050, ZES does consider offsets and negative emissions technologies, but for extremely limited applications, and are primarily applied during the pre-2050 transition period. ZES has a strong focus on harder-to-abate sectors, such as industry and long-haul transport, with a review of energy implications within the context of what should be technically possible by 2050. ETC expect that low-carbon electricity will need to be the primary energy carrier across the global economy to achieve net zero emissions by 2050 (Energy Transitions Commission (ETC), 2020).

2.7 Freight decarbonisation scenarios

In IEA's SDS, most transport modes globally would be decarbonised by 2070; however, trucking, shipping and aviation continue to emit due to challenges in decarbonising these modes, shown in **Figure 9** (IEA, 2020).

In IEA's SDS forecasts, electricity accounts for more than 35%, and hydrogen and hydrogen derived fuels account for more than 30% of final energy demand in the transport sector by 2070, shown in **Figure 10** (IEA, 2020).

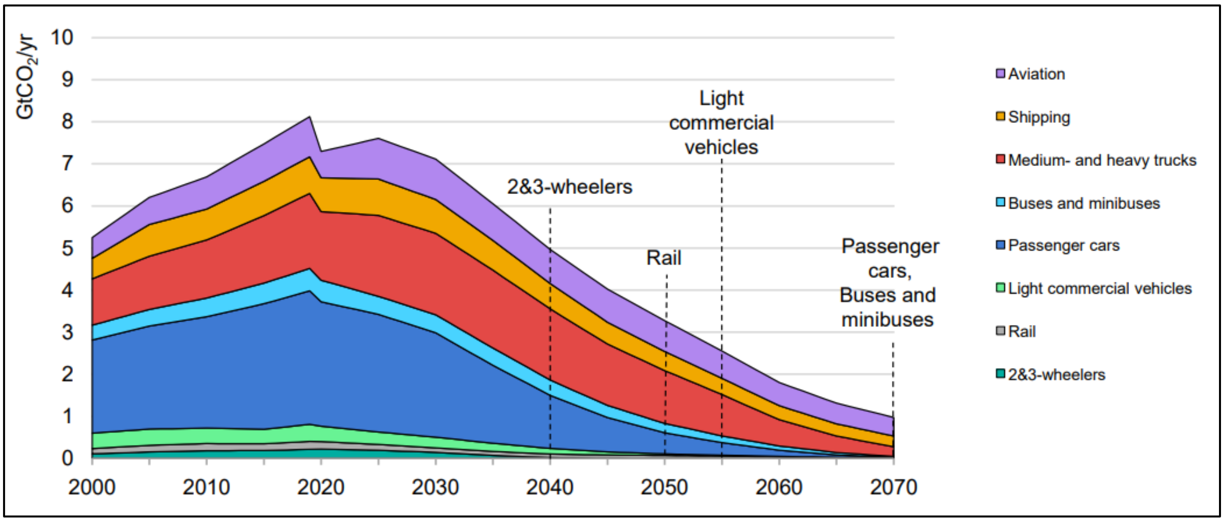


Figure 9: IEA SDS global CO_2 transport emissions by mode 2019 – 2070

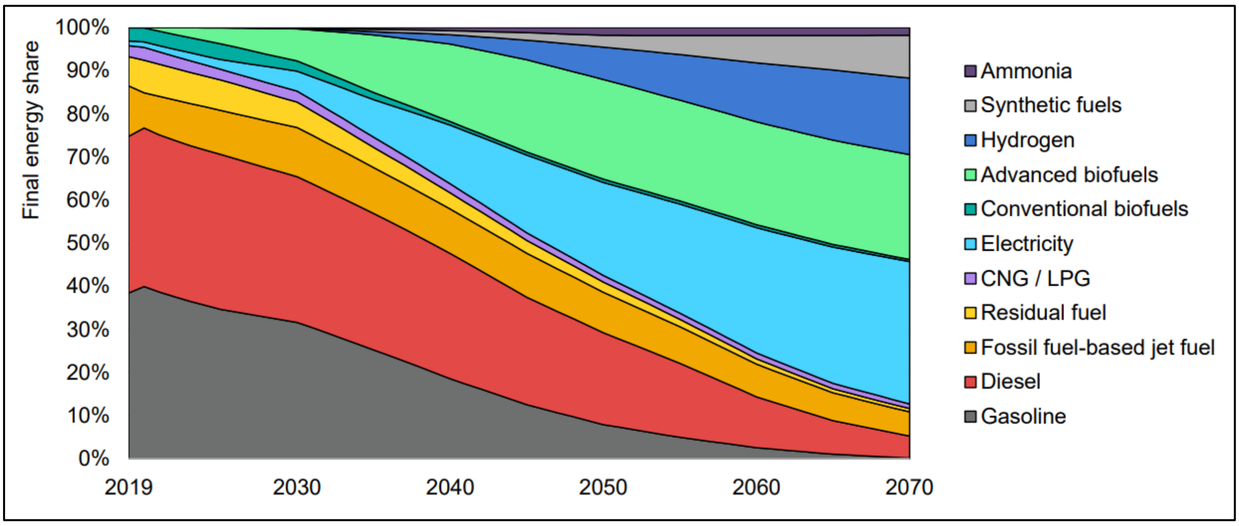


Figure 10: IEA SDS transport energy demands 2019 – 2070

According to IEA's NZE scenario forecasts, in transport, there is a rapid transition away from oil worldwide, which provided more than 90% of fuel use in 2020. In road transport, electricity comes to dominate the sector, providing more than 60% of energy use in 2050, while hydrogen and hydrogen-based fuels play a smaller role, mainly in fuelling long-haul heavy-duty trucks, shown in **Figure 11** (IEA, 2021). Overall, electricity becomes the dominant fuel in the transport sector globally by the early 2040s, and it accounts for around 45% of energy consumption in the sector in 2050 (compared with 1.5% in 2020). Hydrogen and hydrogen-based fuels account for 30% of consumption (almost zero in 2020) and bioenergy for a further 15% (around 4% in 2020). These forecasts are based on rapid developments in the batteries and fuel cells as well as massive investments in new infrastructure, including hydrogen refuelling stations, fast, ultra-fast, mega charging stations for electric trucks and ERS (catenary system) which power vehicles as they travel (IEA, 2020) (IEA, 2020).

In IEA's SDS scenario, biofuels, electricity, hydrogen, and synthetic fuels progressively displace fossil fuels for trucks. Biofuels account for most of the increase in the use of low-carbon alternative fuels in the first half of the projection period, though electricity and hydrogen make a growing contribution, especially in the second half (**Figure 12** and **Figure 13**) (International Energy Agency, 2020). The consumption of biofuels jumps more than six-fold from 13 million tonnes of oil equivalent (Mtoe) in 2019 to 80 Mtoe in 2070. In the longer term, decarbonising trucks requires a transition to powertrains that rely on electricity and hydrogen. The scaling up of plug-in and BETs in the projections starts with medium duty trucks in the 2020s in urban operations, and then extends to broader regional operations. Medium duty and heavy duty HFCTs begin to diversify the fuel mix away from fossil and liquid alternative fuels starting in the late 2030s and operations extend to long-haul routes.

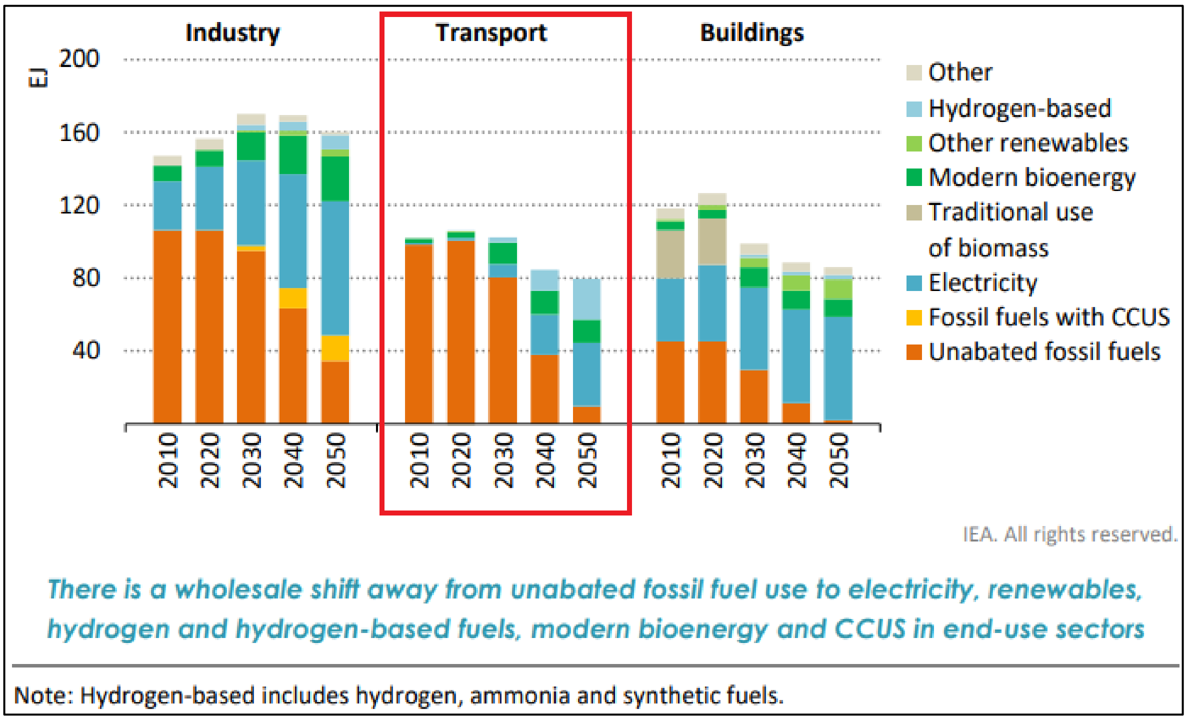


Figure 11: IEA NZE transport energy demand forecasts 2010 – 2050

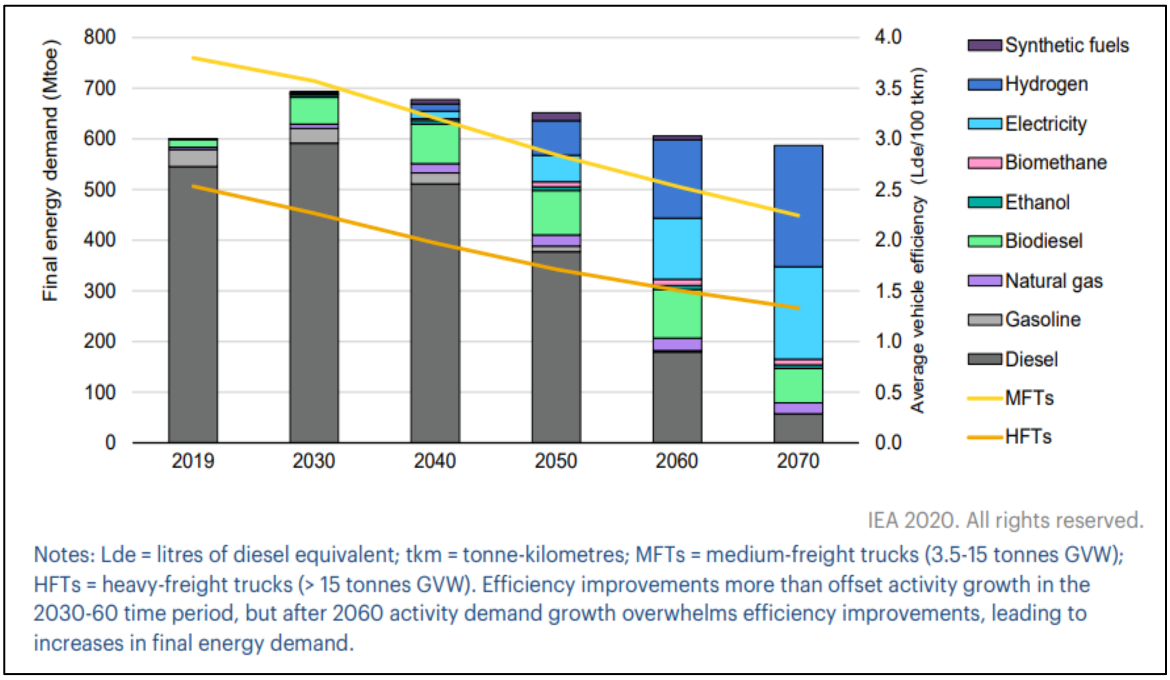
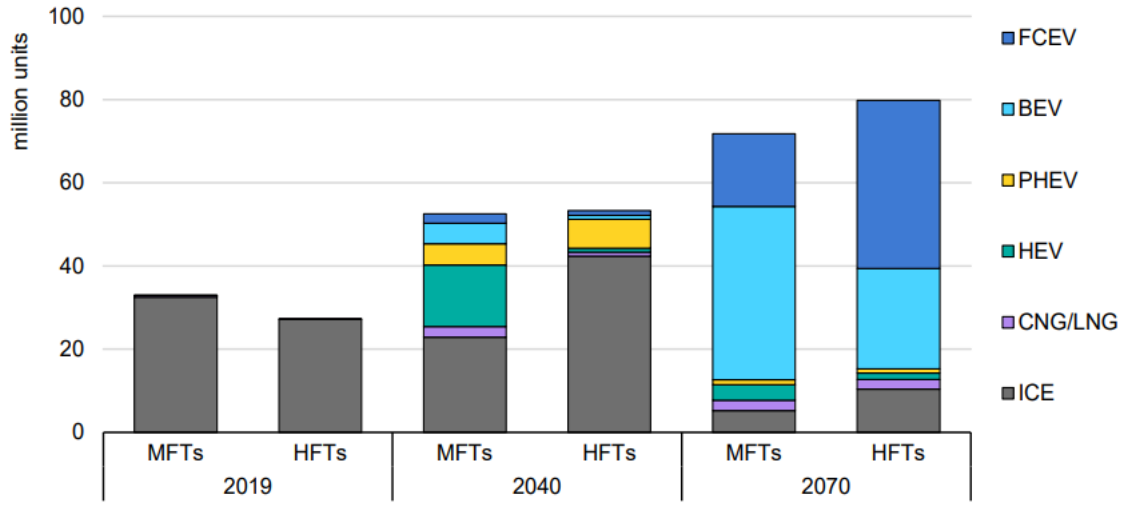


Figure 12: Global heavy truck energy demand - IEA's SDS 2019-70

According to IEA's SDS, by 2070, the equivalent of more than 33 Tesla giga-factories are needed to equip heavy-duty trucks with batteries for energy storage. Hydrogen and electricity together account for around 70% of global final energy use from trucks in the SDS, requiring nearly 2,400 terawatt-hours (TWh) of electricity and 83 Mt of hydrogen.

2.8 Barriers to freight decarbonisation

The road freight sector faces major challenges and barriers in reducing/eliminating GHG emissions. There is limited scope for decoupling road freight from economic activity given the few practical alternatives to trucks for transporting goods inland.



Notes: FCEV = fuel cell electric vehicle; BEV = battery electric vehicle; PHEV = plug-in electric vehicle; HEV = hybrid electric vehicle; CNG/LNG = compressed natural gas/liquefied natural gas vehicle; ICE = internal combustion engine; MFTs = medium-freight trucks; HFTs = heavy-freight trucks.

Figure 13: Heavy-duty truck fleet by powertrain in IEA's SDS, 2019 – 2070

Railways and inland waterways could take a share of the freight market, but the infrastructure is not always in place. Alternative low-carbon fuels, including renewables-based electricity and hydrogen and advanced biofuels could replace fossil fuels, but electricity and hydrogen are not yet either technically or economically viable for many truck operations (in particular for regional and long-haul operations) and there are constraints on supply in the case of biofuels (International Energy Agency, 2020). A research paper on decarbonising road freight, which reflects the perspectives of over 150 executives and experts representing 123 organisations across almost all segments of the road freight sector and 22 different countries, gives a comprehensive overview of the major barriers and challenges in decarbonising road freight (**Figure 14**).

According to this report, the road freight sector is facing several barriers to decarbonisation – especially limited infrastructure, insufficient regulatory incentives, and lacking demand from shippers (Shell International, 2021). Major advances in all low carbon technologies will be needed for them to play a leading role in decarbonising road freight in the long term. The market for trucks is highly regional and specialised. There are fewer manufacturers of heavy-duty trucks than cars in both the North American and European Union markets, and most of them are national or regional. Truck manufacturing plants tend to be more flexible than car manufacturing plants in terms of being able to customise vehicle variants on an assembly line. Engines, powertrains, and other components can be fitted onto one or two vehicle platforms, making it possible to produce hundreds or even thousands of variants capable of operating according to specific mission profiles and applications.

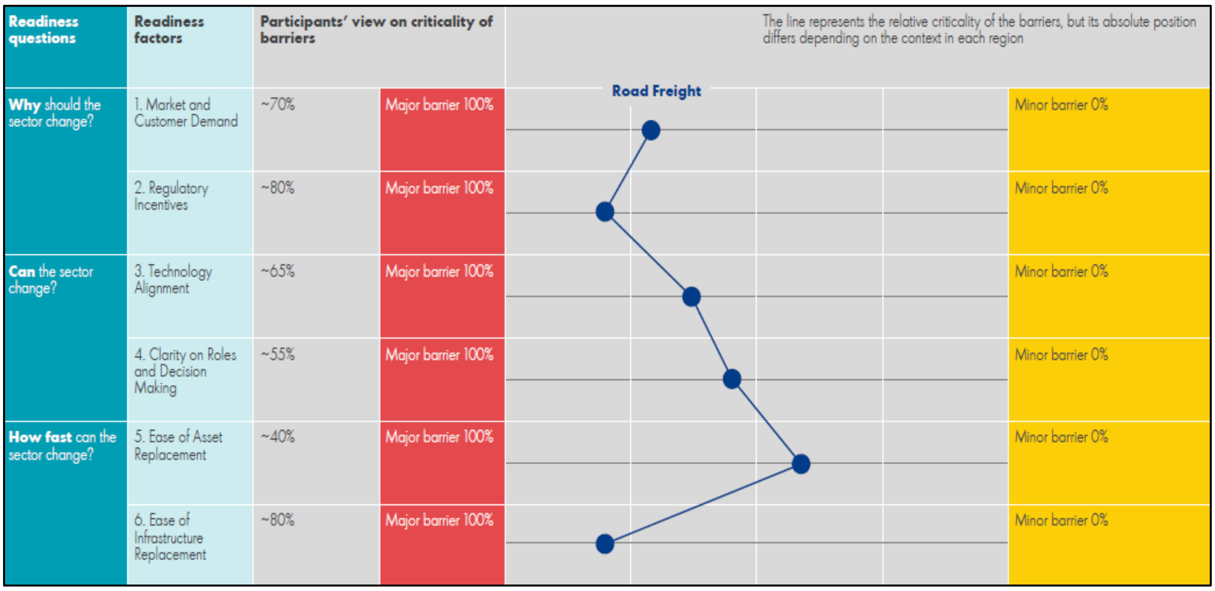


Figure 14: Survey indicating the major barriers in decarbonising road freight
Source: (Shell International, 2021)

OEMs are more flexible than other manufacturers in accommodating customer needs, not only in terms of loads and power, but also in terms of fitting diverse powertrain options. This flexibility enables truck OEMs to customise the powertrains ordered by clients on a single production line, including plug-in, battery, and fuel cell electric trucks, as well as fuel cell range extended trucks. Limited model offers, together with higher purchase prices and limited infrastructure, are the main barriers to adoption of zero-emission trucks. Without significant global R&D investment it will be incredibly challenging to achieve net zero emissions by 2050. Both battery and fuel cell technology will need to continue to improve to be competitive with diesel technology. The major challenge for governments is the significant level of uncertainty in this application yet increasing pressure to start acting now. This is where trials in the near-term can help to provide insight into the advantages and disadvantages of different technology approaches to decarbonise the road freight sector.

2.9 Barriers in the uptake of LZETs

There are many barriers constraining the uptake of LZETs and achieving a successful transition to zero emission road freight at a pace and scale consistent with climate goals will require overcoming real and perceived barriers. The Zero Emission Road Freight Strategy 2020 – 2025 developed by the Hewlett Foundation (Hewlett Foundation, 2020) provides a summary of these barriers and perceptions – initial costs, vehicle model availability, and infrastructure as well as other aspects such as equity, jobs, lifecycle emissions and supply chain, and regulation over-reach, see **Figure 15**. Top perceived barriers and possible solutions are listed in **Table 2** (Hewlett Foundation, 2020).

Many fleet operators and freight buyers have set decarbonisation targets as they believe that road transportation is more feasible to decarbonise compared to other areas of a company's operations, and that it will have a positive TCO outlook. According to a recent survey (McKinsey & Company, 2022), over 60% of fleet operators in the US, Europe, and China plan to switch to zero-emission fleets within the next decade (**Figure 16**). Some have already started deploying LZETs on the road, but most have not yet developed concrete implementation plans. However, fleets seeking to transition to LZETs quickly may face a shortage of available vehicles, and some large fleets have invested in electric truck or electric van start-ups or partnered with OEMs to conduct joint pilot programs to secure supply. According to the survey, only about one-third of fleet operators in major markets are willing to pay an additional 10% or more upfront cost for zero-emission trucks, even though they have substantially lower operating costs. The survey results are shown in **Figure 16**. This means that the industry needs new financing and ownership models to increase the deployment of zero-emission trucks.

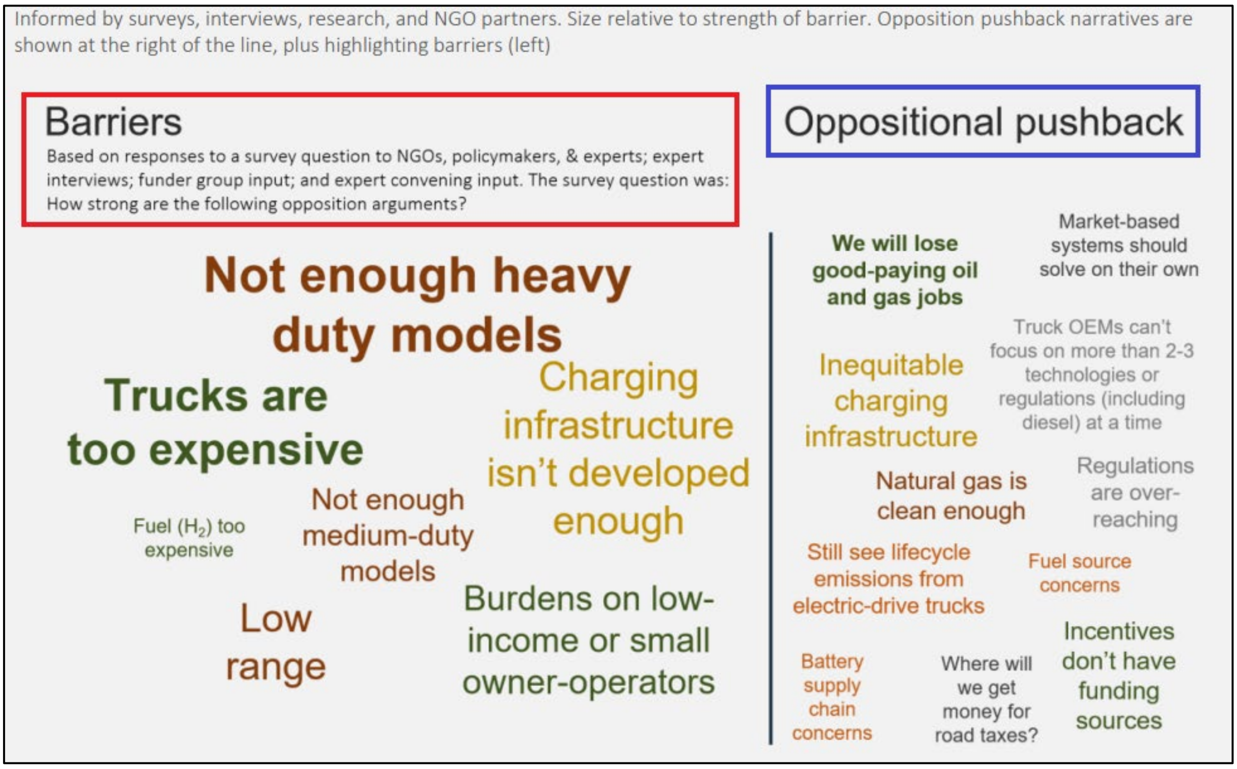


Figure 15: Real and perceived barriers (left) and oppositional pushback (right)
Source: (Hewlett Foundation, 2020)

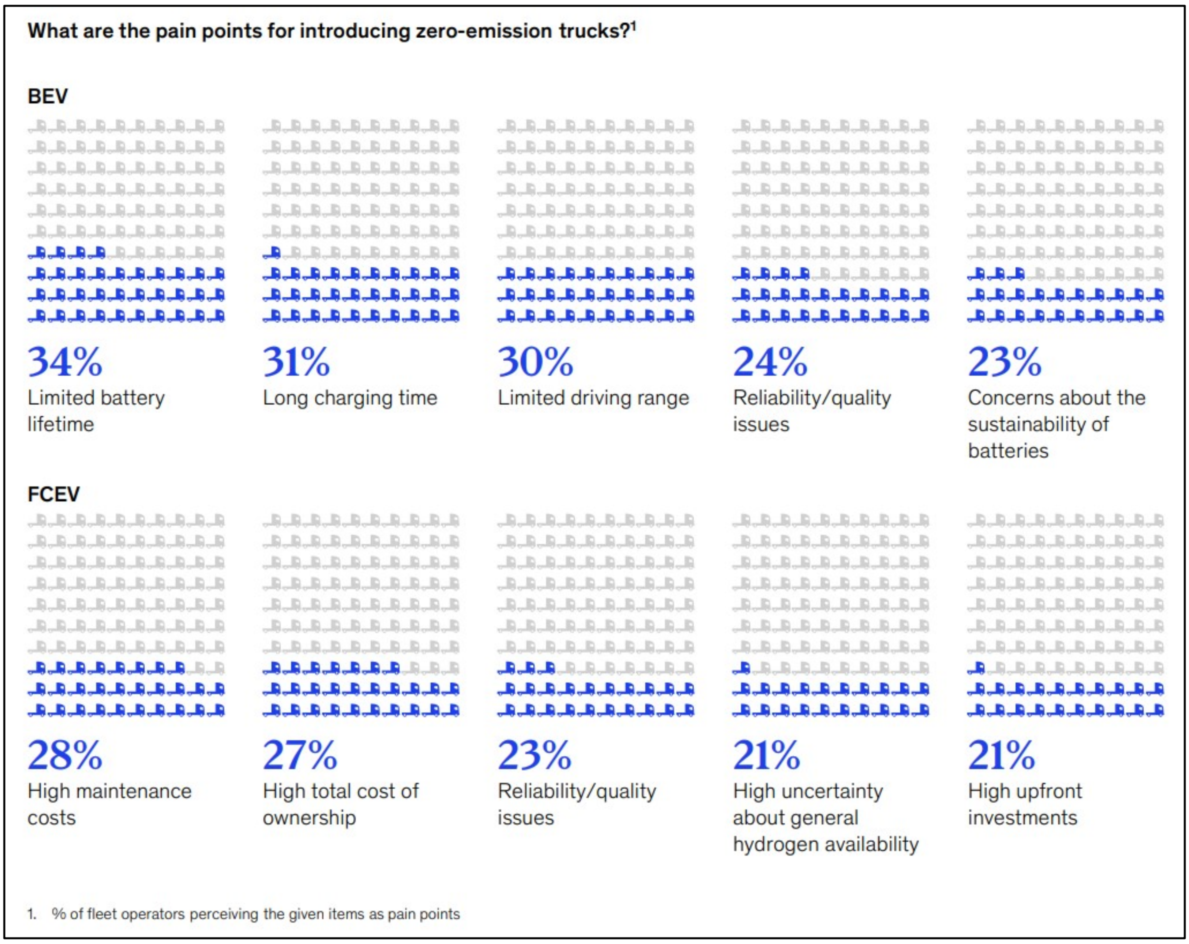


Figure 16: Future of commercial mobility survey - US and Europe
Source: (McKinsey & Company, 2022)

Table 2: Top perceived barriers and possible solutions to uptake of LZET

Source: Hewlett Foundation (Hewlett Foundation, 2020)

Topic	Perceived Barrier	Solution
High purchase price	Individual businesses face increased upfront costs for purchasing LZETs (both BETs and HFCTs)	As a result of falling battery prices, medium and heavy-duty battery electric trucks, including long-haul trucks, are expected to be cost-competitive in the 2020s and 2030s. Additionally, the total cost of ownership (including significant fuel and maintenance savings) for many BET truck applications is already at parity with diesel trucks, and this will improve as battery costs decline. The ETC expect that green hydrogen can become cost-competitive with grey hydrogen (conventional hydrogen produced from gas or coal) in the 2030s, and eventually be cheaper by 2050 (discussed in Chapters 2, 3 and 4).
Limited vehicle models	Models need to exist across widely varying use cases. Different businesses have different freight truck needs, ranging from short-distance drayage trucks, in-city delivery trucks, and heavy long-haul trucks. LZETs need to be either highly adaptable, or solutions must be tailored to specific business needs, which vary within and across countries.	Many Original Equipment Manufacturers (OEMs) have announced the production of new LZET models (both BETs and HFCTs); The Zero Emission Technology Inventory, compiled by Drive to Zero, is an excellent resource for reviewing the global current and upcoming supply of BETs and HFCTs - https://globaldrivetozero.org/tools/zero-emission-technology-inventory/ (discussed in Chapters 2 and 3).
Lack of charging/ refuelling infrastructure	Refuelling/charging infrastructure (especially high-power charging) and power delivery at charging stations is currently insufficient. There is no common standard for refuelling/charging infrastructure. Other obstacles include uncertain impacts on grid, uncertainty on ideal location for new infrastructure and availability of land/ space to match charging demand with grid capacity, and high costs of charging infrastructure.	Pilot projects include creating infrastructure and incentives to promote high-power charging. Strategic efforts to prioritise engaging utilities, large-scale public investment (addressing the issue that the private business case for charging infrastructure is limited), education, sharing information with fleets, and applied research.
Opposition from the oil and truck manufacturing industry, and others	Resistance from the powerful oil and gas industry may deter the transition progress to LZET technologies. Also, laggard vehicle manufacturers opposed to zero emission freight innovation can discourage policymakers. Potential other opponents may include smaller owner/operators, and workers in vehicle maintenance/service.	Developing a strategic communications strategy, cultivating powerful allies such as electric utilities and corporations, and empowering LZET manufacturers to counter opposition. Messaging should promote lower maintenance and fuel costs (and lower TCO); benefits to climate, air quality, and health; the good news about model availability; benefits for vulnerable communities; the negative side of dirty diesels (Diesel Death Zone) and busting myths.
Truck OEMs slow to supply vehicles	There are significant delays and waiting times associated with the supply of zero emission trucks from big OEMs, even in the face of significant orders. (Hewlett Foundation, 2020)	Some shippers have invested directly in zero emission freight vehicles, because operators couldn't convince current OEMs to produce LZETs at the scale needed. Hence, it is crucial to impose supply regulations on manufacturers and not rely only on private sector demand.

2.9.1 Barriers specific to Australia

LZETs are almost non-existent on Australian roads; the Australian Trucking Association (ATA) in partnership with the Electric Vehicle Council (EVC) identified specific barriers through a series of workshops, in which truck operators, truck manufacturers, charging infrastructure providers and the electricity sector highlighted that limited model availability, price of vehicles, lack of charging infrastructure, cost of charging infrastructure installation, limited consumer awareness, and restrictive Australian Design Rules are key barriers to the transition to LZETs, specifically BETs, shown in **Figure 17** (ATA and EVC, 2022).

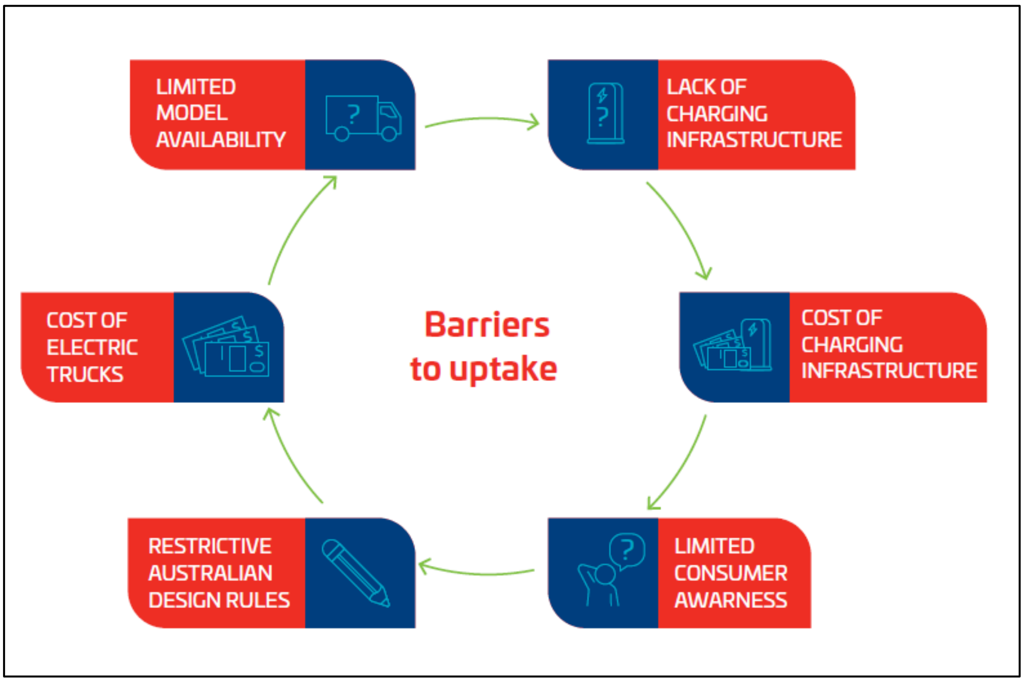


Figure 17: Barriers to uptake of BETs in Australia
Source: (ATA and EVC, 2022)

The ATA-EVC report also states that Australia currently lags most of the world in the electrification of freight trucks making the need for reform urgent. Even though the report in focussed on BETs, it is evident from the report that the Government needs to remove regulatory barriers that are reducing the availability of both BETs and HFCTs, including our truck width rules which are out of step with both Europe and North America.

2.9.2 Relative competitiveness of diesel in Australia

The relative fuel costs of driving a BET versus an ICE truck for 100 km in different jurisdictions is shown in **Figure 18**. These costs were based on numbers provided by Noll et al (Noll, del Val, Schmidt, , & Steffen, 2022), as well as snapshot estimates of Australian 2023 prices of electricity at 28.66 c/kWh and $1.94 for a litre of diesel. Fuel efficiencies of 28 litres per 100 km, and 1.1 kWh per km were assumed, based on data from Volvo on similar vehicle types, shown in **Figure 18**.

Electricity can be sourced in NSW at a cheaper rate cheaper than this, if produced for example using solar PVs (with prices as low as 6 c/kWh for example) or based on cheaper deals. The price of diesel also seems to be trending upwards so this may be an underestimation of the fuel costs into the future. Importantly, however, many freight operators receive a fuel tax credit that currently returns 22 c per litre of diesel. With the presence of the fuel tax credit in Australia, electricity as a fuel is the least competitive vis-à-vis diesel compared to all other jurisdictions.

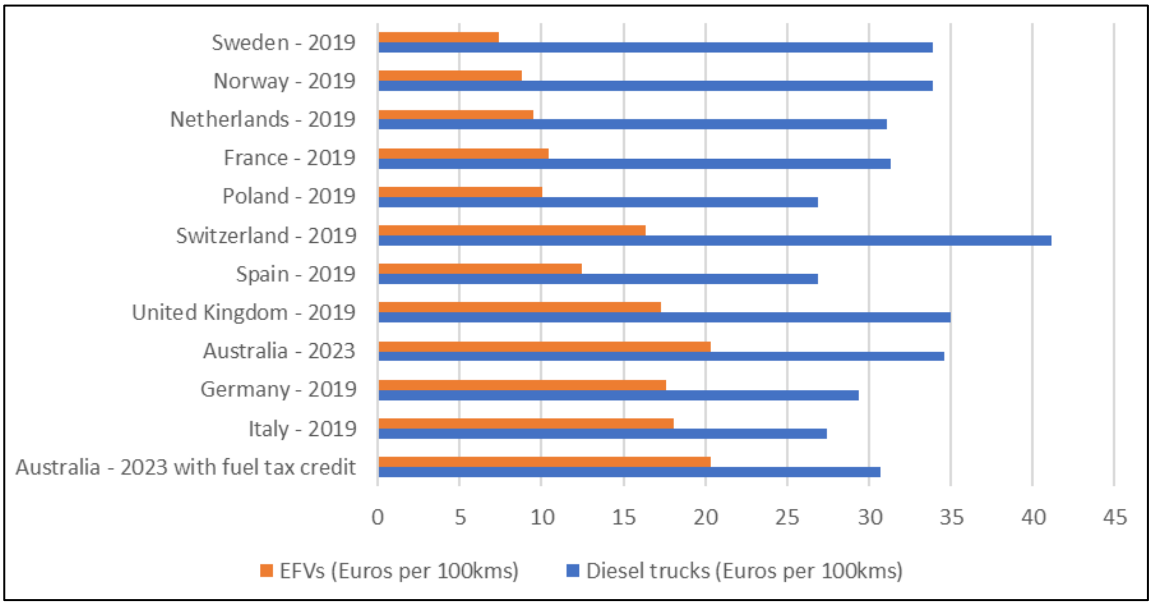


Figure 18: Relative fuel costs for driving a truck for 100 kms
Source: (Noll, del Val, Schmidt, , & Steffen, 2022) & snapshot of 2023 fuel prices in Australia

2.10 Pathways to road freight decarbonisation

Several publications were analysed in order to identify key solution areas, each containing a list of specific solutions that provide a comprehensive list of freight transport measures to reduce and eliminate carbon emissions (ALICE-ETP, 2019), (IEA, 2017), (IEA, 2020), (McKinnon, 2018) (Palmer & Allen, 2021), shown in **Table 3**. As mentioned in the earlier sections of this report, this study will mainly focus on strategies to reduce road freight emissions by supporting a **switch to lower and zero emission fuel / technology** in road freight vehicles in the short, medium, and longer terms.

ITF conducted an expert opinion survey in 2018 which involved road freight transport experts from the government, the private sector, international organisations, and academia providing insights into the effectiveness of available logistics measures and technologies to reduce GHG emissions (ITF, 2018). Respondents were asked to score the effectiveness of each measure on a scale of 0 to 10. The results are shown in **Figure 19**.

2.10.1 Rail mode shift potential

An assessment of the emissions reduction potential of shifting freight from roads to rail in the US found that supply chain emissions could be reduced by 52% within the largely unfeasible scenario of a complete shift to rail (Nealer, Matthews, & Hendrickson, 2012). A study in Pakistan (Ahmed, Mehdi, Baig, & Arsalan, 2022) estimated the potential emissions impact of shifting freight from road to rail. They found that over a 10-year period, if 50% of freight shifts from road to rail, then 42% of greenhouse gas emissions could be avoided (Ahmed, Mehdi, Baig, & Arsalan, 2022).

Table 3: Freight transport measure to reduce and eliminate GHG emissions

Key solution areas	Specific solutions
Reducing the level of freight transport demand	Consumer behaviour On/re shoring of supply More local sourcing Dematerialisation 3D printing Circular economy
Shifting freight to lower-carbon transport modes	Rail Inland waterways Cargo bikes Synchro-modality Intermodal equipment
Improving asset utilisation	Collaboration Retiming of deliveries Delivery frequency Vehicle loading Higher productivity vehicles Double deck trailers
Organisation of physical logistics systems	Supply chain networks Regional & urban distribution hubs Platooning Autonomous vehicles Modular packaging The physical internet
Digitalisation	Artificial intelligence Internet of things Predictive analytics Big and broad data Telematics Route planning Intelligent transport systems
Increasing energy efficiency	Engine technology Aerodynamics Tyres selection Idling reducing technologies. Light weighting of vehicles Fuel additives and lubricants Vehicle maintenance Automatic tyre inflation Driver assistance systems Driver training Fuel management programme
Switching to lower and zero emissions fuel / technology	Battery electric vehicles Electric road systems Hydrogen fuel cell vehicles Advanced biofuels Gas Hybrid vehicles
Energy systems	Battery technology Renewables Hydrogen production Smart grid technology Energy storage Advanced biofuels

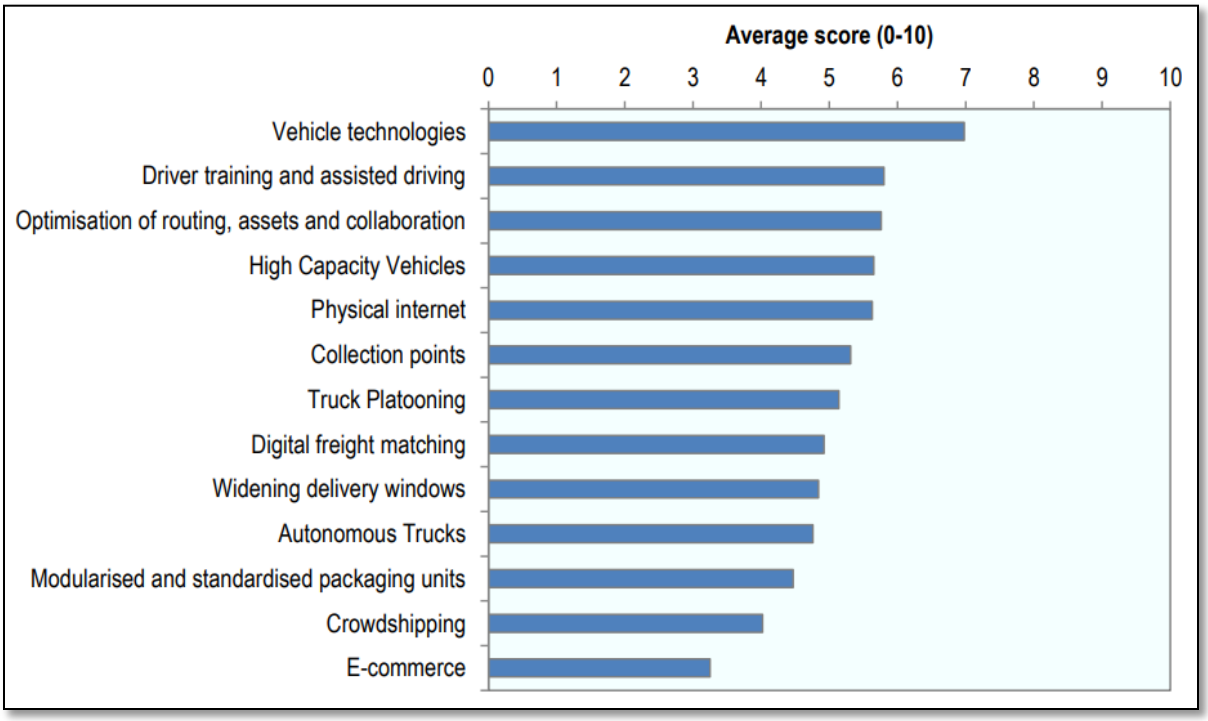


Figure 19: Expert opinions on effectiveness of freight decarbonisation measures

A study by Bickford et al (Bickford, et al., 2014) in the US Midwest found that approximately 2.3% of intraregional freight "*could be economically shifted off of truck and onto train, if adequate rail infrastructure existed, and policy incentives were structured to favour freight rail selection by shippers*". In the scenario where all such economically viable shift to rail freight occurred, plus all Midwest through-freight (i.e., all freight going through the region) shifted to rail, they estimated that this could lead to up to 31% reduction in greenhouse gas emissions in key parts of the freight system.

Although rail is not a viable option for all types of freight, as international evidence suggests:

- Railways has a competitive advantage of lower costs for longer distances. The adoption of the multimodal system in which trains are used for longer distances and trucks for shorter distances as well as covering those routes that connect railway terminals has far better advantages (Ahmed, Mehdi, Baig, & Arsalan, 2022) (Samimi, Kawamura, & Mohammadian, 2011).
- Due to the relative cost-effectiveness of transporting heavier and large shipments, these are also more likely to be transported by rail (Samimi, Kawamura, & Mohammadian, 2011).
- The most significant commodities (by tonnage) with the potential to shift to rail in most cases are base metals, other foodstuffs, non-metal mineral products, and motorised vehicles (Bickford, et al., 2014).
- Accessibility of rail as a mode for freight transport is a key factor. This indicates considerable potential of a shift in the design and construction of standard rail service network (Mustapha, 2022).
- The road–rail intermodal freight mode is often preferred by freight forwarders. Specifically, heavy commodities are more likely to be transported by the intermodal mode and containerization for export commodities is an essential factor when promoting intermodal transportation (Liu, Zhang, Jian, & Zhang, 2022).

2.11 Global policies and case studies

More countries are planning to introduce standards for heavy duty vehicles and Governments globally are seeking to accelerate the adoption of clean transport technologies, and phase out internal combustion engine vehicles (ICEVs) to meet climate commitments, as well as capitalise on the array of economic and social benefits that these low and zero emission technologies can deliver. To do this, governments internationally have introduced a range of supportive policies via LZET incentives, ICEV disincentives, and public awareness campaigns. This section takes stock of these international policies and seeks to provide an analysis of their suitability in the NSW context. Several governments have specific targets for heavy-duty trucks that were announced over last few years, listed in **Table 4** (IEA, 2021) (IEA, 2020).

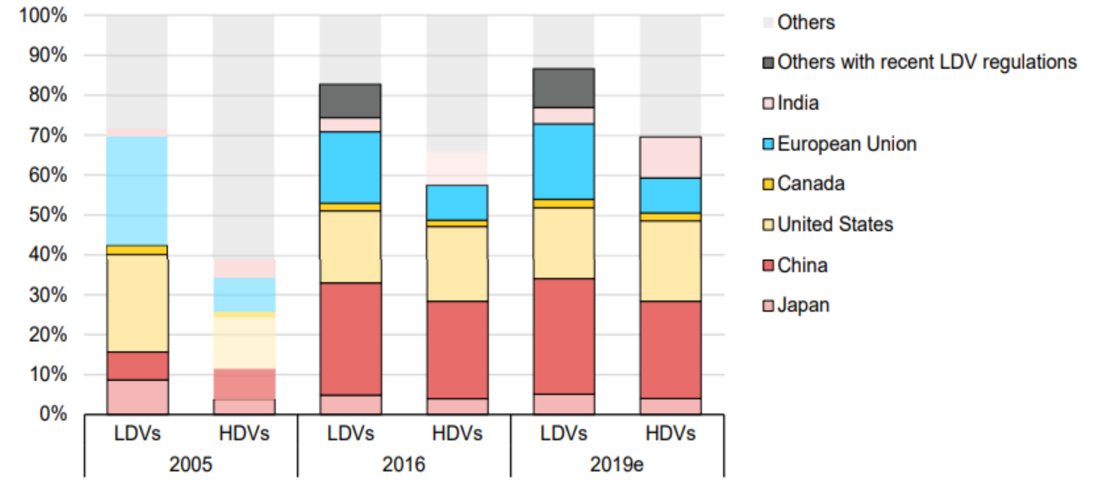
In 2020, California was the first to propose a zero-emission vehicle sales requirement for heavy-duty trucks with the Advanced Clean Truck Regulation due to take effect from 2024. The Netherlands and several other countries are implementing zero-emission commercial vehicle zones and pioneering deployment efforts for LZETs. This is a 'hard to abate' sector and freight decarbonisation efforts require policy support and commercial deployment like that which passenger cars enjoyed in the 2010s (IEA, 2021). Despite the sizeable contribution to global oil demand and emissions, road freight historically has not been the focus of policy as much as passenger car vehicles. Although policies to curb air pollution emissions from road freight vehicles exist in many countries, only five countries – Canada, China, India, Japan, and the United States, and one regional block – the European Union, have adopted regulations for fuel economy/ CO_2 standards for heavy-duty vehicles (trucks and buses). Regulations for heavy vehicles are a critical first step and, in the countries, and regions specified above, the vehicle efficiency and CO_2 emissions standards for heavy-duty vehicles are catching up with those of light-duty vehicles (**Figure 20**) (IEA, 2020). In Europe, there are several policies in place to decarbonise the heavy vehicle sector. These include:

- The European Union (EU) CO_2 standards for heavy-duty vehicles, which set targets for reducing CO_2 emissions from new heavy-duty vehicles sold in the EU.
- The EU's Alternative Fuels Infrastructure Directive, which requires Member States to establish a network of refuelling and charging stations for alternative fuels, including electric vehicles (EVs) and hydrogen fuel cell vehicles.
- The EU's Connecting Europe Facility (CEF), which provides funding for projects that support the deployment of alternative fuel infrastructure and the uptake of low-emission vehicles.
- The EU's Clean Vehicle Directive, which encourages the deployment of low-emission vehicles, including EVs and hydrogen fuel cell vehicles, in public fleets.
- The EU's Innovation Fund, which provides funding for breakthrough technologies that can significantly reduce GHG emissions in the heavy-duty vehicle sector.
- The EU's Green Deal, which aims to make Europe's economy sustainable, with the goal of achieving carbon neutrality by 2050, including the heavy-duty vehicle sector.

Table 4: Targets announced by governments to decarbonise road freight trucks

Country/region	Announcement Year	Description
United States	2021	The government issued an executive order that calls on the EPA and DOT to consider new emissions and fuel economy standards relating to heavy-duty trucks as well as light- and medium-duty vehicles.
Ireland	2021	New targets for 10% of trucks procured by public bodies to be low- or zero-emissions, rising to 15% by 2030.
Austria	2021	100% of new registrations of heavy-duty vehicles less than 18 tonnes to be zero-emissions starting in 2030, and for those greater than 18 tonnes, in 2035.
France	2020	By 2023, target of 200 hydrogen heavy-duty vehicles. By 2028, target of 800 to 2,200 hydrogen heavy-duty vehicles.
MoU states[1] (United States)	2020	Sales of new medium- and heavy-duty trucks to be 30% zero-emissions by 2030 and 100% by no later than 2050.
California (United States)	2019/2020	All medium- and heavy-duty vehicles in operation should be 100% zero-emissions by 2045, where feasible.
Cape Verde	2019	100% electric sales target for new medium- and heavy-duty trucks by 2035. All vehicles on the roads, including trucks, to be electric by 2050.
Pakistan	2019	30% of new heavy-duty trucks to be electric by 2030, and 90% by 2050.
Japan	2019	Fuel economy to be improved 13.4% by 2025 for heavy trucks relative to 2015 levels.
South Korea	2019	Target of 30,000 HFCTs by 2040
European Union	2019	CO_2 emission standards for new heavy-duty trucks to be reduced by 15% by 2025 and by 30% by 2030 (reference period: 2019/2020). Revision of the Clean Vehicles Directive including minimum requirements for trucks (6- 10% in 2025 and 7% to 15% in 2030).
Netherlands	2019	In 2025, target of 3,000 hydrogen heavy-duty vehicles on the road.
Canada	2018	Tighter GHG emissions standards for heavy-duty trucks from 2021 and increasing stringency up to 25% relative to 2017 in 2027.
Norway	2017	50% zero-emission sales target for new heavy-duty trucks by 2030.
Sweden	2017	Targets of: Reduction of CO_2 emissions from transport by 70% in 2030 relative to 2010 and Net zero GHG emissions by 2045.

[1] The MoU states are California, Colorado, Pennsylvania, the District of Columbia, Maryland, Maine, Hawaii, Massachusetts, Connecticut, Washington, Rhode Island, Vermont, New Jersey, North Carolina, and New York.



Notes: LDVs = light-duty vehicles; HDVs = heavy-duty vehicles; e= estimated. Countries and regions shown without outline and in transparent colours have not adopted standards. India put new HDV fuel economy standards in place in April 2018. Mandatory reporting of fuel consumption and CO_2 emissions began in the European Union in January 2019, and binding standards will come into force for four classes of heavy-duty trucks in July 2025.

Figure 20: Share of vehicle sales in regions with fuel economy/emissions standards

The European Commission's "Europe on the Move" package, which announced several proposals to reduce emissions from the transport sector, including heavy-duty vehicles. In the **US**, the **state of California** has been tackling road transport decarbonisation for over 30 years using few different policies including:

- The Advanced Clean Trucks (ACT) rule, which requires manufacturers to sell a certain percentage of zero-emission trucks in California by a certain year.
- The Low Carbon Fuel Standard (LCFS), which encourages the use of low-carbon fuels, including electricity and hydrogen, in heavy-duty vehicles.
- The California Hybrid, Electric, and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), which provides vouchers to cover a portion of the incremental cost of purchasing or leasing eligible zero-emission and hybrid heavy-duty vehicles.
- The Truck and Bus Regulation, which requires large truck and bus fleets operating in California to gradually transition to cleaner technologies.
- The California Air Resources Board (CARB) is also working on implementing a Zero Emission Drayage Truck (ZEDT) regulation that would require trucking companies to transition to zero-emission trucks.

2.11.1 Inflation Reduction Act (IRA)

On August 16, 2022, American President Joe Biden signed the Inflation Reduction Act (IRA) into law. The United States has over 4 million heavy-duty trucks that travel over 150 billion miles and create over 260 million tons of GHG emissions per year. With the IRA in place, the total cost of ownership of electric trucks will be lower than diesel ones approximately five years sooner, leading to far greater electric truck sales and thus accelerating decarbonisation, shown in **Figure 21** (Kahn, Westhoff, & Mullaney, 2022). According to Rocky Mountain Institute (RMI), this dramatic decarbonisation will potentially reduce heavy duty truck fleet

GHG emissions by 59% by 2035, nearly double what would happen without the IRA (Kahn, Westhoff, & Mullaney, 2022).

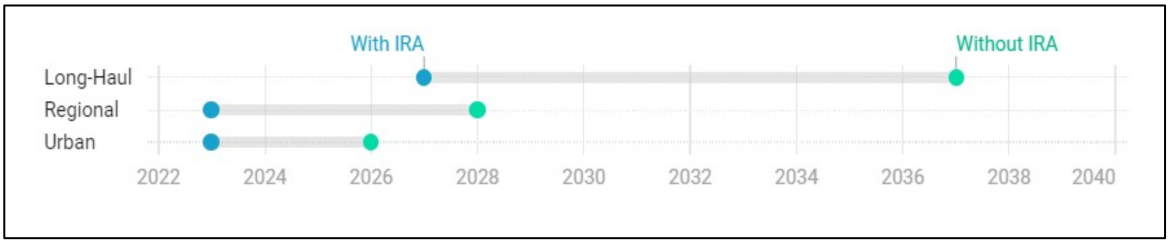


Figure 21: Electric truck parity dates with diesel trucks – with and without IRA

Source: (Kahn, Westhoff, & Mullaney, 2022)

These projections are based on the IRA tax credits for both the vehicle and the charger infrastructure:

- **Qualified Commercial Clean Vehicles Credit**: Vehicles greater than 14,000 lbs/ 6.35T that operate on batteries alone receive a tax credit of US$40,000 or 30% of the vehicle cost, whichever is lower.
- **Alternative Fuel Refuelling Infrastructure Credit**: Charger infrastructure tax credits are 30% of the cost of installation, up to a lifetime benefit of US$100,000 per site.

The IRA also includes a new US$1 billion Clean Heavy Duty Vehicles rebate program for state, municipalities, Indian tribes, and school associations to convert fleets to zero-emissions heavy-duty vehicles and other funding for disadvantaged communities that could be used to electrify local depots. Additionally, IRA incorporates expansions and extensions of utility-scale renewable tax credits, which lower utility costs and improve the fuel cost advantage electric trucks have over diesel vehicles by making vehicle charging cleaner and more affordable.

Australia is yet to implement a comprehensive policy package to decarbonise heavy vehicles. However, there are some initiatives and programs that have been put in place to encourage the adoption of cleaner technologies for heavy vehicles:

- The Federal Government is establishing Australia's first National Electric Vehicle Charging Infrastructure Strategy (NEVS); they released an 18-page consultation paper in September 2022 (Department of Climate Change, Energy, the Environment and Water, Australia , 2022) and received over 500 feedback submissions on NEVS – representing over 200 organisations and over 1500 individuals. The feedback received will assist in creating a comprehensive national strategy to ensure that Australians have access to the most advanced transportation technologies and help achieve emission reduction goals. The strategy will aim to provide benefits in areas such as social, economic, business, health, and the environment. This will ensure that we take advantage of opportunities and smoothly transition to transportation electrification.
- The NHVR Heavy Vehicle Productivity Plan (2020 – 2025), which aims to improve the efficiency and productivity of the heavy vehicle industry using technology and infrastructure improvements (NHVR, 2020).
- The Australian Renewable Energy Agency (ARENA) has also provided funding for several projects to develop and demonstrate electric and alternative fuel heavy vehicles.
- The Low Emissions Technology Roadmap which identifies the key technologies that can reduce emissions from the road transport sector, including electric and hydrogen fuel cell vehicles, as well as efficient internal combustion engines.

- The Clean Energy Finance Corporation (CEFC) also provides finance and investment opportunities for commercial and industrial projects, including those related to the heavy vehicle sector, such as electric or hydrogen fuel cell trucks and buses.

2.11.2 Policy options

LZETs and their supporting infrastructure are at very early stages of deployment, mostly only in urban pilot projects. Transition to zero emission trucks will be more dependent on policy support given the bigger gap in upfront purchase price and higher requirements for fast charging than light-duty vehicles. Countries and regions, where LZET models have been deployed, adoption has been spurred by either policy incentives or corporate initiatives, and most commonly by a combination of the two. Current zero-emission heavy-duty vehicle policies and incentives in selected countries are listed below in **Table 5** (IEA, 2021).

Table 5: Current zero-emission heavy-duty vehicle policies and incentives

Policy Category	Policy	Canada	China	European Union	India	Japan	United States
Regulations (vehicles)	**Zero emissions heavy-vehicle sales requirements**			Voluntary to earn credits economy standards under fuel. Municipal vehicle purchase requirements.			**California:** new bus sales 100% ZEV by 2029. **California and New Jersey:** new truck sales up to 75% by 2035.
	Fuel economy standards	✓	✓	✓	✓	✓	✓
	Weight exemptions			2 tonnes over class.			**California:** 2,000 pounds over class.
Incentives (vehicles)	**Direct incentives**	✓*	✓*	✓*	✓	✓	✓*
Incentives (fuels)	**Low-carbon fuel standards**	✓*					✓*
Incentives (EVSE)	**Direct investment**	✓			✓	✓	✓*
	Utility investment						✓*

* Indicates implementation only at state/local level. Notes: zero-emission vehicle includes BEV, PHEV and FCEV; EVSE = electric vehicle supply equipment. Weight exemptions support freight operators by allowing LZETs to exceed strict weight restrictions by a set amount. Because batteries weigh more than diesel fuel combustion technologies, LZET operators may need to reduce their cargo to meet weight restrictions, resulting in lower profits and inefficient freight delivery. Utility investment: electric utilities tend to be large companies with business interests in EV charging, but they may be unwilling or unable to invest in charging infrastructure. Leading provinces and states have enabled or directed utilities to develop plans and deploy HDV charging infrastructure.

2.11.3 International case studies

A few different international case studies on LZET fleet deployments are provided in **Appendix A**. Case studies are examined to assess the demonstration, acceptance, and performance of different LZETs in other jurisdictions. These case studies also help to understand the challenges and opportunities experienced by countries with more advanced decarbonisation in the freight sector.

Low Emissions Freight

3. Road Freight Low Emission Technologies and Energy Systems

Different LZETs for road freight decarbonisation – battery electric trucks (BETs), hydrogen fuel cell trucks (HFCTs), electric road systems (ERS), hybrid trucks, biofuel trucks are reviewed to understand their competitiveness compared to fossil fuel technology today.

3.1 Battery electric trucks

Battery Electric Trucks (BET) are 100% electric vehicles with the ability to charge using an external electricity source (**Figure 22**). BETs are generally charged using grid electricity at the depot or at public charging infrastructure. BETs are regarded as one of the most promising LZETs due to several significant benefits. BETs have 3 to 5 times higher drivetrain efficiency than diesel trucks, leading to significantly lower operating costs (Hacker, 2020) (Smit, Whitehead, & Washington, 2018). BETs also have a high potential to significantly reduce lifecycle GHG emissions compared to diesel trucks (Wolff, Fries, & Lienkamp, 2019).

Figure 22: SEA Electric BET used by Woolworths Australia (SEA Electric, 2019)

The GHG emissions reduction potential of BETs depends primarily upon the electricity grid emissions intensity both for battery manufacturing and for vehicle operations. The NSW Government's goal of 12 GW renewable energy and 2-3 GWs of storage by 2030 can help BETs deliver deeper emissions cuts from the road freight fleet. Furthermore, BETs are reported to require lower maintenance than diesel trucks (Oberon Insights, 2020). The lifespan and residual value of light-duty BETs is also expected to be better than that of diesel trucks. Additionally, battery packs are expected to last the lifetime of the light-duty trucks. There are, however, some concerns about battery replacement during the lifetime of heavy-duty trucks (Oberon Insights, 2020) (Smith, et al., 2019). Recent findings have shown that several electric vehicle features improve the safety of BETs. Electric vehicles have a lower risk of fire than conventional vehicles because they do not have a fuel system that can ignite in a crash. In addition, many EVs have advanced battery management systems that can detect and mitigate potential fire hazards (SEA Electric, 2019). EVs also have advanced safety features, such as autonomous emergency braking, which can help prevent accidents.

BETs currently require longer refuelling time to charge batteries than diesel trucks (Transport and Environment, 2020). Recently there have been improvements in battery technology to accept higher charge rates using Direct Current Fast Chargers (DCFCs). Charging a heavy-duty long-haul truck in 30 minutes would require a 2 MW DC fast charger (Debnath, Khanna, Rajagopal, & Zilberman). The Charging Interface Initiative (CharIN) and its members in the High-Power Commercial Vehicle Charging Task Force (HPCVC) are currently working to develop high power Mega chargers for electric trucks and buses with a charging capacity in the 500 kW to 3 MW range (Electrive.com, 2019). These Mega chargers, once rolled out, would significantly reduce on-route charging time. One of the major opportunities for charging BETs is during driving breaks or overnight. The BET SWOT analysis, **Figure 23**, shows BETs have a high potential to decarbonise light-duty trucks, however, due to higher battery weights, costs, and slower refuelling, BETs face challenges for heavy-duty applications in the current scenario, which will need to be addressed through continuing R&D, and potential policy changes to reach parity with diesel in the future.

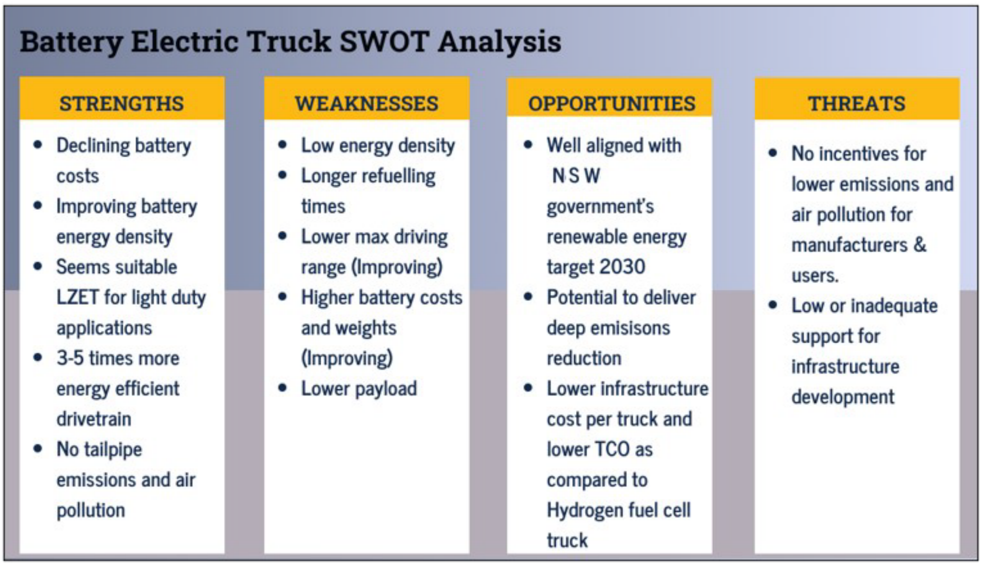


Figure 23: SWOT analysis of BETs

3.2 Hydrogen fuel cell trucks

Hydrogen fuel cell trucks (HFCT) (**Figure 24**) are powered by electricity generated through a chemical reaction between hydrogen and oxygen in a fuel cell. A typical fuel cell works by passing hydrogen through the anode and oxygen through the cathode. Catalysts split the hydrogen molecules into electrons and protons. Electrons pass through the circuit generating electricity (FCHEA, 2020). HFCTs have an on-board battery which is charged using energy from the fuel cell and regenerative braking. The battery size of a HFCT is generally smaller, as compared to that of BET, but is required to fill in the gaps in the fuel cell's power curve – particularly during acceleration, due to the fuel cell's relatively poor ability to quickly respond to sudden increases in power requirements. Several studies consider HFCTs as a potential LZET for heavy-duty long-haul applications due to the possibility to store relatively high quantities of renewable energy if the gas is sufficiently compressed (Hydrogen Council, 2020)

(IEA, 2020). The higher energy density of compressed hydrogen also presents opportunities for lower tare weight compared to BETs. HFCTs – under the right conditions – also have the potential to have relatively fast refuelling times, more comparable to diesel trucks (Transport and Environment, 2020).

Figure 24: Hyundai XCIENT HFCT introduced by NZ Post (Deals on Wheels, 2022)

On the other hand, hydrogen fuel cell drivetrains face multiple challenges, such as lower powertrain efficiency, higher costs, hydrogen refuelling, and storage constraints. The production, compression, and transport of hydrogen gas, as well as the operation of the fuel cell, are all energy-intensive processes, compared to charging and operation a battery-electric powertrain (Hacker, 2020). Generally, for every kilometre a HFCT is driven, that same amount of energy could power 2.5 to 3 BETs over the same distance. The energy inefficiency reduces the ability of HFCTs to decarbonise road freight if electricity is used directly from the NSW electricity grid to produce hydrogen. In fact, HFCTs would only deliver an improvement in emissions over diesel if the energy used to produce hydrogen had an emissions intensity of less than 300 grams CO_2-e/kWh (Sophia,, Jana, & Christina, 2018). NSW's average grid emissions intensity is currently more than double this at more than 730 grams CO_2-e/kWh (Australian Government, 2022). Hydrogen produced from steam methane reforming of natural gas and used in a fuel cell vehicle provides only 15 to 45% lower well-to-wheel emissions than conventional diesel vehicles, and this largely depends on the extent of fugitive emissions from natural gas extraction (Liu, et al., 2020).

The high cost of fuel cells and storage tanks is another major barrier to the adoption of HFCTs (IEA, 2020) (Pacific Northwest National Laboratory, 2019). Production and refuelling of hydrogen also pose safety challenges. Fast-flowing hydrogen through throttle valves generates heat, creating safety hazards (Li, et al., 2019). Construction of large volume hydrogen refuelling stations at highways can also be very challenging as these stations require at least ten times greater volume than urban H2 stations (Zhao, Wang, Fulton, Jaller, & Burke, 2018).

One of the main challenges facing the introduction of HFCTs is the need to establish appropriate, sufficient, safe, and economical refuelling infrastructure. Hydrogen for fuel cell vehicles can be produced from a diverse range of resources including fossil fuels, renewables, and nuclear energy. The primary challenge for hydrogen production is reducing the cost and environmental impacts of the different production technologies. Hydrogen produced at industrial sites must be stored, transported, and delivered to fuelling stations. The cost of hydrogen distribution methods and technologies depends on the amount of hydrogen delivered, the delivery distance, the storage form (compressed gas or cryogenic liquid) and the delivery mode (pipeline, high-pressure tube trailers or liquified hydrogen tankers) (Greene, Ogden, & Lin, 2020).

The HFCT SWOT analysis, **Figure 25**, highlights that HFCTs face several challenges and currently do not appear to be competitive with diesel. As pointed out by the U.S. Department of Energy, HFCTs will require additional R&D over the coming years to overcome the challenges. There have been a few local initiatives to develop a technology investment roadmap for developing the Australian hydrogen supply chain to meet both international and local demand. Hydrogen has an important role to play more broadly in decarbonising the global economy, particularly in terms of green steel, cement, and fertiliser production, both locally and globally. There may be synergies between transport vehicles operating near facilities using green hydrogen for other purposes, but these are expected to be relatively niche, and mostly focussed on regional ports, as opposed to widespread adoption, given the broader challenges HFCTs face – at least in the near term.

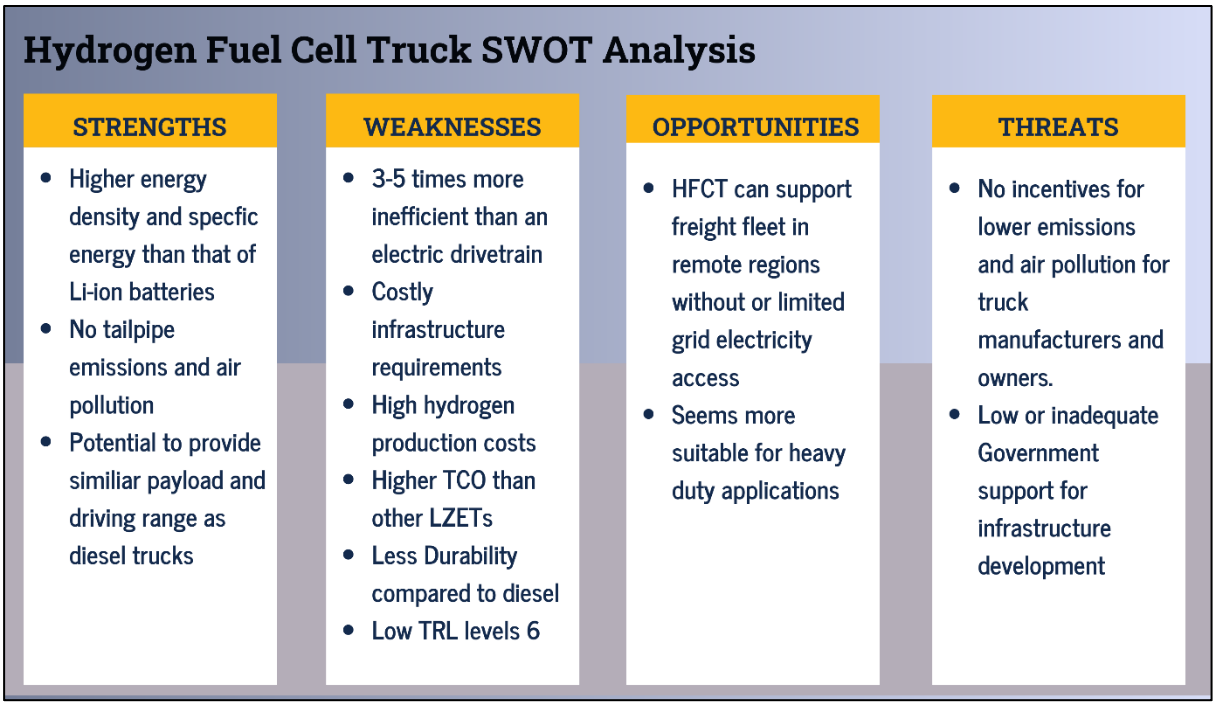


Figure 25: SWOT analysis of HFCTs

3.3 Electric road systems

An Electric Road System (ERS) is a technology used to charge a truck while in motion (**Figure 26**). ERS, also known as "electric highways," can propel and charge any truck with a battery on board. It uses a system of conductive rails or wires embedded in the road surface to supply electric power to a vehicle as it drives along the roadway. This allows the vehicle to recharge its battery or even operate entirely on electricity from the grid, rather than relying on the battery alone. This could include BETs, HFCTs, or even hybrid trucks. ERS has the potential to solve some of the primary challenges faced by other LZETs for long haul heavy-duty applications (Navidi, Cao, & Krein, 2016):

- Increased maximum driving range - An average truck requires 120 kW for traction, and it is technically possible to transfer 200 kW to the truck using ERS. The surplus 80 kW could be used to charge the battery of a BET, HFCT, and/or hybrid truck to reduce the length of required ERS infrastructure (Siemens Mobility, 2017).
- Potential to reduce the size of the vehicle battery, reducing vehicle capital costs, particularly for BETs (Brown, Fleming, & Safford, 2020).
- Smaller size of the battery increases truck payload.
- ERS reduces charging/refuelling time, as well as stationary charging/refuelling infrastructure requirements (and costs) (Siemens Mobility, 2017).

There are three primary ERS infrastructure approaches being pursued:

a) Overhead catenary lines
b) Rail/inroad conductive
c) Wireless induction power transmission

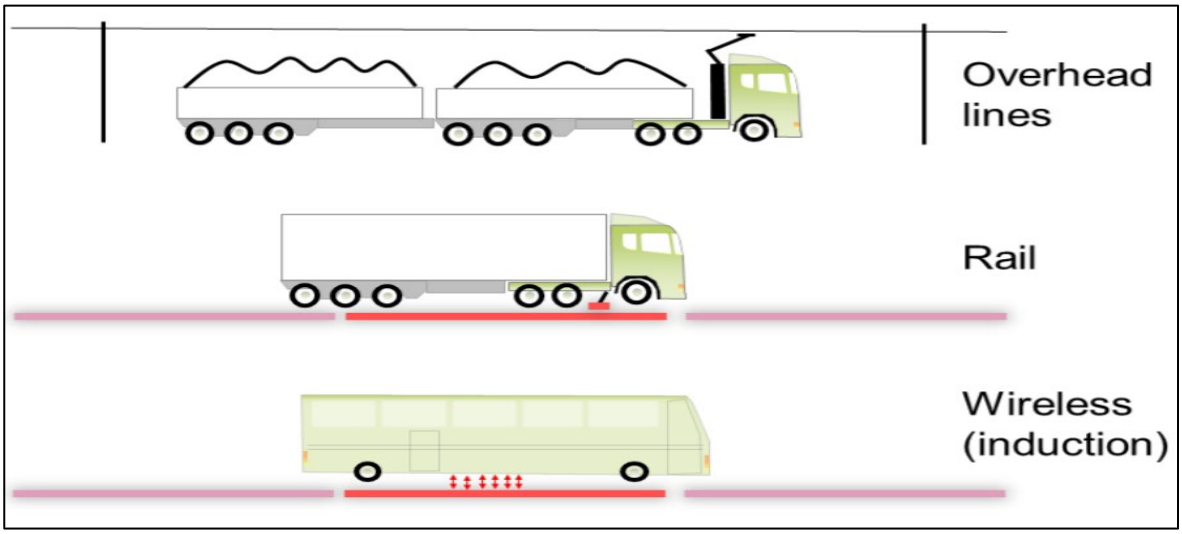


Figure 26: Three main infrastructure approaches to implementing an ERS
Source: (Gustavsson, Hacker, & Helms, 2019)

Overhead catenary electric road system (OCERS)

OCERS is a mature technology (**Figure 27**). It was first applied to road transport in 1882 with the invention of Siemens Electromoto, in Berlin, Germany. With this technology, a truck makes direct and constant connections using a pantograph to overhead electric wires for energy transfer (Bateman, Leal, & Reeves, 2018).

Figure 27: Siemens e-highway – overhead catenary electric road system

OCERS has been demonstrated in several field trials and shown in the first applications, e.g., mining haul trucks and port trucks (**Figure 28**).

Figure 28: Mining truck using ABB's OCERS system at a mining site

The first overhead catenary truck was demonstrated by Siemens in Sweden in 2016 (Plötz, Gnann, & Jochem, 2019). Currently, Siemens has completed several demonstrations in the EU and USA. Owing to higher drivetrain efficiency, OCERS trucks use less than a quarter of the energy compared to conventional diesel trucks (Mareev & Sauer, 2018). The TCO of

OCERS is also estimated to be comparable to or lower than that of diesel trucks. OCERS has the potential to significantly reduce emissions from heavy-duty trucks, particularly when paired with renewable electricity generation (U.K. Government Office of Science, 2019). The Centre for Sustainable Road Freight (SRF) white paper 2020 recommends OCERS as the most suitable low-cost technology to decarbonise the UK's long haul road freight system (Ainalis, Thorne, & Cebon, 2020). Other studies by IEA (**Figure 29**) and ICCT also present OCERS as an important LZET for providing deep decarbonisation (IEA, 2020) (ICCT, 2017). OCERS, for mining applications, is a mature technology and is already offered by several companies including ABB (ABB, 2019) and Caterpillar (Caterpillar, 2020). Except for a few successful demonstrations and trials, OCERS has not yet been widely deployed on highways in any nation.

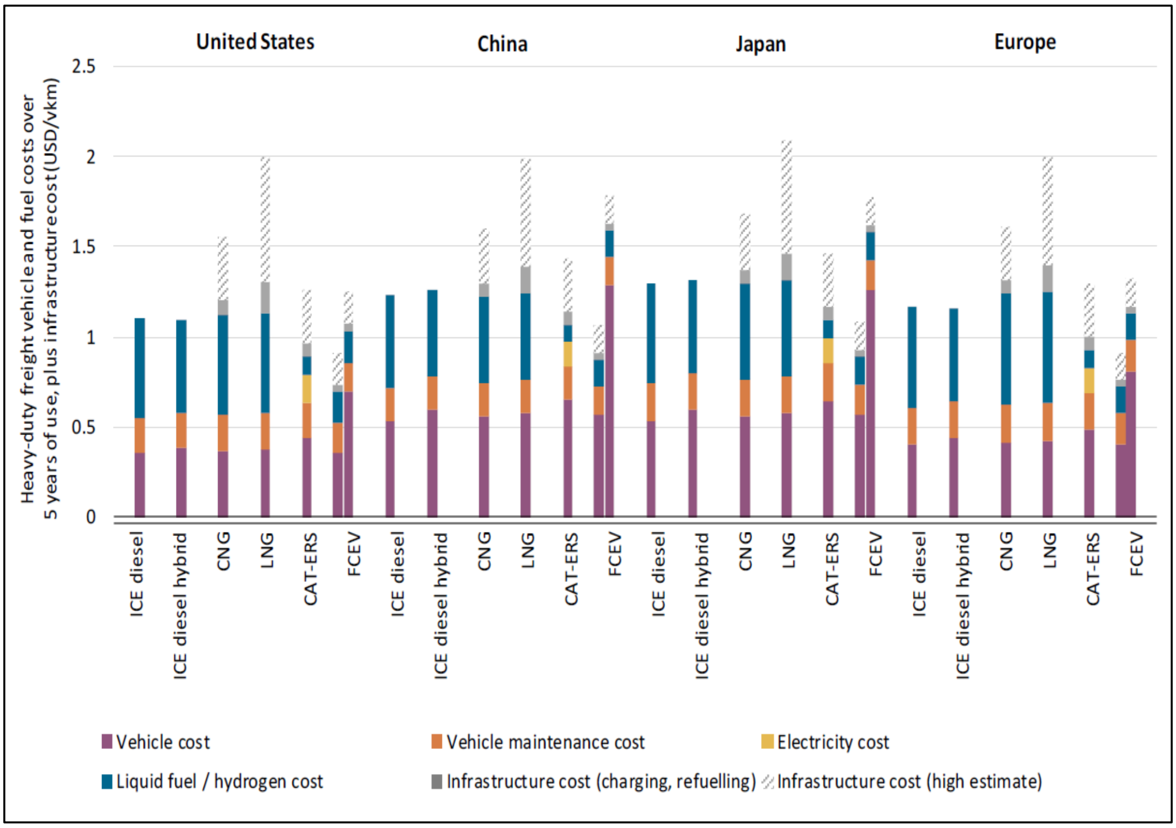


Figure 29: Heavy duty vehicle and fuel costs over five years of operation

Source: IEA modern truck scenario (IEA, 2020)

OCERS requires the build out of new infrastructure. Although several studies have shown that OCERS has lower or comparable infrastructure costs as compared to other LZETs, including HFCTs (IEA, 2020) (Zhao, Wang, Fulton, Jaller, & Burke, 2018), as shown in **Figure 29**, this can be region-specific, and a detailed assessment of NSW, and broader Australian context is required to assess its local feasibility.

The TCO of OCERS depends upon traffic volume using OCERS system. It is crucial to analyse NSW road freight data, including traffic volumes and route choice, to adequately assess the feasibility of adopting OCERS locally. Another study conducted by ICCT estimates a lower TCO for OCERS compared to diesel by 2030 (ICCT, 2017), shown in **Figure 30**. Although the studies analysed suggest a lower TCO for OCERS compared to hydrogen fuel cell and diesel technology soon, there are still substantial upfront infrastructure costs that would need to be funded to the technology to be widely adopted.

The SWOT analysis for OCERS (**Figure 31**) demonstrates that OCERS is a mature technology ready for deployment for long-haul HDTs (Wolff, Fries, & Lienkamp, 2019). However, there are several infrastructure challenges that are required to be addressed, primarily in terms of upfront costs.

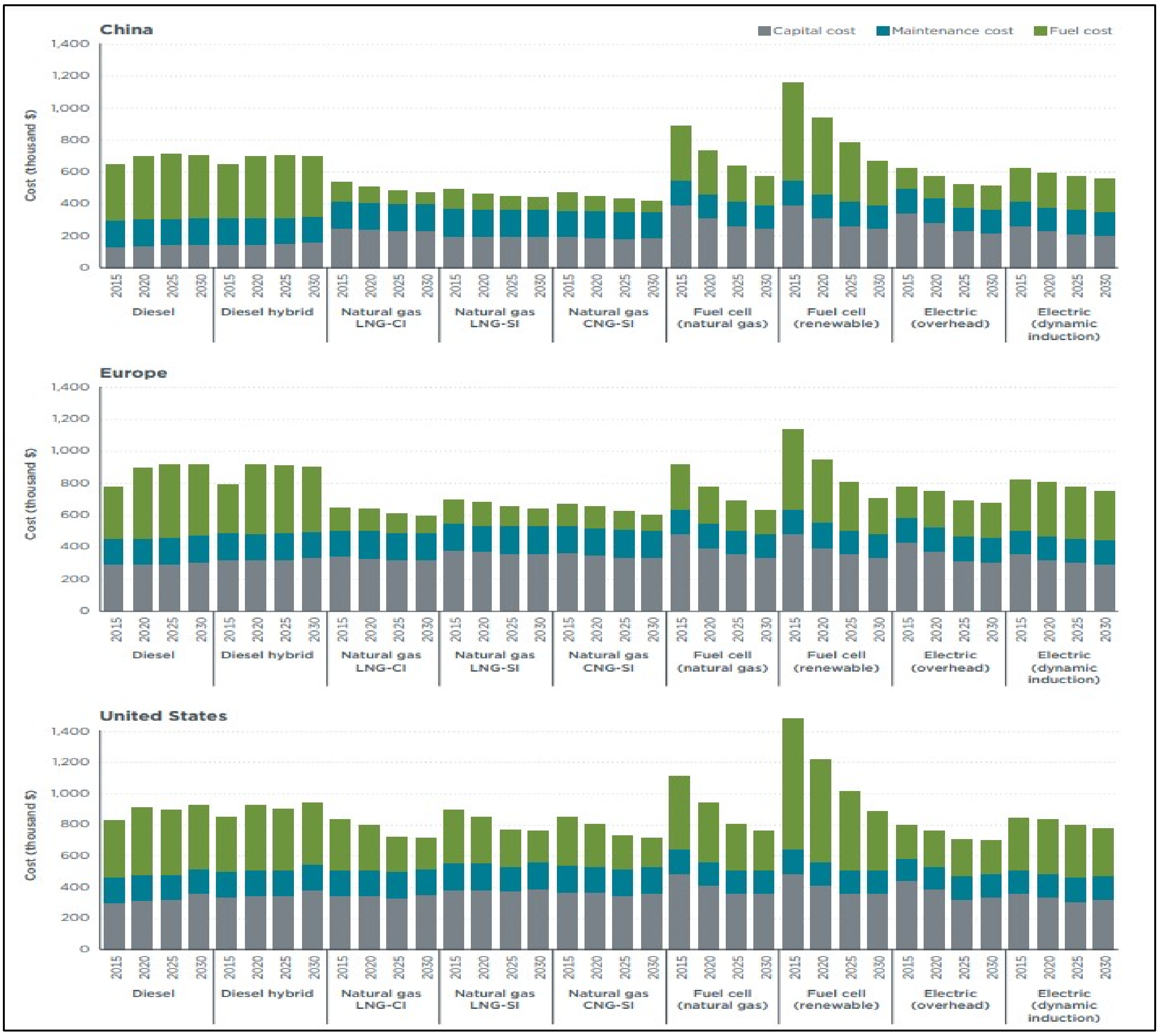


Figure 30: TCO in China, Europe, and the US for long-haul trucks 2015- 2030

Note: Cost is broken down by capital, maintenance, fuel costs (ICCT, 2017)

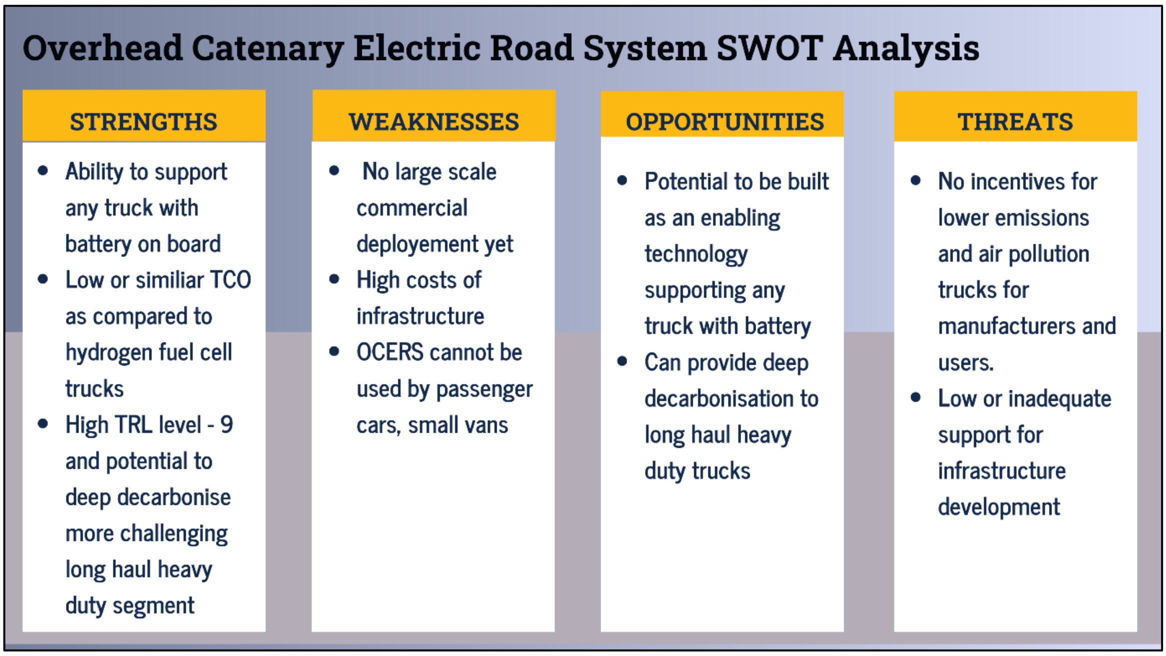


Figure 31: SWOT analysis of OCERS

In-road conductive electric road system

For In-road conductive electric road system (ICERS), energy is transferred to the vehicle via a movable arm under the vehicle (**Figure 32**). Unlike OCERS, ICERS can be used by any vehicle, including cars and small vans. ICERS also reduces the need for larger size batteries.

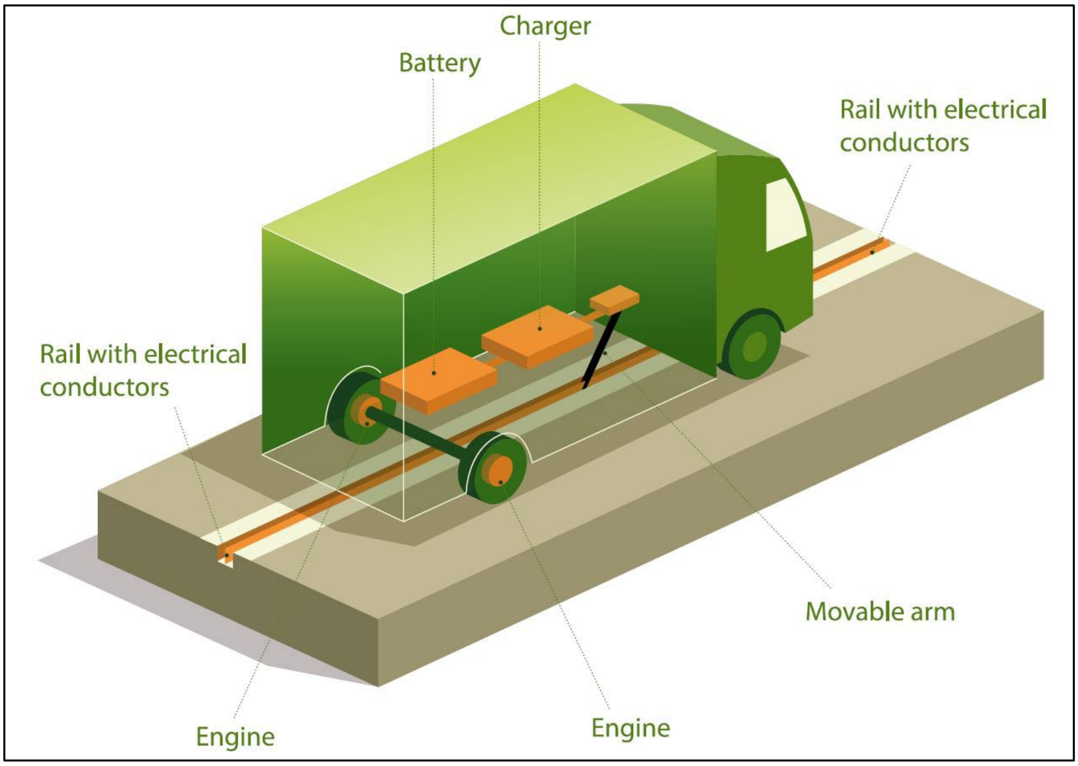


Figure 32: In-road conductive transfer ERS concept

Source: (Elways , 2020)

ICERS also has a high potential to reduce emissions; however, ICERS are still in the development phase and have lower TRL levels 4 or 5 (Bateman, Leal, & Reeves, 2018). IEA has not considered it as a potential future option in its *Future of Trucks* report (IEA, 2020). Furthermore, ICERS is expected to have a significantly higher infrastructure cost and TCO than that of other LZETs due to the need to embed/attach a conductive rail into the road pavement surface (ICCT, 2017).

Wireless inductive electric road system

In wireless inductive electric road system (WIERS), energy is transferred to a vehicle using induction coils without vehicles having a physical connection with the road. WIERS can charge all types of vehicles - trucks, buses, passenger cars. A global overview of existing trials or demonstrations for WIERS indicates there are no major trials focused on investigating the potential of WIERS for long-haul heavy-duty trucks (Bateman, Leal, & Reeves, 2018). There are several technical and economic potential challenges, and WIERS is still in the development phase (Gill, Bhavsar, Chowdhury, & Johnson, 2014). Specific system costs for BET with wireless power transfer are high compared to other available LZETs, including OCERS (ICCT, 2017). WIERS may become viable later this century but is not expected to be a major contributor to transport decarbonisation prior to 2050.

WIERS (or dynamic induction/charging) has the highest infrastructure cost compared to other technologies, except for HFCTs. One paper estimates that the TCO for WIERS will remain higher than OCERS, even by 2030 (ICCT, 2017).

The review of WIERS indicates that it is not yet a mature or competitive technology. There are several infrastructure costs challenges, as such, it appears WIERS is less likely to play a significant role in decarbonising road freight fleet before 2050 but may become more feasible in the second half of this century.

3.4 Advanced biofuel trucks

Biofuels are an alternative fuel that is developed from biological, natural, and renewable sources and are an attractive option due to their high energy density and convenient handling and storage properties. Biofuels can be used on its own (with some precautions or restrictions) or blended with petroleum fuels in the transition period to 2050 to reduce the carbon content. Indeed, renewable diesel (also known as hydrogenated / hydrotreated vegetable oil (HVO) in Europe) has similar chemical composition to petroleum diesel, which allows the fuel to be used as a ‘drop-in’ replacement for fossil diesel without the need for blending. The term ‘drop-in’ indicates that the fuel can be integrated into existing engine infrastructure without any modification and most OEMs support its use if it meets standard diesel fuel quality specifications (U.S. Energy Information Administration, 2020). An example renewable diesel truck is shown in **Figure 33.**

Figure 33: Renewable diesel in Scania test engines in Queensland
Source: (Scania, 2019)

Depending on the type of biomass feedstock used for their production, biofuels are categorised into three classes: first, second, and third generation biofuels (Pishvaee, Mohseni, & Bairamzadeh, 2021).

- First-generation feedstocks include sugar feedstocks (e.g., sugar cane and sugar beet), starch feedstocks (e.g., corn and wheat), and edible oil feedstocks (e.g., rapeseed and soybean)
- Second-generation feedstocks include lignocellulosic feedstocks (containing biomass residues, organic wastes, and dedicated lignocellulosic crops) and nonedible oil feedstocks (containing waste cooking oil, animal fats, and dedicated oil crops)
- Third-generation feedstocks are derived from microalgae.

Advanced biofuels such as ethanol, methanol, fatty acid methyl ester (FAME), renewable diesel, hydrotreated vegetable oil (HVO) or biomethane (either compressed or liquefied) can be made from waste material such as sewage sludge, landfill gas or from residues from agriculture, households, and the food industry. The original production method of these fuels used sugars, starch, and vegetable oils which it has been argued (Transport & Environment, 2017) produces more well to wheel emissions than fossil fuels. Finnish company Neste, the world's leading provider of renewable diesel and sustainable aviation fuel (SAF) stated that in 2018 and 2019, about 80% of their renewable diesel feedstock consisted of waste fats and oils. The waste and residues consist of used cooking oil (UCO), palm fatty acid distillate, bleaching earth oil, technical corn oil, and animal fats. Neste's goal is to reach a 100% waste and residues share by 2025 (OFI Magazine, 2021).

According to Neste, their 'MY Renewable Diesel', made entirely from waste biological raw materials, helps reduce the GHG emissions by up to 90% when emissions over the fuel's life cycle are compared with petroleum diesel (Neste, 2021). According to the 2020 report from

Advanced Biofuels, USA, renewable diesel has some of the largest lifecycle greenhouse gas reductions with a carbon intensity of about 30 compared to 102 for ultra-low sulphur diesel (Advanced Biofuels USA, 2020). For renewable diesel, the outcome of the analysis is greatly dependent on the feedstock source. **Table 6** shows the list of carbon intensity values used by California Air Resources Board (CARB) for petroleum diesel and different feedstock derived renewable diesel varieties available in the USA (California Code of Regulations (CCR)).

Table 6: Carbon intensity for diesel and renewable diesel used in the USA.
Source: (California Code of Regulations (CCR))

Fuel	*Pathway Identifier*	*Pathway Description*	*Carbon Intensity Values (gCO2e/MJ)*		
			Direct Emissions	*Land Use or Other Indirect Effect*	*Total*
Diesel	ULSD001	ULSD - based on the average crude oil delivered to California refineries and average California refinery efficiencies	94.71	0	94.71
Renewable Diesel	RNWD002	Conversion of tallow to renewable diesel using higher energy use for rendering	39.33	0	39.33
	RNWD003	Conversion of tallow to renewable diesel using lower energy use for rendering	19.65	0	19.65
	RNWD001	Conversion of Midwest soybeans to renewable diesel	20.16	62	82.16

CARB emission tests, using Neste's hydrotreated vegetable oil (NExBTL fuel), showed that renewable diesels help improve air quality when compared to petroleum diesel. The tests determined that for RD100 (100% renewable diesel), Particulate Matter (PM) emission results demonstrated an average decrease of about 30%, Nitrous Oxides (NO_x) emission results demonstrated a decrease of about a 10%, and Total Hydrocarbon (THC) and Carbon Monoxide (CO) generally decreased by about 5% and 10%, respectively. Other toxic emissions tests conducted for various carbonyls, volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs), showed reduction in most PAHs and VOCs. Major freight companies in Europe and the USA are transitioning their fleet to renewable diesel/HVO (**Figure 34**).

The "Greenhouse gas and sustainability footprints of potential biofuels for Queensland" study conducted by Lifecycles for Department of Environment and Science, analysed 20 fuel scenarios, including seven feedstocks for ethanol, two sources of biodiesel and eleven feedstocks for renewable diesel (Grant , 2018). Of the 20 different fuel scenarios studied, 18 of them showed climate change benefits (reduction in LCA) compared to conventional fossil fuel.

Leading parcel delivery company, DPD UK, recently announced that it is to switch its entire diesel heavy duty truck fleet to Gd+ HVO (**Figure 34)**, an advanced HVO fuel by end of 2023 (DPD Group, 2022). By using Gd+ HVO fuel, operators of diesel engines typically save lifecycle greenhouse gas emissions by 90%, and consequently help improve local air quality. In-field and controlled environment-independent tests have shown that compared to standard diesel emissions, Gd+ HVO achieves up to 80% reductions of particulates and up to 20%

reductions of nitrogen oxides emissions. DPD UK will begin switching its 1,600-truck fleet to Gd+ HVO immediately, and following a four-month trial, the company aims to convert 60% of its vehicles within 2022, reducing emissions by 70,282 tonnes compared to 2021. The remaining vehicles will switch by the end of 2023. DPD Ireland has also started switching to HVO as a replacement fuel for diesel in its heavy goods vehicles (Fuel Oil News, 2022).

Figure 34: DPD UK switching diesel truck fleet to renewable biofuel by end 2023.

Source: (Fuel Oil News, 2022)

The appeal of biofuel subsidies in Europe and Low Carbon Fuel Standard credits in the USA, has led to the development of several major commercial renewable diesel ventures (Bryan, 2021). There is no direct subsidy support for producers or consumers to encourage greater use of biofuels in Australia; as a result, renewable diesel is not produced on a large scale in the country. However, developmental research and production of renewable diesel is currently growing in Australia.

3.5 Plug-in hybrid trucks

Plug-in hybrid trucks (PHTs) combine the benefits of both electric and traditional diesel drivetrains (**Figure 35**). They can operate emission-free when necessary while also maintaining extended range using diesel or biofuels. PHTs can be charged using electricity from the grid and have a higher drivetrain efficiency than conventional diesel trucks, resulting in lower costs and emissions (IEA, 2020). Some companies, such as Hyliion, specialise in retrofitting traditional heavy duty long-haul trucks with plug-in hybrid or hybrid systems (Hyliion, 2020) (Hino, 2020). However, these retrofits are typically limited to difficult to decarbonise road freight applications, as BETs and HFCTs (with or without ERS) are likely to be more competitive soon.

Currently, there are several plug-in hybrid heavy-duty truck models available in the international market. The Mack class 8 PHT has a Mack MP7 diesel engine integrated in parallel with an electric powertrain (**Figure 35**). This vehicle has successfully trialled for drayage operations in California (Mack Trucks, 2019).

Figure 35: Mack class-8 plug-in hybrid truck used for drayage in California, USA
Source: (Mack Trucks, 2019)

Studies show PHTs have limited ability to reduce emissions, and if adopted at a large scale may risk achieving net zero emissions before 2050 (ICCT, 2017) (Wolff, Fries, & Lienkamp, 2019). PHTs do not require substantial new infrastructure, and so as mentioned previously, may have a role to play in some limited applications. The SWOT analysis, **Figure 36**, shows PHTs present opportunities to reduce emissions by upgrading the feasible existing fleet. PHTs using biofuels can also be used in remote locations difficult to develop charging or hydrogen refuelling infrastructure.

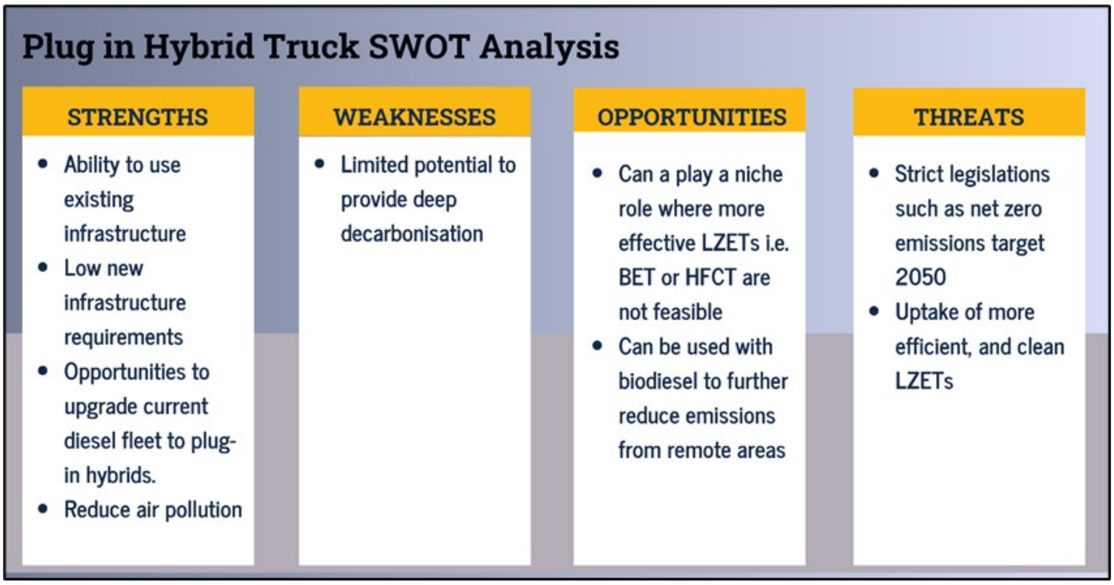


Figure 36: SWOT analysis of PHTs

3.6 Performance-based standards

High Productivity Vehicle (HPV) combinations are novel road freight transport solutions that present immediate opportunities for decarbonising the road freight sector. These solutions, which focus on optimising vehicle designs and configurations for specific freight tasks, offer environmental benefits which makes them an integral component of any strategy aimed at reducing carbon emissions in road freight.

HPVs are defined as a heavy road freight vehicles that can carry a greater payload than a B-double or general access vehicle permitted on a particular road. They are greater in length, width, and height of mass than B-doubles and are therefore classified as restricted access vehicles.

In Australia, HPVs are mainly regulated through the national PBS scheme, operating since 2007, which aims to encourage innovation and the development of safer and better equipped HPVs and an alternative to the prescriptive system for regulating heavy vehicles. PBS-approved vehicles are tested against stringent standards that include 16 performance and safety standards, and four infrastructure standards. The PBS scheme focuses on how well the vehicle performs on the road, by assessing the vehicle design against a set of safety standards, rather than assessing a vehicle based on prescriptive limits.

Utilising Performance-Based Standards (PBS) high productivity trucks is gaining prominence as an important strategy in the drive to decarbonise freight transportation. These trucks, designed around stringent performance criteria rather than prescriptive limits, enable increased freight volume or weight capacities. This increase in capacity results in fewer journeys, thereby reducing GHG emissions. By fine-tuning vehicle dimensions and capacities, PBS trucks facilitate more efficient and eco-friendly freight transportation, establishing themselves as an essential asset in the shift towards a low-carbon freight transport infrastructure.

The National Transport Commission (NTC) report reveals that PBS scheme vehicles exhibit 15 to 30 per cent greater productivity than conventional heavy vehicles, depending on the freight, leading to fewer vehicles on the roads and consequent reductions in fuel consumption, carbon emissions, and road maintenance costs (National Transport Commission , 2018).

3.7 Electric trucks with biofuel range-extenders

A range-extender electric truck uses a small ICE that runs on biofuels to generate electricity to charge the battery and power the electric drivetrain. The ICE runs at a constant speed and generates a steady supply of electricity, which allows the truck to have a longer range than a BET with the same battery capacity.

The use of biofuels as a range extender for electric trucks can have some benefits, such as:

- Increased range: biofuels have a higher energy density than batteries, which means that it can store more energy per unit of volume.
- Reduced dependence on battery technology: biofuels can be used as a backup power source if the battery is low or if the truck is operating in a remote area where charging infrastructure is not available.

- Reduced emissions: compared to diesel engines, biofuel-powered internal combustion engines have lower emissions of particulate matter, nitrogen oxides, and GHGs.

The University of Minnesota's Centre for Transportation Studies (CTS) has been involved in several research projects on range-extender electric trucks as part of its mission to improve transportation systems and reduce their environmental impacts (University of Minnesota, n.d.). Research is currently being conducted on using E85 in an ICE that charges the battery, acting as an ethanol range-extender for electrified vehicles.

Rosenbauer, a global leader in firefighting technologies, presented and tested their first fully electric fire truck with an ICE range extender, shown in **Figure 37**. The Rosenbauer AT electric truck, built on a Volvo FE Electric chassis, can operate as a fully electric firefighting vehicle that utilises both an electric driveline and an electric fire pump (Rosenbauer, 2022).

Figure 37: Rosenbauer's first fully electric fire truck with ICE range extender

Source: (Rosenbauer, 2022)

The pump is powered by an electric motor, which is standard with the chassis and draws power from the vehicle's high-voltage system. Additionally, a range extender provides extended energy for longer operation. The vehicle is powered by two lithium-ion batteries with a total capacity of 66 kWh. These batteries can be charged via a charging cable with a maximum power of 150 kW DC or 22 kW AC, or, if necessary, at the site of operation via the range extender (Rosenbauer, 2022). Currently these range extenders run on diesel but there might be future to use biofuels. The driving distance with a fully charged battery is approximately 100 km, depending on the terrain.

3.8 Comparison of different LZETs

Table 7 provides an overview of different low and zero carbon energy fuels that could be used to power road freight trucks (Plötz, Hacker, & Jöhrens, 2018).

Table 7: Different low/zero carbon energy fuels to power road freight trucks

	Fuel cell (FC)	Battery electric (BE)	Overhead catenary (OC)	Synthetic fuels (PtG /PtL)
Motors and technology	Electric motor and fuel cell with hydrogen as energy storage	Electric motor and battery as energy storage	Electric motor and power from overhead lines, if necessary with battery as energy storage or additional combustion engine	Internal combustion engine and pressurized gas or liquid tank as energy storage device
Conversion steps Fuel production from electricity	Conversion to hydrogen (electrolysis)	Direct Use	Direct Use	Conversion to hydrogen (electrolysis) and further to carbonaceous fuel
Efficiency today with the use of renewable electricity	Circa	Circa	Circa	Circa
tank-to-wheel	40 – 50 %	90 %	90 %	35 – 40 %
well-to-tank	60 – 70 %	90 %	90 %	50 – 60 %
well-to-wheel	25 – 35 %	80 %	80 %	20 – 25 %
Technological readiness level of vehicles	(TRL 6-7)	(TRL 8)	(TRL 6-7)	Conventional vehicles
Key challenges	Infrastructure development and increased power requirements due to high conversion losses, cost reduction in fuel production	Limited range, long charging time and payload losses	Infrastructure development, acceptance, integration in logistics processes	Strongly increased power demand due to highest conversion losses, cost reduction in vehicle and fuel production

Some of these technologies and fuels are more efficient than others; Transport & Environment (Transport & Environment, 2020) show a comparison of four pathways for energy efficiency of fuel production and use – direct electrification (BETs), hydrogen (HFCTs), power to liquid or synthetic fuels (conventional ICE vehicles) and power-to-methane or synthetic gas (conventional gas vehicles) – for 2020 and 2050 (**Figure 38**).

The literature indicates that battery electric vehicles are clearly the favoured option for urban type operations and the current technology and expected developments will make this option ever more attractive for the vehicle sizes, ranges and operational patterns involved in urban distribution.

Table 8 lists the technology / fuel sources deemed in the literature to have the greatest decarbonisation potential for each type of road freight mode in 2030 and 2050 considering energy production, infrastructure and other barriers to implementation and uptake (ALICE-ETP, 2019), (IEA, 2017), (IEA, 2020), (McKinnon, 2018) (Palmer & Allen, 2021).

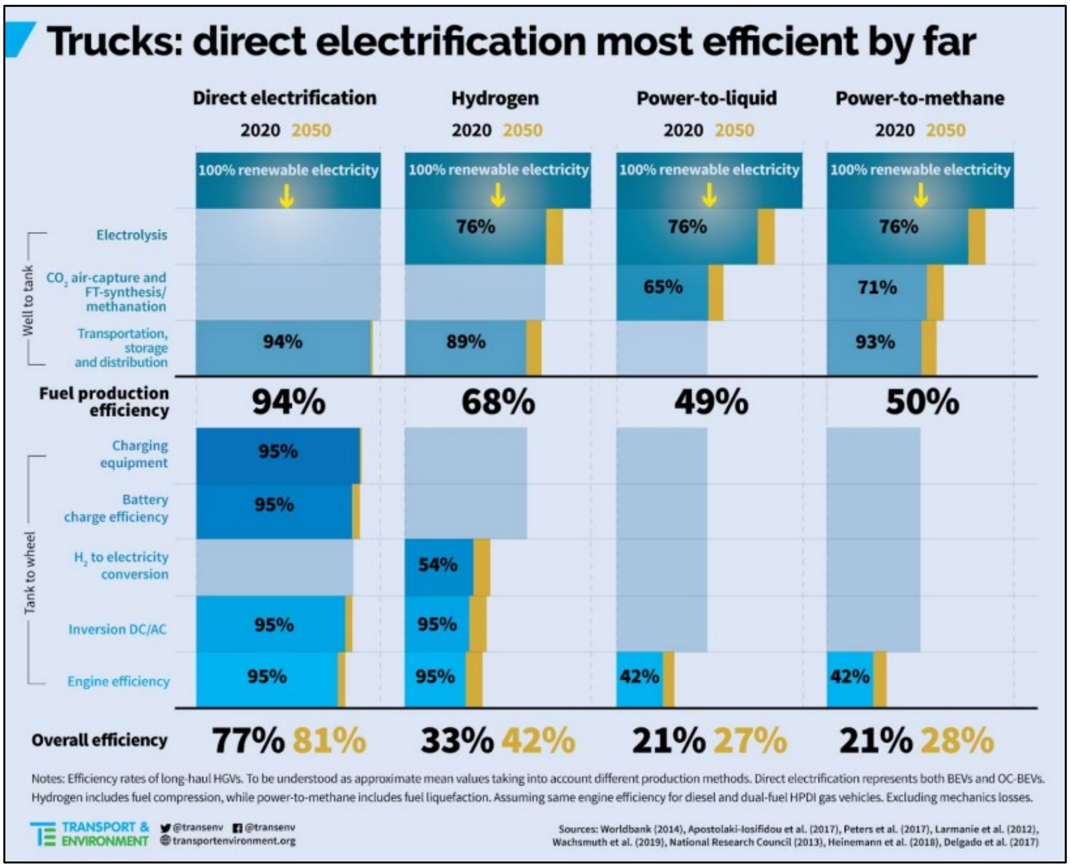


Figure 38: Comparison of pathways for energy efficiency of fuel production

Several OEMs are developing a zero on-road emission truck for the global market, with most of them being BETs, as shown in **Figure 39**. By 2024, fleet operators in Europe and North America will be able to choose from more than 70 different zero emission truck models, compared with almost 130 models available with diesel powertrains. The majority of zero emission truck models currently available are primarily intended for urban and regional use and do not have the range capabilities necessary for long-haul applications, shown in **Figure 40** (McKinsey & Company, 2022).

However, in 2022 several major OEMs began series production of heavy duty (US Class 8) electric trucks. A standout moment was Tesla's announcement in early October about the initiation of "early production" of its Tesla Semi at the Nevada Gigafactory. By December 2022, Tesla had begun delivering the Semi. Out of the 100 Semis ordered, PepsiCo received 36. 15 of these are now operational at Frito-Lay in Modesto, California, while 21 are stationed at their main Sacramento location, which boasts four Tesla chargers, each with a charging capacity of 750 kW (Electrive, 2023).

Table 8: Technology and fuels with greatest decarbonisation potential for road freight

Transport mode	2030	2050
MDT and LDT	• Battery electric	• Battery electric
HDT (short distance)	• Battery electric • Biofuels • Natural gas (CNG and LNG)	• Battery electric • Hydrogen fuel cell
HDT (long distance)	• Natural gas (CNG and LNG) • Biofuels	• Overhead electric (ERS) • Battery electric • Hydrogen fuel cell • Advanced synthetic biofuels

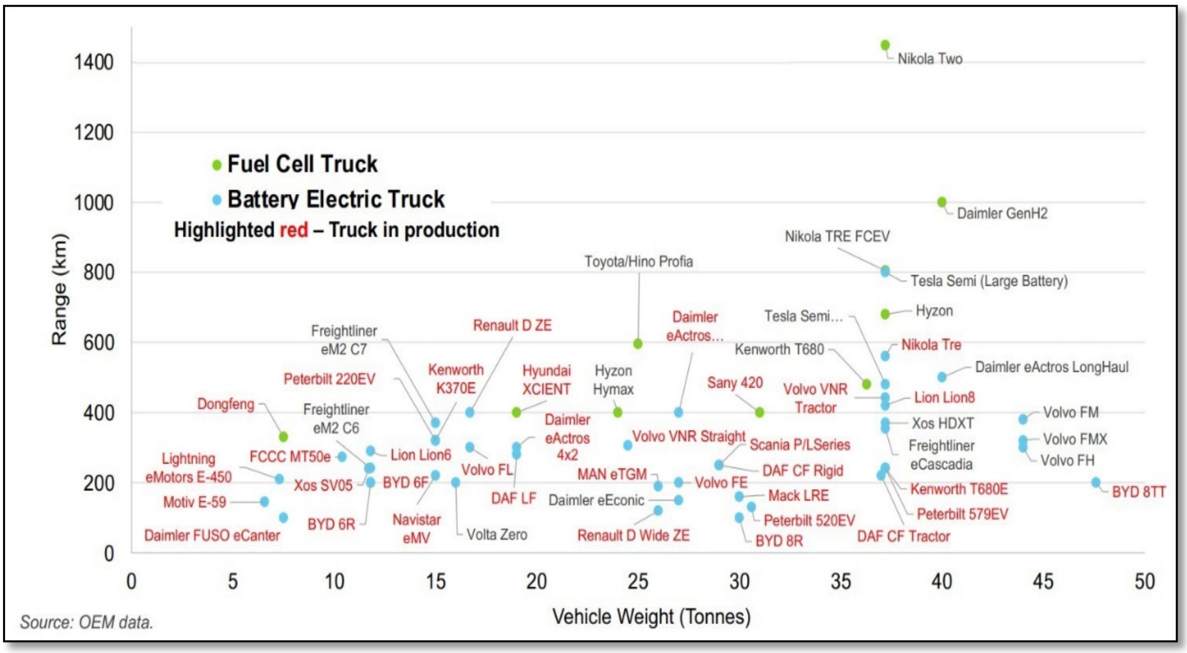


Figure 39: OEMs developing BET and HFCT trucks globally
Source: (IDTechEx, 2022)

In September 2022, Volvo Trucks announced the series production of electric versions of Volvo FH, FM, and FMX trucks, which can operate at a Gross Combination Weight (GCW) of 44 metric tonnes and the three models represent around two thirds of the company's sales. The move has made Volvo the first global truck manufacturer to begin series production of the broadest heavy-duty electric truck line-up (Prime Mover Magazine, 2022). A smaller number of HFCT trucks are in development, offering a superior driving range. As of 2020, the global BET fleet reached approximately 31,000 vehicles, with 7,400 new vehicles registered in 2020 alone. These new sales were dominated by China, registering 6,700 new electric trucks, with a further 450 in Europe and 240 in the US. In comparison, as of 2020 the global HFCT fleet reached 3,200 vehicles, with 99% of these vehicles in China (IEA, 2021). However, the hydrogen-powered vehicle market is beginning to take off and several OEMs aim to manufacture and deploy thousands of HFCTs in the next decade. Hyundai has already delivered 46 heavy-duty HFCTs to Switzerland as of July 2021 and plans to deploy

1,600 vehicles in the country by 2025, while the Port of Rotterdam and Air Liquide have created an initiative to deploy 1,000 HFCTs by 2025 and a joint call signed by over 60 industrial partners aims for up to 100,000 trucks by 2030 (IEA, 2021).

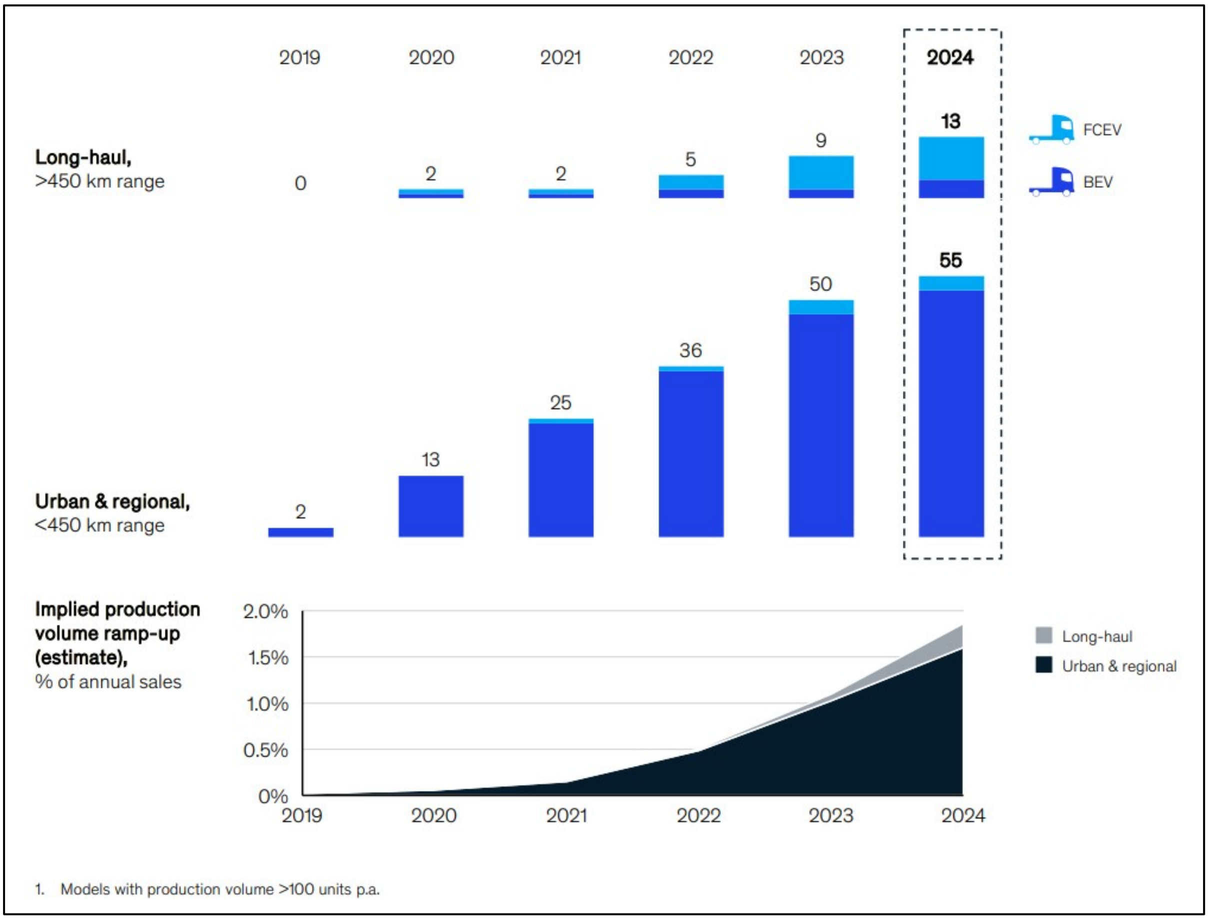


Figure 40: Medium and heavy-duty zero emission truck models in the market

Source: (McKinsey & Company, 2022)

Truck makers such as Daimler, Renault, Scania, MAN and Volvo have all indicated their commitment to a future of zero-emission trucks, including BETs and HFCTs. Hyzon has received orders for over 1,500 HFCTs to be delivered by 2024 to New Zealand and Europe. Daimler and Volvo also plan to commence series production of HFCTs in 2025 as part of a joint venture (IEA, 2021).

It is worth noting that ERS is also being actively discussed by several countries as a technology-neutral approach to supporting both battery electric and hydrogen fuel cell heavy vehicles, while reducing operating costs for both technologies. The upfront infrastructure costs of ERS are significant, but some studies suggest it could be cost-competitive for high utilisation corridors, shown in **Figure 41** (Ainalis, Thorne, & Cebon, 2020).

Both electric (battery and ERS) and hydrogen offer potential as energy sources to decarbonise truck operations. Several publications examined, identify that electrification of freight transport offers the most important power source for road freight decarbonisation by 2050, but other energy types such as hydrogen and advanced fuels such as renewable diesel, synthetic methane, synthetic methanol, and synthetic liquid hydrocarbons will also play a role.

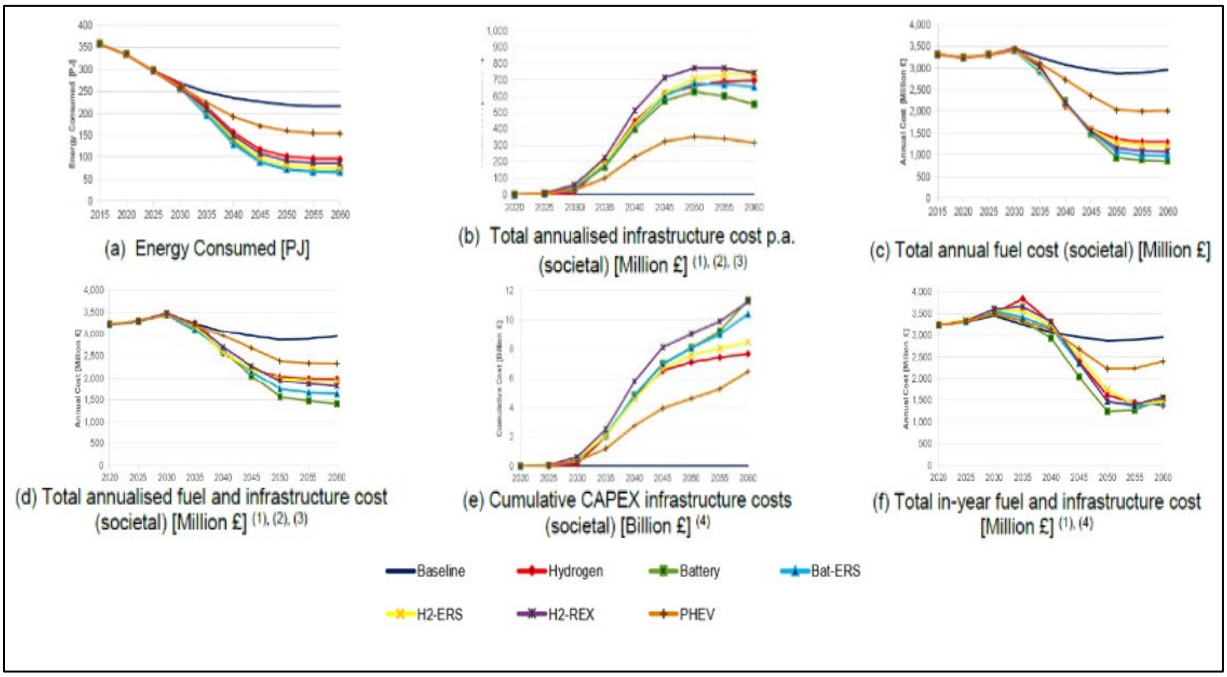


Figure 41: UK cumulative energy/CAPEX for infrastructure pathways

Source: (Ainalis, Thorne, & Cebon, 2020)

According to a new zero emission truck report, battery and fuel cell electric powertrains are expected to be the leading technologies by 2030, from both an emission and TCO perspective (McKinsey & Company, 2022), shown in **Figure 42**. This makes them the two most relevant options for fleet operators. The operational cost savings, mainly on energy and potentially maintenance, will offset the higher capital expenditures (capex) for batteries and fuel cell systems within two to four years. The operational cost savings, mainly on energy and potentially maintenance, will offset the higher capital expenditures for batteries and fuel cell systems within two to four years. In the meantime, advancements in battery technology and charging speeds will enable BETs with sufficient range and acceptable charging times. Additionally, the expansion of hydrogen refuelling infrastructure and improvements in thermal management of the powertrain will allow for the widespread deployment of HFCTs.

Other options for achieving zero emissions in truck fleets include using hydrogen combustion and renewable fuels. These options may be more viable in the near term due to the current high costs of batteries, lack of infrastructure, and limited production volumes of BETs and HFCTs, and can help to speed up the process of decarbonising truck fleets.

Compared to diesel trucks, both BETs and HFCTs have payload restrictions due to the weight of the battery or the size of the hydrogen tank. However, at this point, the practical consequences are limited as many regulators allow for exceptions in vehicle dimensions or weight to mitigate these disadvantages. However, physical limitations of infrastructure, such as roads and bridges, may not allow for these exceptions when they are needed by a large share of the fleet. Over time, improved battery energy density and higher-pressure or liquid hydrogen tanks will likely further reduce these limitations.

Favoring powertrain adoption | Neutral to powertrain adoption | Limiting factor for powertrain adoption | Zero-emission powertrain/ fuel options | Fossil fuels

				Key TCO determinants 2030			Operational considerations 2030		
	Tailpipe emissions	Availability today	Projected TCO by 2030	Powertrain capex	Efficiency Well-to-wheel	Infrastructure costs	Range	Refueling time[1]	Payload
Battery electric	Zero	Low Limited production volume and high vehicle costs	Low Lower TCO than for current Diesel powertrain	High	High	High	Medium	Medium	Medium
H_2 Fuel cell electric	Zero	Low Limited production volume and high vehicle costs	Low Lower TCO than for current Diesel powertrain	High	Medium	High	High	Fast	Medium
Hydrogen ICE	Low NOx emissions (requires SCR after-treatment)	Low No truck models on the market today	Medium Lower TCO than for current Diesel powertrain, but higher than BEV/FCEV	Medium	Medium	High	High	Fast	Medium
Bio-/ Synfuel	Medium CO_2 (depending on CO_2 source), NOx and PM emissions	Medium Limited availability of fuels	High Expected to remain more expensive than fossil Diesel/ natural gas	Low	Low	Low	High	Fast	High
CNG/ LNG	High CO_2 and PM emissions	Medium Limited availability of refueling infrastructure	Medium Lower TCO than Diesel powertrain	Low	Low	Medium	High	Fast	High
Diesel	High CO_2, NOx and PM emissions	High Standard fuel today	Medium	Low	Low	Low	High	Fast	High

1. Refueling times for Diesel, gas and hydrogen are approx. 15-20 min. Recharging times for BEV trucks will depend on the charger technology used and can range from 30-45 min to multiple hours

Figure 42: BETs and HFCTs technologies emission and TCO perspectives by 2030

Source: (McKinsey & Company, 2022)

3.8.1 LZETs in Australia

According to the recent report from Queensland Transport and Logistics Council (QTLC), LZETs represent less than 0.5% market share of the new trucks purchased in Australia, as shown in **Figure 43** (QTLC, 2022). The QTLC report also provides an indicative TCO analysis for BETs and HFCTs compared to diesel trucks, assuming appropriate vehicles are available in Australia by 2025, shown in **Figure 44**.

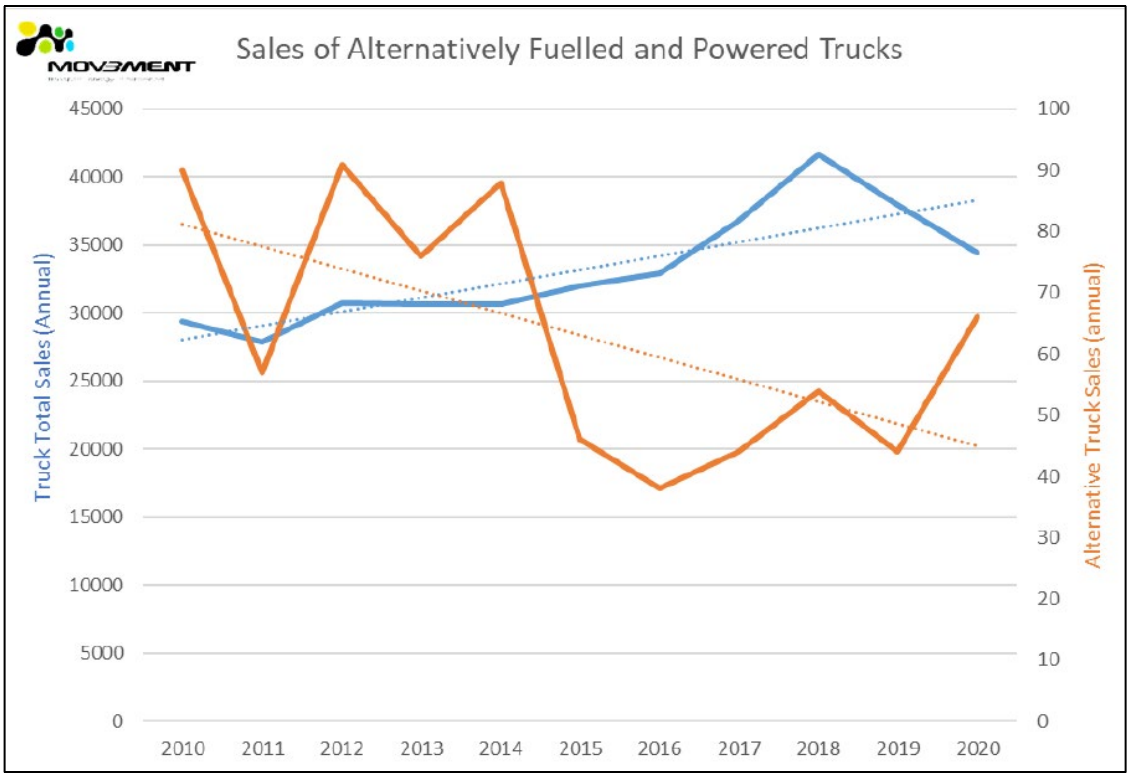
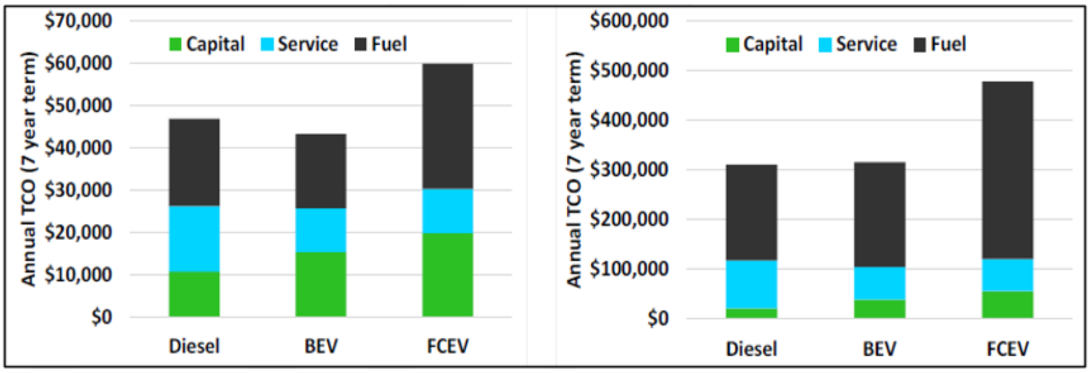


Figure 43: LZET sales in Australia

Source: (QTLC, 2022)



	Heavy rigid urban delivery			Articulated line-haul		
Annual	40,000 km			250,000 km		
	Diesel	**BEV**	**FCEV**	**Diesel**	**BEV**	**FCEV**
Price	$200,000	$320,000	$420,000	$400,000	$800,000	$1,200,000
Service	40 c/km	26 c/km	26 c/km	40 c/km	26 c/km	26 c/km
Energy use	37 L/100km	900 Wh/km	7.4 kg/100km	55 L/100km	1,700 Wh/km	14.3 kg/100km
Fuel cost	$1.40 /L	18 c/kWh	10 $/kg	$1.40 /L	18 c/kWh	10 $/kg

Figure 44: Expected TCO in Australia in 2025

Source: (QTLC, 2022)

The range of LZET models available in Australian market is scarce relative to many comparable markets internationally, shown in **Table 9**. Foton Mobility has just launched their iBLUE light duty electric truck in Australia at the Australasian Fleet Conference and Exhibition held and expect to have more than 100 trucks arrive in Australia before the end of 2022 (Fleet Auto News, 2022). One of Queensland's largest, privately owned transport & logistics organisations, APT has joined forces with CarBon to electrify the last mile delivery sector, starting with four Foton iBLUE Electric trucks with more to follow (Fleet EV News, 2022). Woolworths has also placed an order for 25 electric trucks from Foton Mobility as part of its initiative to electrify its home delivery fleet. Previously referred to as the iBLUE, the Foton T5 is a light-duty electric truck equipped with an 82kWh CATL battery and is accompanied by a warranty of 5 years or 200,000km. Limited model offers, together with a perceived risk for effective aftersales support is a major barrier to adoption of LZETs.

Table 9: BET and van model availability in Australia (ATA and EVC, 2022)

Manufacturer	Model	Segment	Range (km)
ACE	ACE Cargo Light	Light Commercial	200
ACE Daimler Truck and Bus	Fuso e-canter	Light Duty Truck	100
Electric Trucks Australia / TrueGreen Mobility	BYD T3	Van	300
EV Automotive	EC11	Van	200
JAC motors	N55 EV truck	Light duty truck	200
Janus Electric	Kenworth T403	Truck conversion	400-500
Renault	Kangoo Maxi	Light commercial van	200
SEA Electric	E4V	Van	300
	SEA 300-85	Truck Cab-Chassis	275 (Unladen)
	SEA 500-140	Truck Cab-Chassis	200 (Unladen)
	SEA 500-225	Truck Cab-Chassis	220 (Unladen)
	SEA 300-45	Truck Cab-Chassis	275 (Unladen)
Volvo Trucks	Volvo FL Electric	Medium Duty Truck	300
	Volvo FE Electric	Medium Duty Truck	120 - 200

3.8.2 LZETs in NSW

As discussed in previous sections, there are currently only a few LZET models available in the Australian market. Australian freight company, Team Global Express (TGE), has made the largest order for electric trucks in Australia, securing a A$20 million deal with ARENA to purchase 36 medium duty BETs from Volvo and 24 light rigid Fuso e-canter BETs from Daimler Fuso (**Figure 45**), along with charging infrastructure for its Sydney base (Dowling, 2022). The purchase order represents the largest single electric truck order for Volvo and will be the largest electric truck trial in Australia and possibly the world. The ARENA funds will cover nearly half of the $44 million cost of the trucks and investment in the Bungarribee parcels depot in western Sydney, which will include 63 chargers and a 1MWh battery, as well as additional rooftop solar. TGE will also contract for additional grid consumption from wind and solar suppliers. The trial aims to evaluate the emissions reduction of electric trucks before potentially replacing TGE's 6,500-strong heavy transport fleet.

Figure 45: TGE buys 60 BETs – Australia's biggest road-freight electrification project.

In 2019, fleet delivery service ANC introduced its first commercial electric vehicle fleet in NSW dedicated to client Ikea's last-mile home delivery services, shown in **Figure 46** (SEA Electric, 2019). The fleet consists of three 100% electric vehicles, built on a Hino 917 Series glider, with SEA Electric's SEA Drive 120a electric components. The zero-emissions commercial trucks will save an estimated 36 tonnes of CO_2 per annum when compared to a typical diesel equivalent. ANC is committed to Ikea's goal of having a 100% electric home delivery fleet by 2025 and the company's fleet will continue to expand in the future.

Recent plans by Janus Electric have also been unveiled to trial retrofitted electric trucks running between Brisbane and Sydney, utilising a deployment of battery swapping stations (Schmidt, 2022). The converted prime movers (**Figure 47**) can travel at an average of 400 to 600 km on each charge and with Janus' ground-breaking battery technology, swapping drained batteries for freshly charged ones at their charge-and-change stations only takes three minutes. Janus Electric plans to install these charge-and-change stations on major routes, starting with Sydney, Port Macquarie, Grafton, and Brisbane, to reduce charging time. It has also secured a site at Port Augusta in Adelaide and has plans to expand down and across to Melbourne. Janus' charge-and-change stations offer a three-way charging system that allows for the transfer of energy between the grid, batteries, and back to the grid. This system allows for the storage of renewable energy, which can then be fed back into the grid to create a balanced energy source and reduce fluctuations and power outages. The "battery swap" method is like what EV maker Nio is using in China and Norway for its electric cars.

Figure 46: ANC's BETs in NSW Ikea's last-mile home delivery services

Figure 47: Retrofitted electric trucks utilising battery swapping stations

Australia Post had placed an order of 20 Fuso eCanter light duty trucks (**Figure 48**) in September 2021, these eCanters will operate across the Australia Post and StarTrack businesses in major capital cities in two body configurations and will be supported by the Daimler Trucks network.

Figure 48: Australia Post – 20 Fuso eCanter light duty trucks for major cities

The $250 million Future Fuels Fund managed by Australian Renewable Energy Agency (ARENA) was expanded in 2022 and will support the uptake of commercial LZET modes over the next four years. Businesses can now apply for grants under the second round of the expanded Future Fuels Fund, with up to $127.9 million available to support the integration of electric vehicle technologies into both light and heavy vehicle fleets. The fund will also support the commercialisation of hydrogen as a transport fuel in fleets (The Hon Angus Taylor MP Media Releases, 2022).

3.9 Energy systems supporting LZETs

As discussed in the previous sections, electrification, hydrogen, and biofuels all have important roles to play to decarbonise road freight transport. For all these new technologies, renewable electricity is essential, not only for battery charging or ERS, but also to produce alternative fuels and gases such as hydrogen, synthetic fuels, and biofuels.

3.9.1 Battery technology

There are many research projects looking at battery technology. Recent studies have shown development and breakthrough in vehicle powertrain that are powered by battery systems. Battery energy densities have risen as battery costs have fallen, reducing overall weight of BETs and in turn improving their freight capacities and driving ranges (Marcacci, 2021). The new Tesla 4680 Dry-Cell battery has better energy density (380 Wh/kg compared to the existing 260 Wh/kg), improved power-to-weight ratio, and lower costs (Field, 2020). Further potential for improvement in terms of energy, performance and safety can be expected from the expansion of existing battery technologies and the use of new materials and material combinations. One of the biggest problems with batteries is the length of time it takes to charge. Current research is looking at electrolytic components to improve lithium-ion batteries (Advanced Propulsion Centre (APC), 2019). Further development and research into battery technology offers the long-term opportunity to multiply the energy density and thus the range of electric vehicles to reduce costs. Lithium-ion battery prices have fallen 85% in 10 years and are projected to fall below $100/kWh by 2024, reaching $60/kWh by 2030, and still lower in the 2030s (Energy Transitions Commission, 2021), as shown in **Figure 49**.

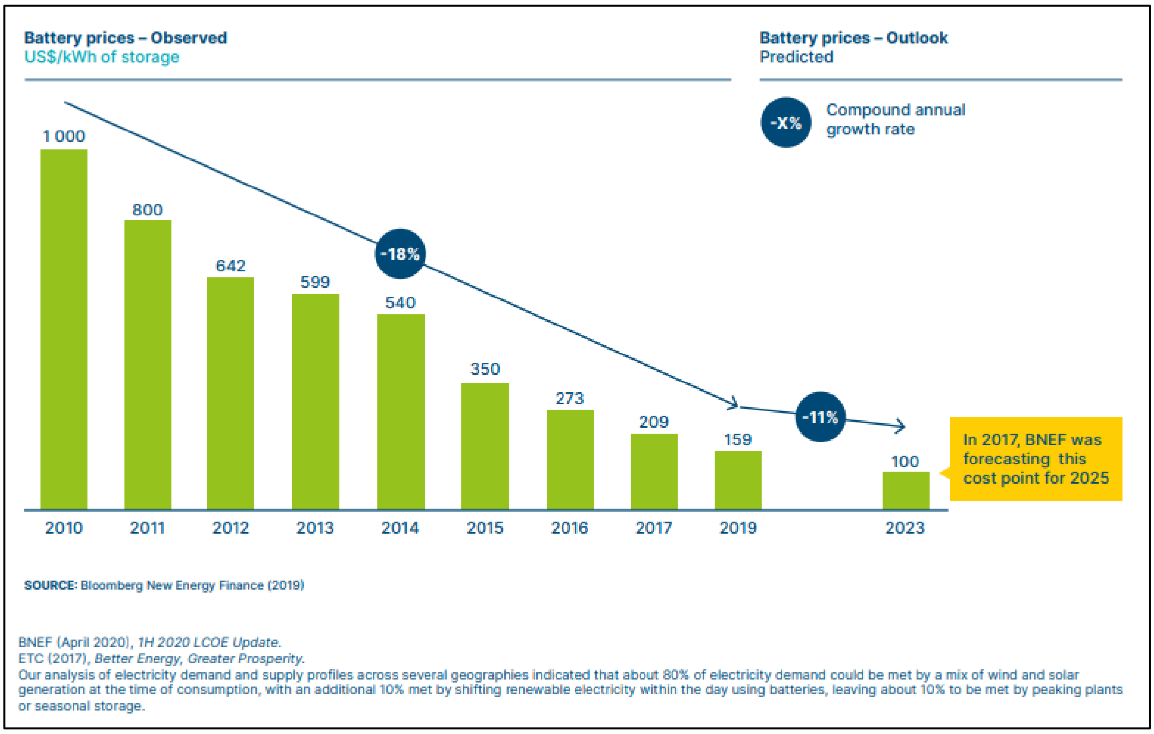


Figure 49: Battery prices in the last decade

Source: (Energy Transitions Commission (ETC), 2020)

As a result of falling battery prices, medium and heavy-duty battery electric trucks, including long-haul trucks, are expected to be cost-competitive in the 2020s and 2030s, as shown in **Figure 50** (McKinsey Center for Future Mobility, 2017) (Energy Transitions Commission (ETC), 2020). Whatever form batteries take in the future, only renewable electricity should be used to charge them if zero emissions are to be achieved.

Many Original Equipment Manufacturers (OEMs) have announced the production of new BET models; The Zero Emission Technology Inventory, compiled by Drive to Zero, is an excellent resource for reviewing the global current and upcoming supply of BETs - https://globaldrivetozero.org/tools/zero-emission-technology-inventory/ (Global Commercial Vehicle, 2022).

3.9.2 Charging infrastructure for BETs

BETs and their supporting infrastructure are currently being deployed mostly in urban areas, mainly because these tend to be medium-duty trucks (with smaller payloads and limited ranges), and urban operations offer more opportunities to optimise charging stops and more accessibility to charging infrastructure both along routes and at depots for overnight charging. Electrification of longer distance routes, such as long-haul freight trucks on regional distribution will require development of adequate dedicated high power charging stations. Some are likely to be private and used exclusively by the fleet operators. Nonetheless, tailored policies to promote the roll-out, as well as to ensure inter-operability and standardisation of certain technical and operational specifications of public rapid charging infrastructure can help spur the transition to BETs in these operations.

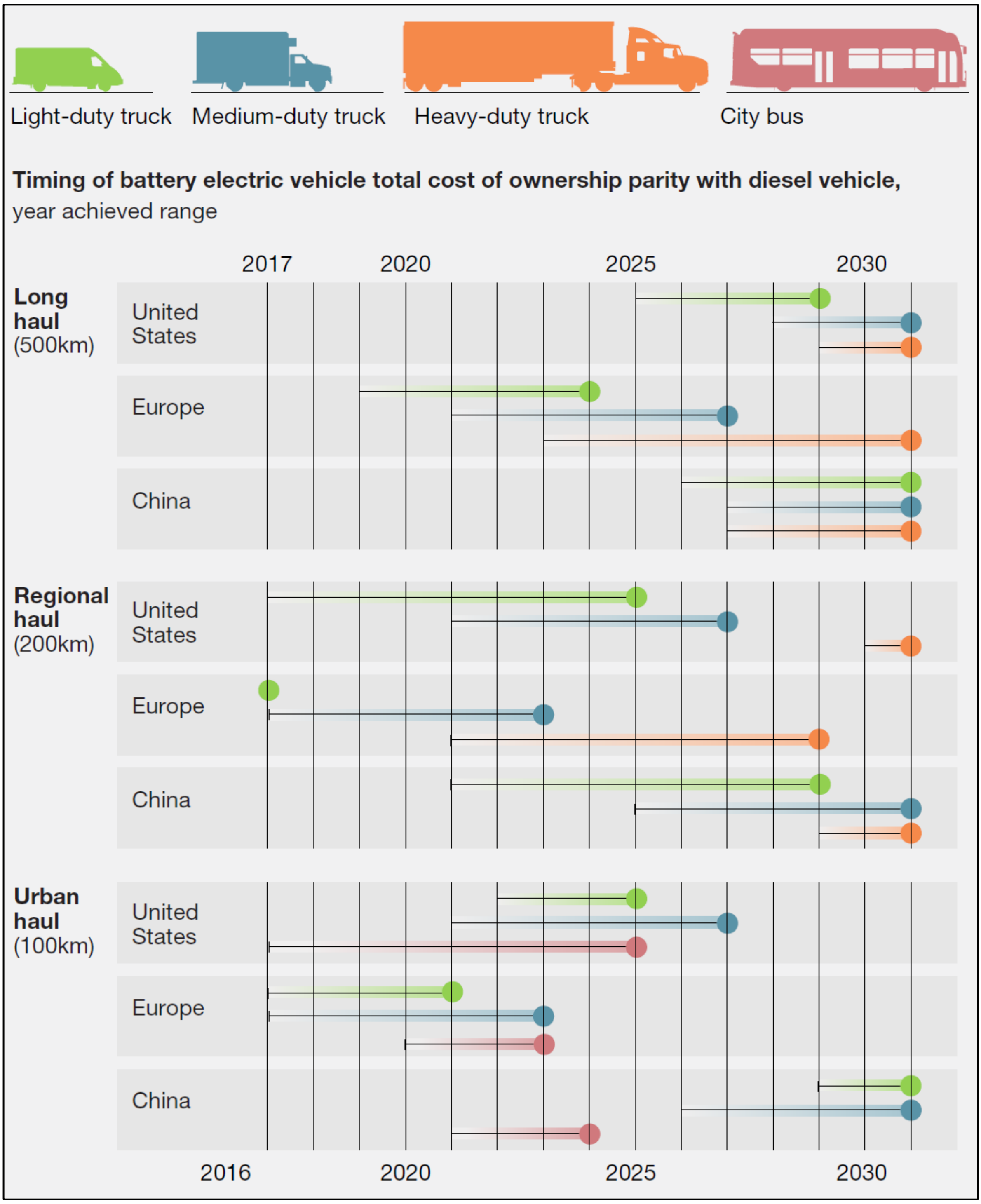


Figure 50: Timing of total cost of ownership parity of BETs and diesel trucks

Source: (McKinsey Center for Future Mobility, 2017)

Corporate trials of models like Tesla's Semi and Daimler's e-Cascadia are relying on chargers that have power ratings from around 100 kW to more than 1 MW (the latter consisting of four 350 kW charging plugs). As discussed in previous sections, CharIN and its members in the

HPCVC are currently working to develop even higher power Mega-charger for electric trucks and buses with a charging capacity in the 500 kW to 3 MW range (Electrive.com, 2019).

As battery electric vehicles become more popular, there are other environmental considerations that need to be planned for, including the repurposing and recycling of used batteries. In the first instance, repurposing of used vehicle batteries appears to be a promising opportunity, given the cells are expected to still hold around 70% of full capacity when deemed ‘end-of-life’ for transport purposes, and could therefore be used for other energy storage applications, such as home batteries. Reelectrify – an Australian-based company – has already developed a process for repurposing used electric vehicle batteries into ‘second life’ energy storage products (Reelectrify, n.d.).

Batteries used in electric trucks can also be recycled using sophisticated procedures to harvest useful reusable materials such as lithium, nickel, and cobalt (Institute for Energy Research, 2019). The materials obtained from recycling can then be used to make new batteries. In 2019, the US Department of Energy (DOE) announced the creation of the DOE’s first Li-ion battery recycling R&D centre (U.S. Department of Energy, 2019). Scientists in the UK have established the Reuse and Recycling of Lithium-Ion Batteries (ReLiB) project which is dedicated to improving the recycling of Li-ion batteries from electric vehicles (Harper, Sommerville, Kendrick, & al., 2019).

3.9.3 Charging infrastructure in NSW

The NSW government has pledged $171 million to construct top-tier electric vehicle charging infrastructure over the next four years, ensuring that residents have access to charging stations every 5km along major commuter corridors in Sydney, every 100km along major highways in the state, within 5km of residential areas with limited off-street parking, and in or near commuter car parks and other land owned by Transport for NSW (NSW Government, n.d.). While commendable for its impact, it should be recognised that this network will mostly consist of 50 kW chargers, which is insufficient for freight trucks travelling longer distances. Wherever possible, ultra-fast chargers of 350 kW or greater, should be installed to minimise charging times, and maximise convenience.

The NSW Government has not made any specific announcement regarding building charging network for freight trucks; however, under the NSW Electric Vehicle Strategy, the NSW Government plans to coinvest in the installation of 350 kW ultra-fast chargers at 100 km intervals along all major highways in the state, resulting in the creation of "EV Super Highways" across NSW, shown in **Figure 51** (NSW Government, 2021).

Significant public funds have been put to fast-charging networks for light vehicles, however, public charging infrastructure rolled out along NSW's highway network should also support road freight vehicles. Public charging infrastructure will be required at locations across metro regions, along NSW’s key freight routes and at service stations to support existing LZET operations. Charging infrastructure should be prioritised on planned key freight routes most frequently travelled by freight vehicles. DC fast chargers currently being installed in areas frequented or nearby truck routes or depots should include access considerations for trucks. This infrastructure is already being rolled out nationally by Evie Networks and Chargefox, with world-leading fast charger manufacturer, Tritium, building these units in Queensland (Cartwright, 2021).

Figure 51: Indicative map of NSW EV superhighways
Source: (NSW Government, 2021)

3.9.4 Renewable electricity

The Energy Transitions Commission (ETC) expect that to limit global warming to 1.5°C, over two-thirds of the global final energy mix will need to be met through direct electrification, and a further 15% will need to be met through indirect electrification e.g., hydrogen (Energy Transitions Commission, 2021). To achieve this outcome will require a massive increase in electricity generation by 3.5 to 5 times relative to today, primarily via renewable energy generation. That said, if the reliance on indirect electrification was to increase beyond 15%, given the high energy intensity of producing hydrogen, and hydrogen-derived fuels, this would require even greater investment in global low-carbon electricity generation. The ETC believe their scenario strikes the right balance, and is achievable by 2050, but only through a rapid ramp-up in investment in wind and solar, as well as energy storage to deliver system flexibility (shown in **Figure 52**). Renewable power is cheaper than fossil fuel in some parts of the world and, as investments in the various technologies' increase, prices will fall.

There are innovative developments taking place in offshore wind farms run by Shell and Eneco, by using surplus electricity on windy days to produce green hydrogen through electrolysis and to charge batteries at sea. The generated green hydrogen will be converted back into electricity when required. Supporting this are floating solar panels next to the turbines so that a continuous supply of electricity can be produced if there is insufficient wind, and peaks and troughs can be dampened (Shell looks to inflate case for generating wind offshore, 2020).

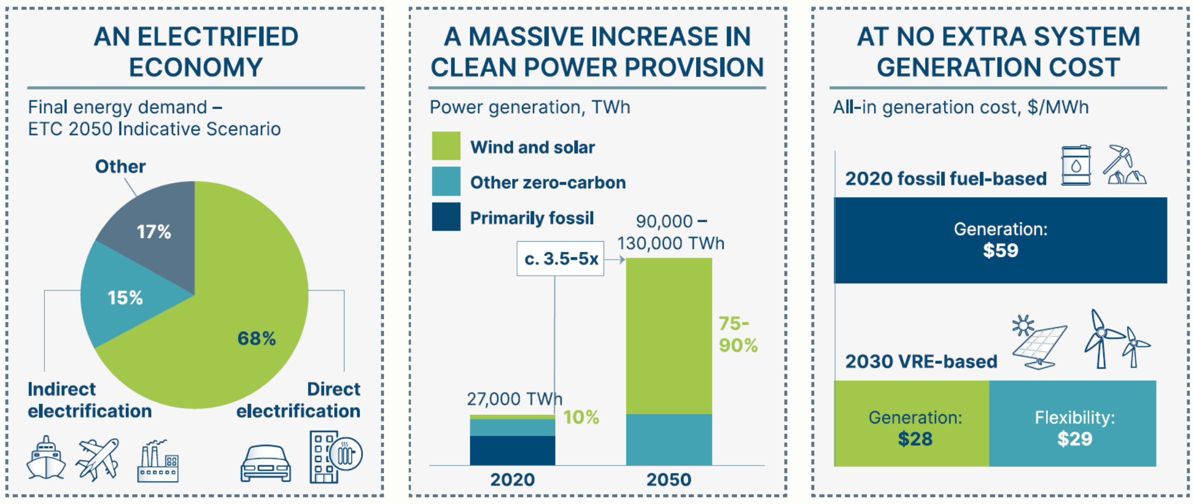


Figure 52: ETC's forecasts for clean electrification
Source: (Energy Transitions Commission, 2021)

ETC scenarios suggest that total electricity use will need to rise from 27,000 TWh to between 90-130,000 TWh by 2050, as shown in **Figure 52**. The transport sector is expected to account for around 23% of final electricity demand by 2050 (including hydrogen-derived fuels) requiring approximately 30,000 TWh per annum, with 13% used in road transport and a further 10% used in shipping, aviation, and rail. This translates to around a 100% increase in global electricity generation compared to 2020, before accounting for electricity applications in other sectors of the economy. **Figure 53** shows a breakdown of the role of electricity as a final energy carrier, and indirect input to hydrogen-based fuels, under ETC's ZES forecasts.

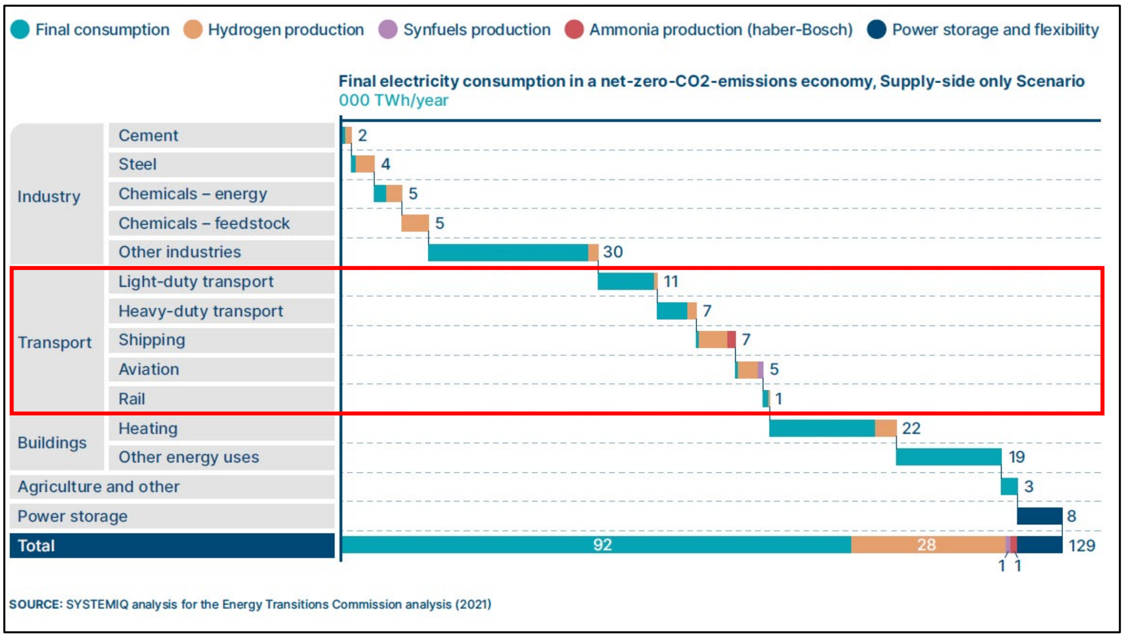


Figure 53: Forecasts for electricity as energy carrier and input to hydrogen fuels

While a 100% increase in electricity generation is significant, this is expected to be the most energy-efficient decarbonisation pathway, striking the right balance between the direct use of electricity, and indirect use via hydrogen, and hydrogen-derived fuels. The timing and shape of the demand arising from widespread direct and indirect electrification is another important issue to consider. If completely unmanaged, this could lead to significant challenges for the electricity grid. Conversely, the direct and indirect electrification of transport provides significant opportunities for providing energy storage and grid balancing, whether it be through smart charging or producing hydrogen during peak renewable energy periods, and even potentially exporting energy back to the grid from electric vehicles via vehicle-to-grid (V2G).

There are also several “smart solutions” being trialled, which include active network management systems that can manage peaks and troughs remotely by momentarily interrupting the electric flow to certain flexible devices, such as electric vehicles, at peak times (Element Energy Ltd, 2015). Another solution is local intelligent EV charging control which can allocate a fixed capacity to several EVs for a set period (Element Energy Ltd, 2015). Using time varying tariffs (dynamic pricing) can be used to manage demand and minimise greenhouse gas emissions – peak use of electricity is planned between a stipulated time of the day with underutilised capacity at other times (EASAC, 2019). Over the decades to 2050 there may be areas of high demand where there are large numbers of plug-in trucks with the need to reinforce the electricity grids in those areas (Advanced Propulsion Centre UK, 2018).

3.9.5 Renewable electricity in NSW

NSW has the natural resources necessary to become a renewable energy leader, and already boasts numerous large-scale renewable energy projects accelerating towards the state’s renewable energy target. The NSW energy sector is undergoing a change with an increasing reliance on renewable energy sources such as solar, hydro, wind, and biomass to generate electricity and reduce emissions. NSW has approximately 13,500 MW of renewable energy, which accounts for 53% of total generation capacity (NSW Government, n.d.).

The share of wind and solar energy in the electricity generation mix in NSW has more than tripled in the past five years, which includes (NSW Government, n.d.):

- Nearly 800,000 households and small businesses have installed small-scale solar, which accounts for more than one in four houses.
- There are 16 major wind farms with a total capacity of over 1800 MW and 24 major large-scale solar farms with a total capacity of over 1900 MW.
- There are almost 200 large-scale renewable energy projects in the planning system, representing an investment of almost $50 billion.

NSW Electricity Infrastructure Roadmap, developed by NSW Department of Planning Industry and Environment (DPIE), plans to modernise the energy system, and increase the use of renewable energy, reducing NSW electricity emissions by 90 million tonnes by 2030 (NSW Department of Planning Industry and Environment, 2020). The Electricity Infrastructure Roadmap also aims to create five Renewable Energy Zones (REZs) in the Central-West Orana, New England, Southwest, Hunter-Central Coast, and Illawarra regions of New South Wales, shown in **Figure 54**. These REZs function as modern versions of traditional power stations, comprising of a combination of renewable energy generation sources such as wind and solar, storage-capable batteries, and high-voltage transmission lines to supply energy to homes, businesses, and industries.

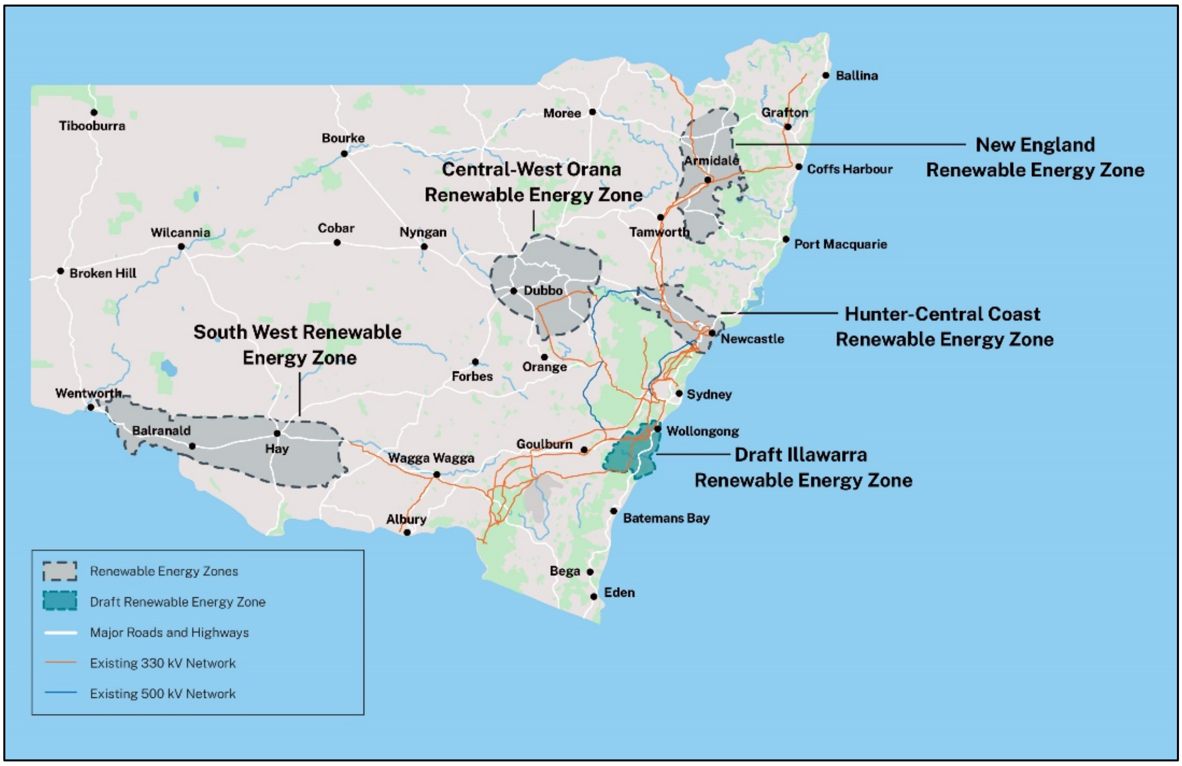


Figure 54: Locations of the REZs in NSW (NSW Government, n.d.)

NSW government is working to provide an affordable, secure, and reliable electricity supply as more renewable energy comes online. This includes investing in more dispatchable generation and energy storage such as pumped hydro energy and batteries to ensure supply is available when needed. The state also plans to manage demand by identifying non-critical uses to smooth peaks in energy demand. NSW has abundant renewable energy resources and a strong pipeline of investor interest in new renewable energy projects. The government is encouraging private-sector investment in renewable energy and dispatchable supply to secure an adequate supply well into the future.

3.9.6 Renewable hydrogen

As discussed in earlier sections of this report, hydrogen-powered vehicles are not as efficient as battery electric vehicles, but research is aiming to improve this efficiency. Despite this inefficiency, hydrogen is an important fuel to achieve carbon neutrality by 2050. For the road freight sector, based on current technology, the two advantages HFCTs have over BETs is that hydrogen vehicles are quicker to refuel and there is lower impact on vehicle payload, particularly for long-distance road haulage compared to battery vehicles. Also, hydrogen vehicles require a lower use of critical scarce materials and have a more cost-efficient end-of-life management approach (City Transport and Traffic Innovation, 2020). Instead of storing hydrogen in gaseous form, Daimler Truck AG is planning a new concept Mercedes-Benz GenH2 truck using liquid hydrogen (known as LH2) with its significantly higher energy density. This approach is claimed to provide higher storage density, greater range, faster refuelling, and superior energy efficiency (electrive.com, 2020). The disadvantage of LH2 is that hydrogen is only liquid at very low temperatures. The storage of cryogenic LH2 is already used in stationary applications at -253 degrees Celsius but is not currently being used in mobile applications on the road. Hyzon Motors also recently announced it will work with Chart Industries to produce a LH2 powered heavy duty truck with a claimed range of up to 1,600 km (Hyzon Motors, 2021). Brunel University backed by Shell and BP, with £1.4m of UK Research and Innovation (UKRI) funding, is also working on a project which aims to look at the development of hydrogen microbubble liquid fuels (Brunel University, 2020). Another project is looking at the use of metal hydride which can absorb and release hydrogen in a controlled way and would eliminate the compression chamber in which hydrogen currently needs to be stored (Ricardo, 2020).

To decarbonise road freight whilst operating HFCTs, the hydrogen used will primarily need to be produced in the form of green hydrogen, although some applications of blue hydrogen (including carbon capture and storage) could also exist. Green hydrogen is currently around 2-4 times more expensive than grey hydrogen to produce. However, a pathway to reaching parity with grey hydrogen will need to see significant cost reductions across all components of the hydrogen value chain for this energy carrier to become cost-competitive with existing fuels, like petrol and diesel. Significant investment in green hydrogen production will be required for the ETC's scenario to be achieved by 2050 (Energy Transitions Commission, 2021). The ETC expect that green hydrogen can become cost-competitive with grey hydrogen (conventional hydrogen produced from gas or coal) in the 2030s, and eventually be cheaper by 2050, as shown in **Figure 55** (Energy Transitions Commission, 2021).

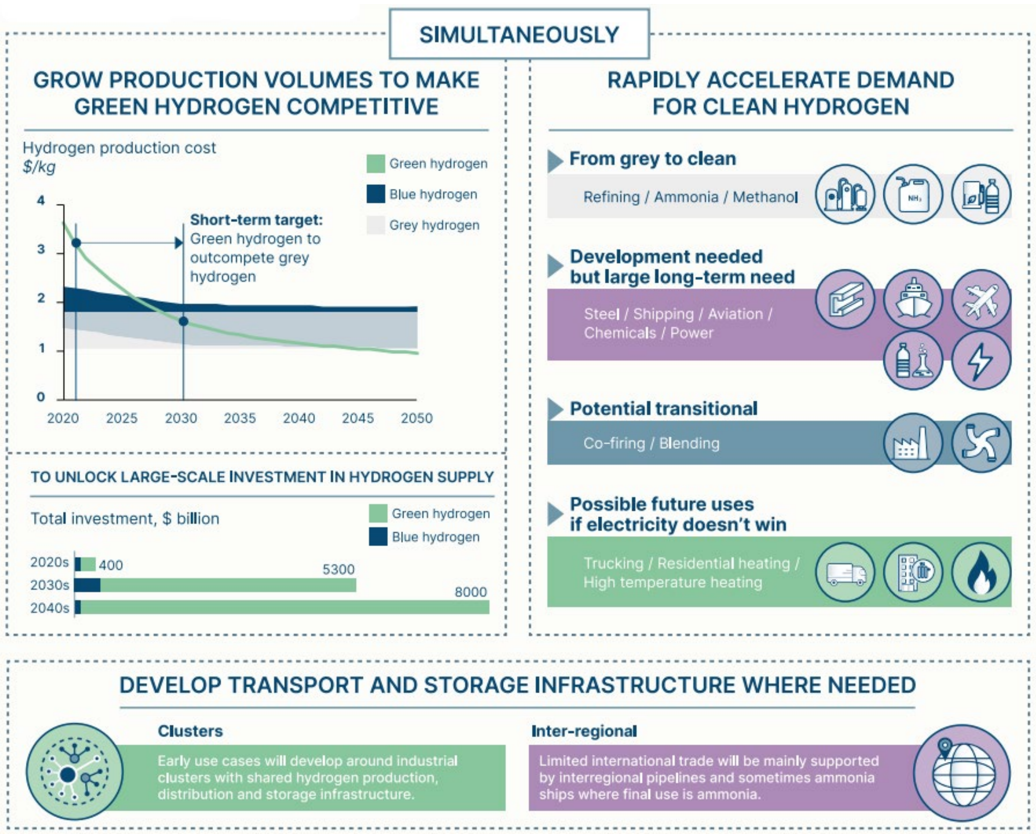
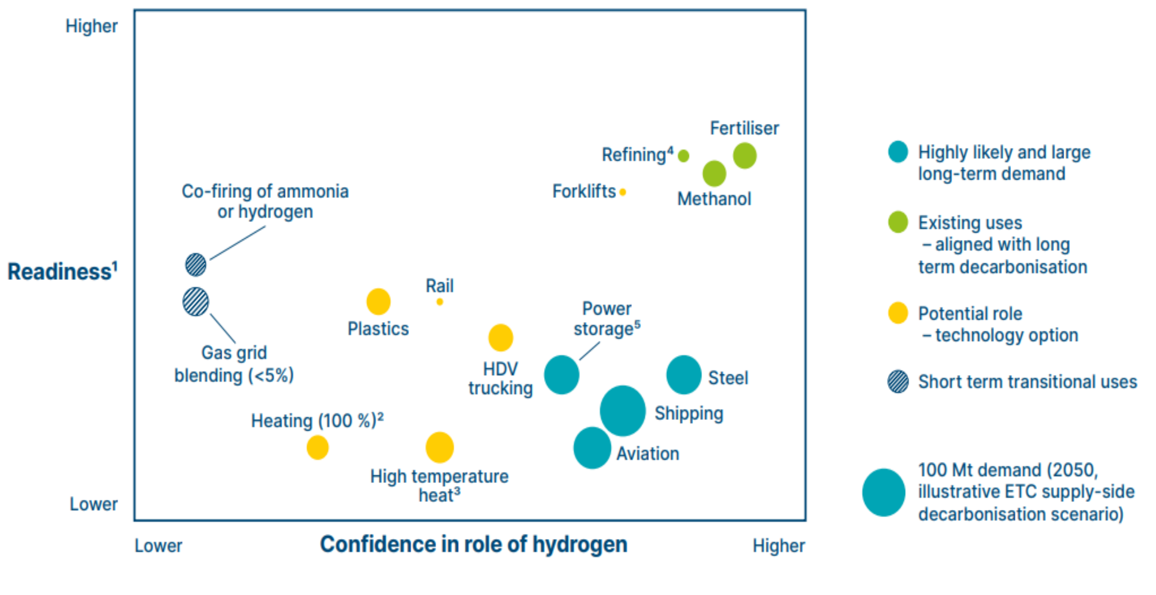


Figure 55: Accelerating the development of hydrogen
Source: (Energy Transitions Commission, 2021)

Hydrogen has an important role to play more broadly in decarbonising the global economy, particularly in terms of green steel, cement, and fertiliser production, both locally and globally. Moving forward it is clear that much greater effort is required to ensure hydrogen is used strategically across the economy to achieve the cost reductions necessary for reaching net zero emissions by 2050, as shown in **Figure 56** (Energy Transitions Commission, 2021).



NOTES: [1] Readiness refers to a combined metric of technical readiness for clean hydrogen use, economic competitiveness and ease of sector to use clean hydrogen. [2] 'Heating (100%)' refers to building heating with hydrogen boilers via hydrogen distribution grid, [3] 'High temperature heat' refers to industrial heat processes above ca. 800°C [4] Current hydrogen use in refining industry is higher due to greater oil consumption. [5] Long-term energy storage for the power system.

SOURCE: SYSTEMIQ analysis for the Energy Transitions Commission (2021)

Figure 56: Role of hydrogen in decarbonising the global economy

To date, hydrogen use in the transport sector has been limited to less than 0.01% of energy consumed, and in 2020 hydrogen-powered vehicles made up a very small share of the global stock of total vehicles (<0.01%) and of electric vehicles (0.3%) (IEA, 2021). However, the hydrogen-powered vehicle market is beginning to take off, catalysed by developments in Asia and the United States. Several OEMs and projects aim to manufacture and deploy thousands of HFCTs in the next decade. According to the IEA, based on current and announced capacity, fuel cell manufacturing could enable a stock of 6 million hydrogen-powered vehicles by 2030, satisfying around 40% of Net Zero Emissions by 2050 Scenario needs (IEA, 2021).

As for the use of hydrogen as an energy source in transport, hydrogen refueling stations represent the pillar for the development of hydrogen fuel cell vehicles. At the end of 2020, more than 540 hydrogen refuelling stations were in operation worldwide, an increase of more than 15% from 2019 (IEA, 2021). For hydrogen to contribute significantly to the clean energy transition, it is critical to develop low-carbon hydrogen production routes that can replace current production and at the same time expand production capacity to meet new demands. The two main low-carbon production routes use fossil fuels coupled with CCUS or water electrolysis. However, these technologies are in their early industrial stages and the clean hydrogen production costs are still extremely high. Political momentum for hydrogen use continues to gather strength and several countries have adopted national hydrogen strategies over the last two years, shown in **Figure 57** (IEA, 2021).

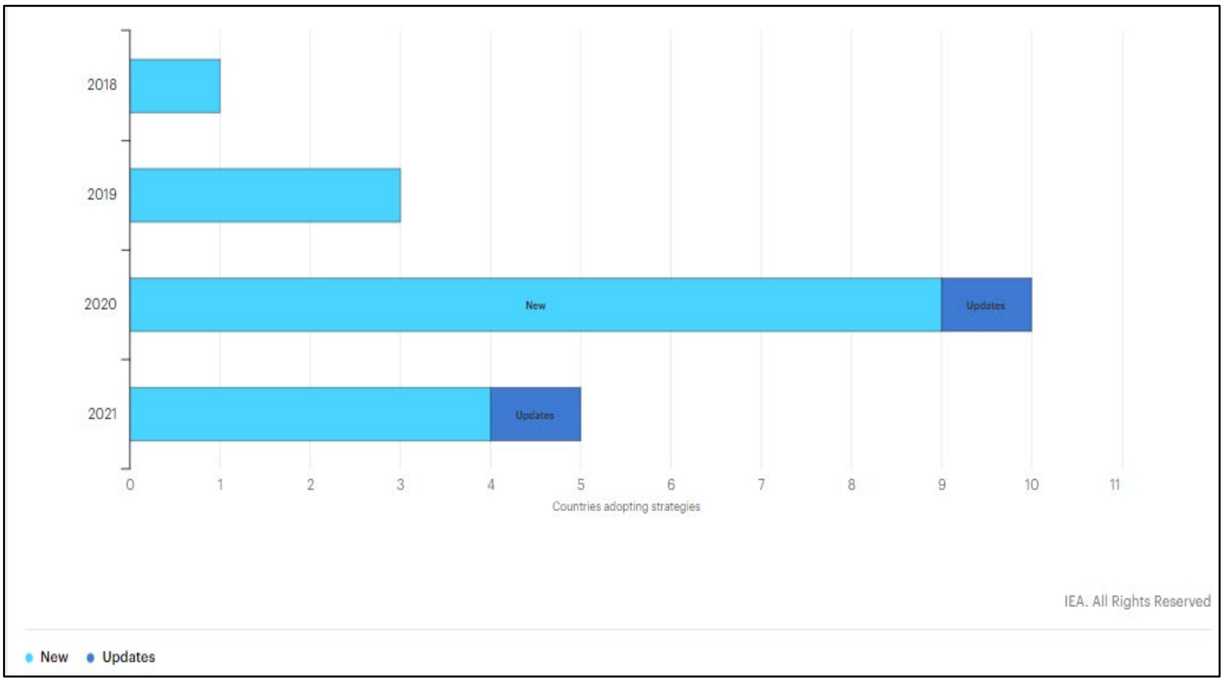


Figure 57: Annual announcements of government hydrogen strategies

Governments are also beginning to announce policies such as carbon contracts for difference, auctions, mandates, and hydrogen requirements in public procurement with the aim of stimulating demand and de-risking investment. A few selected examples of announced policies to stimulate hydrogen demand are listed in **Table 10** (IEA, 2021).

Table 10: Examples of announced global policies to stimulate hydrogen demand.

Government	Policy type	Description	Status
California	Mandate	A state government-issued executive order mandates that all vehicles sold in the state be zero-emissions by 2035.	In force
China	Financial rewards	The FCEV pilot programme rewards clusters of cities that deploy more than 1 000 FCEVs that meet certain technical standards, achieve a maximum delivered hydrogen price of CNY 35/kg (~USD 5/kg) and establish at least 15 operational HRSs.	In force
Germany	Auctions	The government's H2 Global programme will tender ten-year purchase agreements on hydrogen-based products, providing investor certainty on project bankability.	In force
Norway	Public procurement requirement	The government has announced that the country's largest ferry connection will be hydrogen-fuelled.	In force
Switzerland	Tax	The country adopted the LSVA road tax, which levies trucks weighing more than 3.5 tonnes but waives fees for ZEVs.	In force
European Union	Quota	As part of Fit for 55, the European Commission has proposed a Renewable Energy Directive modification to mandate 50% renewable hydrogen consumption in industry by 2030.	Proposed
European Union	Quota	In the ReFuel Aviation Initiative, the European Commission proposed a rising quota for synthetic aviation fuels (from a 0.7% share in 2030 to 28% in 2050).	Proposed
Germany	Carbon contracts for difference	The National Hydrogen Strategy announced a new Carbon Contracts for Difference (CCfD) pilot programme for the steel and chemical industries. It will pay the difference between a project's CO_2 abatement costs and the CO_2 price in the EU ETS. If the EU ETS price is higher than the project's CO_2 abatement costs, companies will have to repay the government the difference.	Proposed
India	Quota	The government announced that, from 2023/24, 10% of refinery hydrogen demand (increasing to 25% in the following five years) and 5% of hydrogen demand for fertiliser production (increasing to 20% in the following five years) should be met with renewable hydrogen.	Proposed
Portugal	Quota	The National Hydrogen Strategy targets blending 10-15 vol% of hydrogen in natural gas by 2030.	Proposed

Source: IEA Global Hydrogen Review 2021.

National hydrogen strategies and roadmaps with concrete targets for deploying low-carbon production, and particularly for stimulating demand, are critical to build stakeholder confidence in the potential for a low-carbon hydrogen market. The future mix of low and zero emission fuels and powertrains in long-haul transport will ultimately be determined by cost reductions and performance improvements, including in energy density, battery, and fuel cell durability, as well as the cost of delivering electricity and hydrogen to vehicles.

3.9.7 Renewable hydrogen in NSW

The NSW government has been working to develop the green hydrogen industry to reach its net-zero emissions target by 2050. They have announced plans to invest in renewable energy-powered hydrogen production, and research and development in the hydrogen sector. The NSW Hydrogen Strategy (NSW Government, 2021) outlines the government's vision and plan for building a successful green hydrogen industry in the state, shown in **Figure 58**. The strategy aims to:

- Decrease the cost of green hydrogen by $5.80 per kg within the next 10 years with production cost under $2.80 by 2030.
- Offer up to $3 billion in incentives to support industry growth.
- Achieve the 2030 targets of 110,000 tonnes of annual green hydrogen production and 700 MW of electrolyser capacity.
- A target of 20% hydrogen vehicles by 2030 in the NSW Government heavy vehicle fleet which will put approximately 1,800 hydrogen heavy vehicles on the road by 2030.
- Promote decarbonisation in the hard-to-abate transport, industrial, and energy sectors to reach net-zero emissions by 2050.

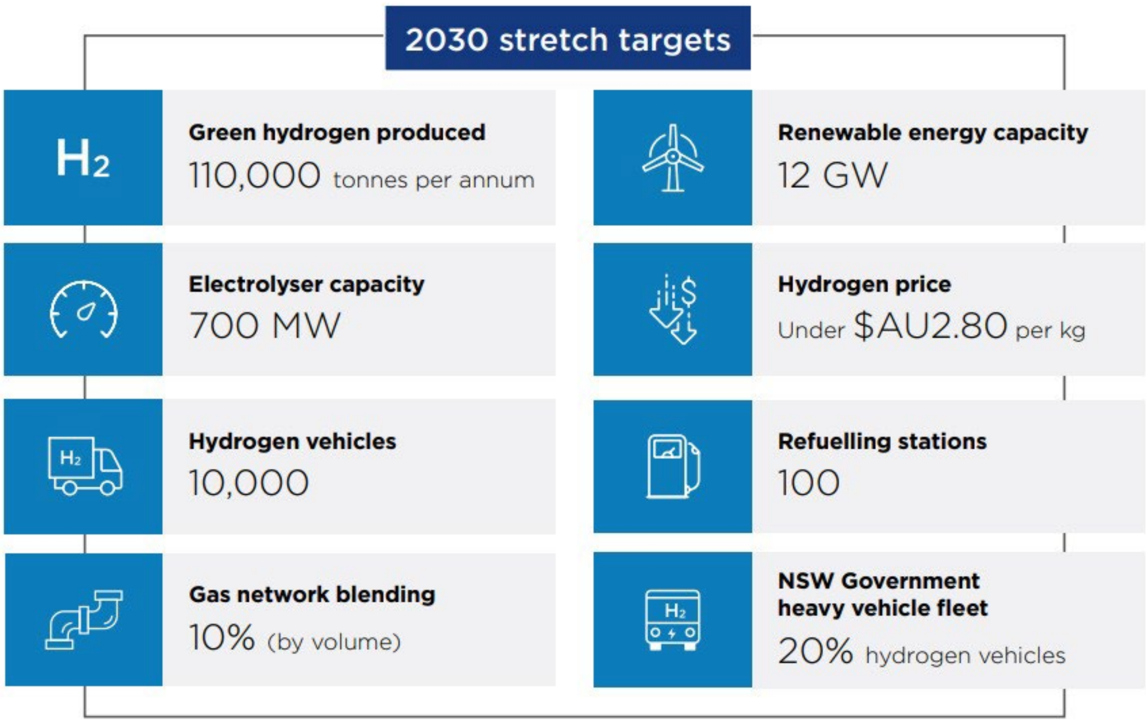
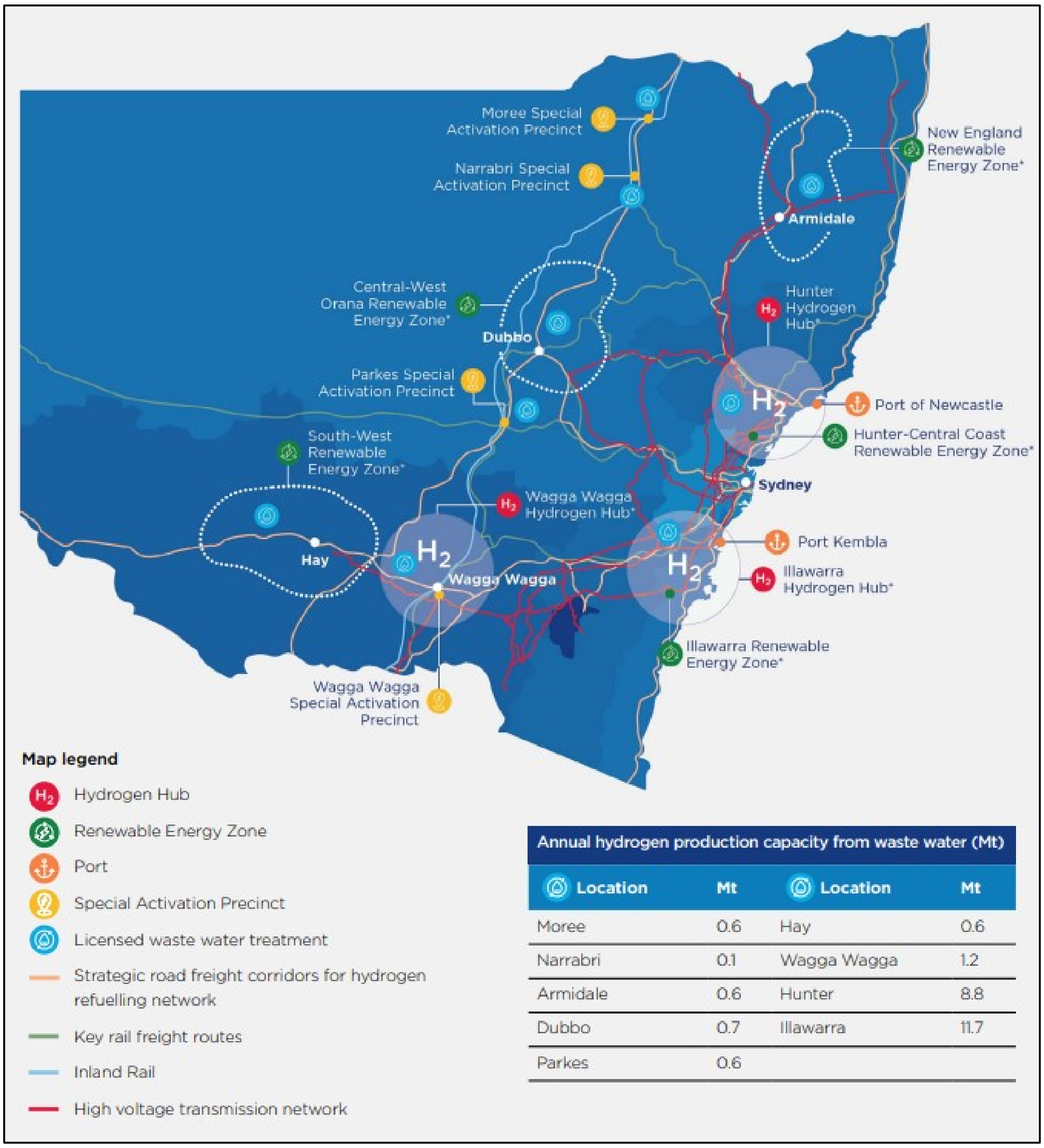


Figure 58: NSW Hydrogen Strategy – 2030 stretch targets

The NSW Government has also allocated $70 million towards the development of hydrogen hubs in the Hunter and Illawarra regions, which is rich in renewable energy resources, shown in **Figure 59** (NSW Government, 2021). They also have plans to provide funding and support to projects that demonstrate the use of hydrogen in the transportation and industrial sectors to help drive the adoption of hydrogen in these areas.

Queensland, NSW, and Victoria announced a landmark tri-state collaboration on 25th March 2022 to develop a renewable hydrogen refuelling network for heavy transport and logistics. Work will centre on the Newell Highway, that links Queensland and Victoria, the Pacific Highway between Queensland and NSW, and the Hume Highway between NSW and Victoria (Queensland Government, 2022), shown in **Figure 60.**

Overall, the NSW Government is actively working to develop the green hydrogen industry, recognising its potential as a clean and sustainable source of energy that can help to reduce GHG emissions and promote economic growth.



Annual hydrogen production capacity from waste water (Mt)

Location	Mt	Location	Mt
Moree	0.6	Hay	0.6
Narrabri	0.1	Wagga Wagga	1.2
Armidale	0.6	Hunter	8.8
Dubbo	0.7	Illawarra	11.7
Parkes	0.6		

Figure 59: Snapshot of planned and potential NSW green hydrogen hubs
Source: (NSW Government, 2021)

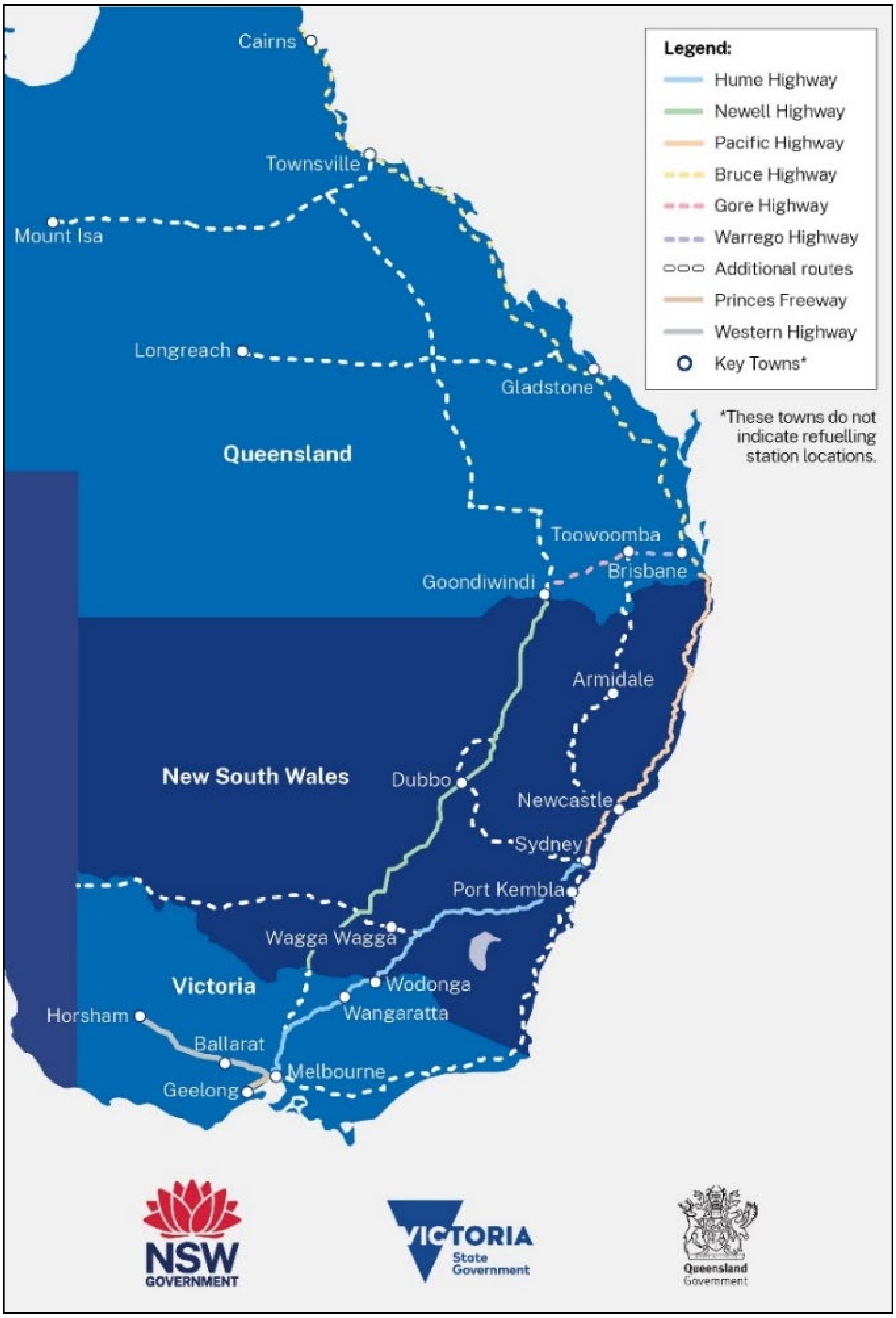


Figure 60: East coast hydrogen refuelling network

3.9.8 Advanced biofuels and synthetic fuels

As discussed previously, advanced biofuels have the potential to play an important but limited role as a drop-in fuel, for reducing emissions in remote areas where hydrogen refuelling or charging infrastructure installation is not feasible. Among all biofuels, renewable diesel or HVO is particularly appealing because it can be sourced from renewables and hold the potential to be used in existing transportation technologies with no additional infrastructure costs. The term ‘drop-in’ indicates that the fuel can be integrated into existing engine infrastructure without any modifications. Most OEMs support its use if it meets diesel fuel quality specifications (U.S. Energy Information Administration, 2020).

The appeal of biofuel subsidies in Europe and Low Carbon Fuel Standard credits in the USA, has led to development of several major commercial renewable diesel ventures (Bryan, 2021). Global demand for biofuels is set to grow by 41 billion litres, or 28% over the next five years. Government policies are the principal driver of the expansion, but other factors such as overall transport fuel demand, costs, and specific policy design influence growth and which fuels grow quickest. Policies in the United States and Europe have helped triple the demand for renewable diesel. The factors influencing biofuel demand are all subject to uncertainty. For example, some governments have responded to the current high price of feedstock by relaxing or delaying biofuel blending mandates, which reduced demand. Biofuel demand must nearly double from the existing case or expand by over 40% from the accelerated case to align with IEA’s NZE Scenario (**Figure 61)**. Liquid biofuels expansion in 2026 for the NZE Scenario is primarily to reduce emissions in road transport and to a lesser extent for planes and ships.

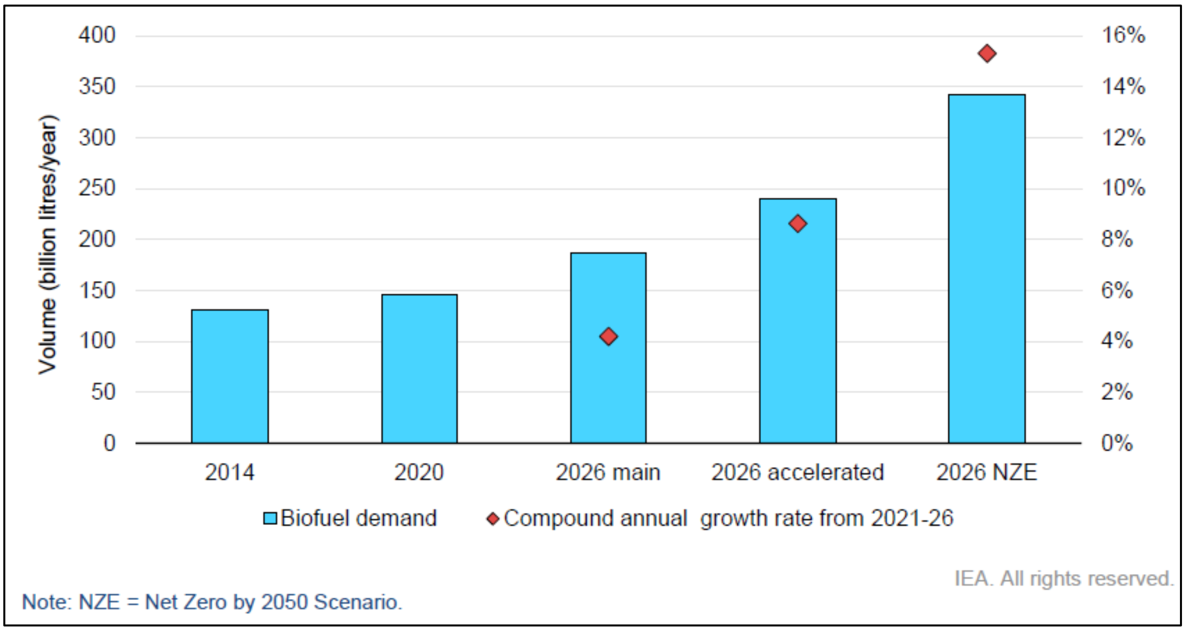


Figure 61: Biofuel demand for various scenarios 2014-2026

Based on several new project announcements, the United States Energy Information Administration (EIA) estimates that the production capacity for renewable diesel in the USA could increase significantly through 2024 (U.S. Energy Information Administration, 2021). In Europe, HVO production is expected to increase with new plants and projects planned in the next few years (**Figure 62)** (Wightman & Seamon, 2021). This growth is driven by higher state and federal targets for renewable fuel, favourable tax credits, and the conversion of existing petroleum refineries into renewable diesel refineries (U.S. Energy Information Administration, 2021).

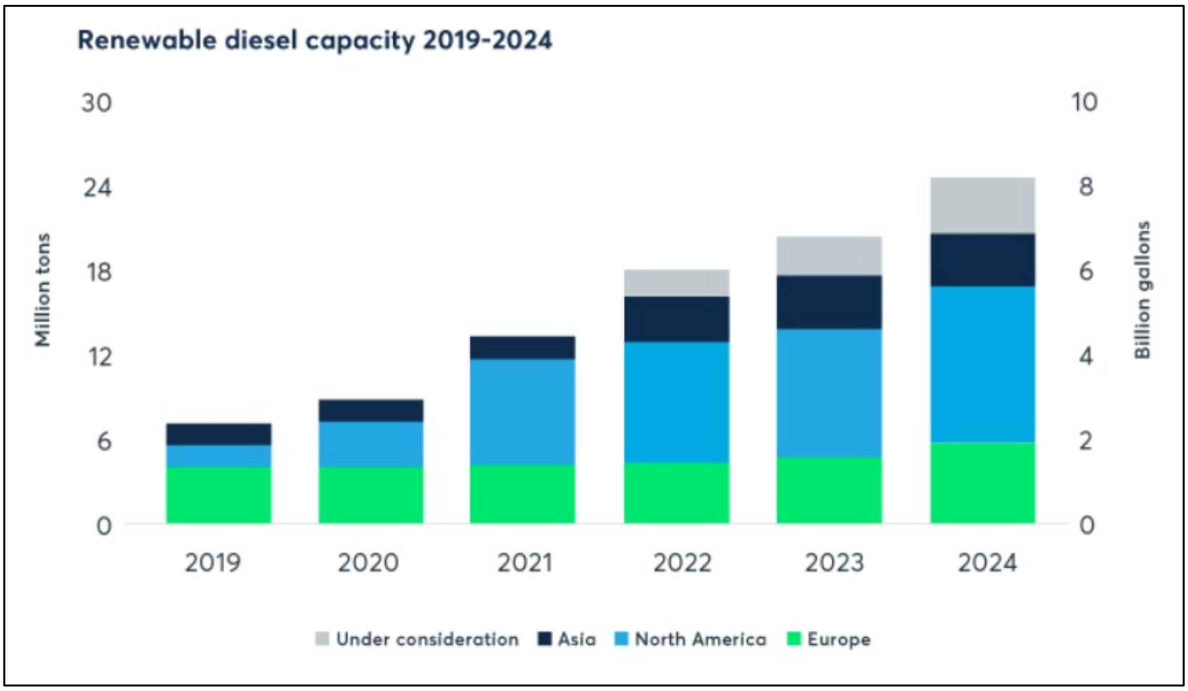


Figure 62: Renewable diesel production capacity (Asia, Europe, North America)

To align with the NZE Scenario, countries would need to implement existing and planned policies, and then strengthen them before 2026. These policies must also ensure that biofuels are produced sustainably and avoid the risk of negative impacts on biodiversity, freshwater systems, food prices and availability. In addition, policies must incentivise GHG reductions, not simply biofuel demand, so that every litre of biofuels used reduces emissions relative to fossil fuels as much as possible.

3.9.9 Biofuels in Australia

Australia's theoretical bioenergy resource potential is significant and is estimated to be over 2,600 PJ per year (ARENA, 2021), shown in **Figure 63**. This potential if made feasible, would represent more than 40% of Australia's current primary energy supply and more than 10 times its current bioenergy production. There is no direct subsidy support for producers or consumers to encourage greater use of biofuels in Australia; as a result, renewable diesel or HVO is not produced on a large scale in the country. Instead, renewable diesel feedstock, such as tallow and UCO, is exported overseas where it is used to make renewable diesel for global markets. However, developmental research and production of renewable diesel is currently growing in Australia and commercial production of renewable diesel within Australia is expected in the next few years, shown in **Table 11.**

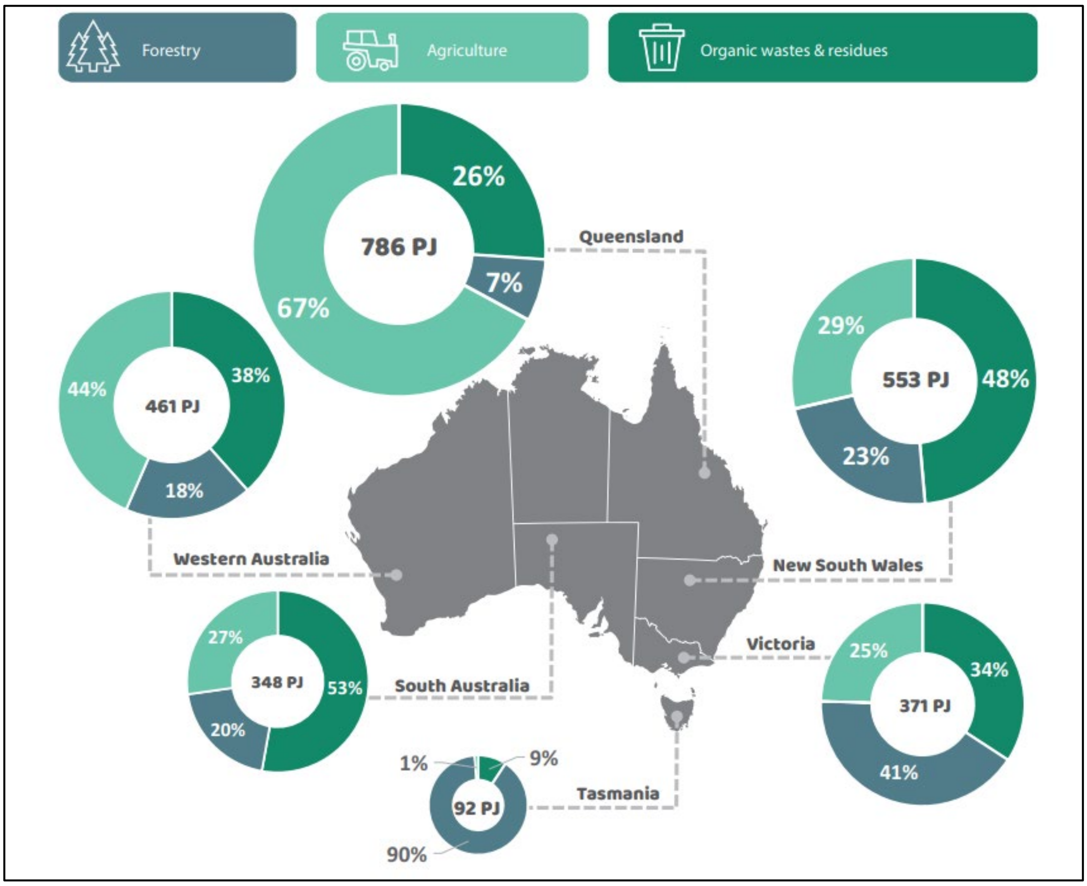


Figure 63: Breakdown of Australia's bioenergy resource potential (ARENA, 2021)

In addition to Northern Oil's Advanced Biofuel Pilot Plant, Gladstone has also been selected as the location for Oceania Biofuels' new $500 million renewable diesel and sustainable aviation fuel biorefinery (Queensland Government, 2022). Construction of the plant is due to commence in 2023 and will use locally sourced waste and sustainable feedstock such as tallow, canola, and UCO to produce more than 350 million litres of sustainable aviation fuel and renewable diesel per year. The plant is being designed to operate on a zero-waste production model using green electricity, renewable hydrogen, and carbon offsets. Renewable diesel accounts for 23% of aviation fuel in California, almost nearly half of which is imported, and according to Oceania Biofuels, their primary market will be the west coast of the United States where carbon reduction mandates are in place for airlines (Wuth, 2022).

FutureEnergy Australia, a joint venture between climate solutions firm Frontier Impact Group and ASX-listed Carnarvon Energy, has plans to establish a network of renewable fuel biorefineries estimated at an investment of $3 billion throughout Western Australia with a combined production capacity of approximately 500 million litres per annum by 2030. In addition, Frontier Impact Group is progressing similar plans on the east coast of Australia to build and operate a further 12 such biorefineries; their expected cumulative renewable diesel production volume is shown in **Figure 64** (Adhikari Smith, Whitehead, & Hickman, 2022).

Table 11: New renewable diesel ventures in Australia

Source: (Adhikari Smith, Whitehead, & Hickman, 2022)

Company	Location	Feedstock	Availability
FutureEnergy Australia (Carnarvon Energy Ltd. And Frontier Impact Group) (Carnarvon Petroleum Limited, 2021) (Adhikari Smith, Whitehead, & Hickman, 2022)	Narrogin, Western Australia	waste lignocellulosic biomass into renewable diesel, high-quality biochar, and wood vinegar. Aim to expand capacity through biomass from oil mallee plantations which will help in the regeneration of the wheatbelt	2023
FutureEnergy Australia (Carnarvon Petroleum Limited, 2021) (Adhikari Smith, Whitehead, & Hickman, 2022)	Western Australia, 16 biorefinery localities	waste lignocellulosic biomass and energy crops/plantations that will be processed into renewable diesel, high-quality biochar, and wood vinegar	2024-2030
Frontier Impact Group 'Renuleum' (Adhikari Smith, Whitehead, & Hickman, 2022)	12 biorefinery localities across Australia	sustainably sourced waste lignocellulosic and energy crops/plantations that will be processed into renewable diesel, high-quality biochar, and wood vinegar	2024-2030
AgBioEn (Arboleda, 2021) (Microsoft News Centre, 2021)	Victoria	agricultural waste into renewable fuels, such as renewable diesel, bio-jet fuel, LPG, and food grade liquified CO_2	Not announced
Southern Oil / Northern Oil (ARENA, 2018)	Queensland	waste plastic, old vehicle tyres, agricultural and forestry waste, and biosolids into renewable diesel fuel	Not publicly available
Sherdar Australia Bio Refinery Pty Ltd (Hydrocarbon Processing, 2021)	Not announced	wide range of animal fat, seed oil and waste greases as feedstock to produce high quality renewable fuels	Not announced
Oceania Biofuels (Queensland Government, 2022) (Wuth, 2022)	Queensland	locally sourced waste and sustainable feedstock such as tallow, canola, and UCO to produce more than 350 million litres of sustainable aviation fuel and renewable diesel per year	2025

Biofuel mandates: There are two state governments (NSW and Queensland) that have introduced biofuel mandates for the use of both ethanol and biodiesel, but these mandates are far from being reached (Biki, 2020). The NSW B5 mandate requires 5% of the total volume of diesel sold via major retail outlets to be biodiesel. However, a range of exemptions are provided to gasoline retailers and as a result the actual percentage of biodiesel supplied in fuels in NSW in 2019 was only 0.2%. The Queensland mandate also sets minimum requirements for the sale of biodiesel blend by retailers and wholesalers; it was set at 0.5%. The biodiesel usage in 2019 was estimated at 0.2%, which is well below target (Biki, 2020). A National low carbon fuel policy would provide a coordinated approach to biofuels.

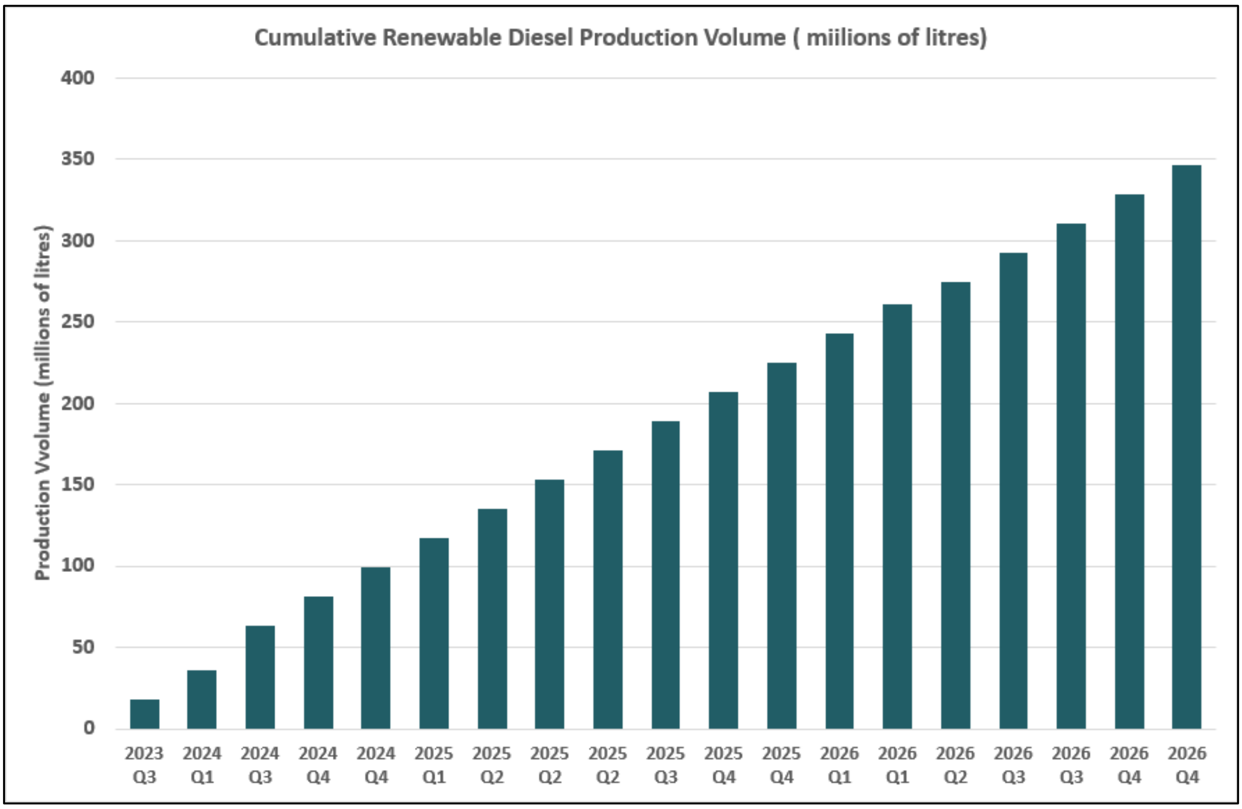


Figure 64: Projected cumulative renewable diesel production volume in Australia

Source: (Adhikari Smith, Whitehead, & Hickman, 2022)

Australia's current Federal biofuel commitments are included in Australia's Bioenergy Roadmap (ARENA, 2021) which commits to reviewing market developments periodically out to 2030 for biofuels in the context of transportation and demonstration projects for Sustainable Aviation Fuel (SAF). Whilst SAF uses similar technology as renewable diesel, there is no recognition or commitment to support a renewable diesel industry. Despite this, the renewable diesel industry is still developing in Australia. There is an opportunity for significant scale up of existing industry should the Federal Government adopt a low carbon fuel policy in line with other global examples such as national targets for renewable fuel, favourable tax credits, and conversion of existing petroleum refineries into renewable diesel refineries. Federal leadership on biofuels would enable both the investment in the industry and development of refineries, as well as make renewable diesel cost competitive or even cheaper, than mineral diesel.

Modelling Framework

4. Freight Emissions and Economic Modelling Framework

In this research, TfNSW transport models and the NSW DPE fleet and emissions models were used to evaluate the impacts of a range of interventions to decarbonise the road freight fleet in NSW. The interventions used were provided by TfNSW based on research and industry feedback based on a consultation program that was undertaken prior to this study. The policy interventions that were provided were assessed for suitability and public interest as well as extensive research in Australian and international jurisdictions as to the viability in the NSW road freight context.

The TfNSW transport models were used to generate VKT for each scenario/intervention. Changes to the fleet and VKT were used by the DPE fleet and emissions models to estimate the emissions reductions and other impacts for each scenario/intervention. This study adopted the methodology described in the *NSW Greenhouse gas emissions projections 2022* (NGT News, 2018)*,* which has been previously used successfully to demonstrate the suitability of these models to estimate the transport emissions reductions of different intervention scenarios.

The NSW transport, fleet and emissions models were used to support the following research tasks in this study:

Model baseline emissions and quantify impacts. This includes the generation of baseline road and rail freight activity projections (Vehicle-Kilometres-Travelled VKT and Gross Tonne Kilometres GTK) and associated emissions projections for agreed base year and on an annual basis out to 2061. The baseline emissions represented the “do nothing” or “current government policy settings” scenarios. DPE ran the model scenarios and provide the research team with the baseline emissions which was used to assess the associated air pollution-related health impacts through the application of a damage-function approach. This task produced a quantitative assessment of levels of baseline VKT, GTK and emissions out to 2061 and associated impacts on air pollution and health impacts (without policy interventions).

Model future freight and rail activity and associated emissions in the presence of policy interventions and quantify impacts. In this research task, the models were used to conduct scenario modelling for each of the identified interventions (or combination of interventions) to project future road freight (and rail freight) activity, LZEV uptake rates and associated freight (and rail) emissions on an annual basis out to 2061. These emissions represented conditions that can be achieved because of implementing each intervention (or suite of interventions). DPE undertook road fleet and road and rail freight emissions modelling based on the activity and vehicle technology uptake projections and provided the research team with emissions for each intervention/horizon year. DPE also applied damage-costs to estimate air quality-related health benefits to be used in the economic evaluation task. This task produced emissions quantity and type with suitable spatial resolution for the economic evaluations, for each scenario.

Economic assessment of the impacts of interventions. In this research task the models provided information on changes in GHG emissions and air quality used to quantify monetary gains/losses associated with interventions defined in Task 3. Changes to VKT similarly provide insights on variable cost considerations in the economic assessment.

4.1 NSW GHG emissions modelling methodology

This section presents a summary of the NSW transport, fleet and emissions models and their relevant components.

Road transport emissions modelling is undertaken annually by DPE as part of the state-and-economy wide greenhouse gas emission projections. DPE's latest 2022 projections considered market trends in vehicle technology uptake rates, and emission reductions forecast for actions under the Net Zero Plan including the NSW EV Strategy, TfNSW's Zero Emission Bus Transition Strategy, the proposed Transport Consumer Information (Vehicle Star Rating) initiative and the NSW Hydrogen Strategy. The 2022 update also addressed the ongoing impact of COVID through the integration of post-COVID transport modelling outputs, market trends, and the impact of other recent NSW Government actions affecting road transport. The latest DPE GHG emissions model was used in this research, informed by outputs generated from the latest TfNSW transport models.

4.1.1 Transport modelling

The NSW transport models (which inform DPE's GHG emissions projections) includes a number of strategic travel models that are used in NSW as in **Figure 65** (consistent with the methodology described in (NGT News, 2018):

- The Freight Movement Model (FMM) generates freight movement demands (including rigid trucks and articulated trucks) and feeds these demands into the Strategic Transport Model (STM)
- The Strategic Transport Model (STM), is used to project travel patterns in the Sydney Greater Metropolitan Area (GMA), is then used to generate VKT outputs (including trucks) and feeds these into the DPE emissions model. Although the FMM has its own route choice models, integrated model (STM) outputs are used for the purpose of the DPE emissions modelling.
- The Regional Freight Model (RFM), which covers the areas in NSW outside of the GMA, is used to determine freight VKT outside the GMA.

These transport models were used to generate VKT outputs for the GMA and for the rest of NSW, shown in **Figure 65**. The VKT outputs include:

- Annual VKT by speed band in the GMA by vehicle type (articulated and rigid trucks).
- Annual VKT (no speed breakdown) for the rest of NSW for articulated and rigid trucks.

Scenarios and years for which VKT data are available in the transport models include base case year 2019, 2026, 2031, 2041 and 2061. VKT for rigid and articulated trucks in the GMA are STM outputs, with AM peak numbers translated to daily and then annual values obtained using a set of predetermined factors.

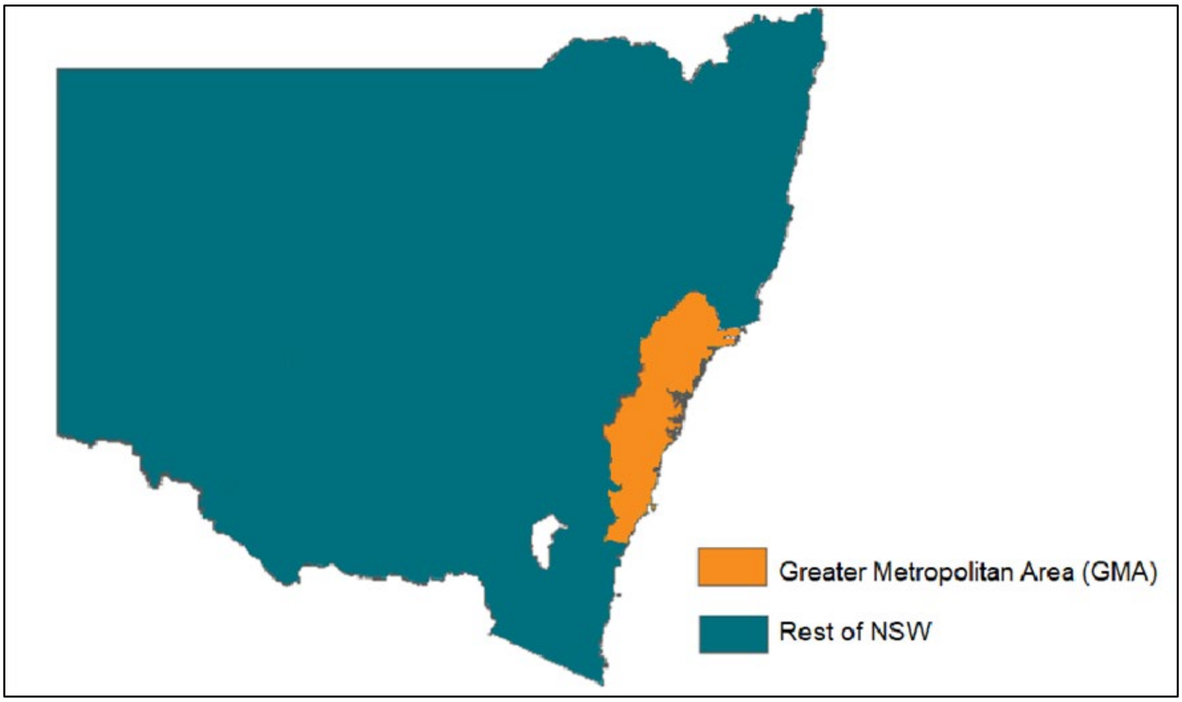


Figure 65: Geographical extent of the GMA and the rest of NSW

4.1.2 DPE fleet and emissions modelling

An overview of the fleet and emissions models is presented in **Figure 66** and consists of two primary components:

- A Fleet Model projects the future fleet profile and vehicle kilometres travelled by estimating fleet growth, vehicle sales and vehicle attrition from a base year of NSW registration data.
- An emissions model estimates the fleet aggregate emission factors (grams of emission per kilometre – g/km) allowing total emissions to be calculated by multiplying the vehicle kilometre travelled (VKT) by vehicle type and fuel type by the emission factor.

The current DPE fleet and emissions models are based on the NSW EPA Air Emissions Inventory for 2008 (NSW EPA, 2012). The models were updated by DPE to include the latest emission factors and vehicle sales trends available as of June 2021 and extended for NSW-wide application.

4.1.3 DPE fleet model

The DPE fleet model incorporates five rigid and three articulated truck size categories based on the Gross Vehicle Mass (GVM) and Gross Combination Mass (GCM), respectively:

- Rigid-small (3.5t < GVM <=5.5t)
- Rigid – small-medium (5.5t < GVM <=7.5t)
- Rigid – medium (7.5t < GVM <=12.5t)
- Rigid – medium -large (12.5t < GVM <=20.5t)
- Rigid – large (GVM > 20.5 t)
- Articulated – small (GCM <= 31.5 t)
- Articulated – medium (31.5 < GCM <= 42.5 t)
- Articulated – large (GCM > 42.5t)

The DPE's rigid and articulated fleet growth estimations are based on historical growth in fleet numbers from the TfNSW registration database, supplemented by the ABS Motor Vehicle Census. Historical trends of the total fleet, disaggregated by fleet model size category, are established using the detailed analysis by the National Transport Commission, which included 30 heavy vehicle configurations (GVM/GCM) and truck-trailer combination types by axle configuration. The fleet is projected from the base year of 2012 by applying the actual growth from the registration records, resulting in model fleet numbers that match available registration data. New truck sales are estimated by the difference between the growth of the fleet minus the annual attrition, taking into consideration interstate transfer of vehicles and other unidentified factors contributing to erratic year-on-year trends in vehicle numbers by year of manufacture (YOM).

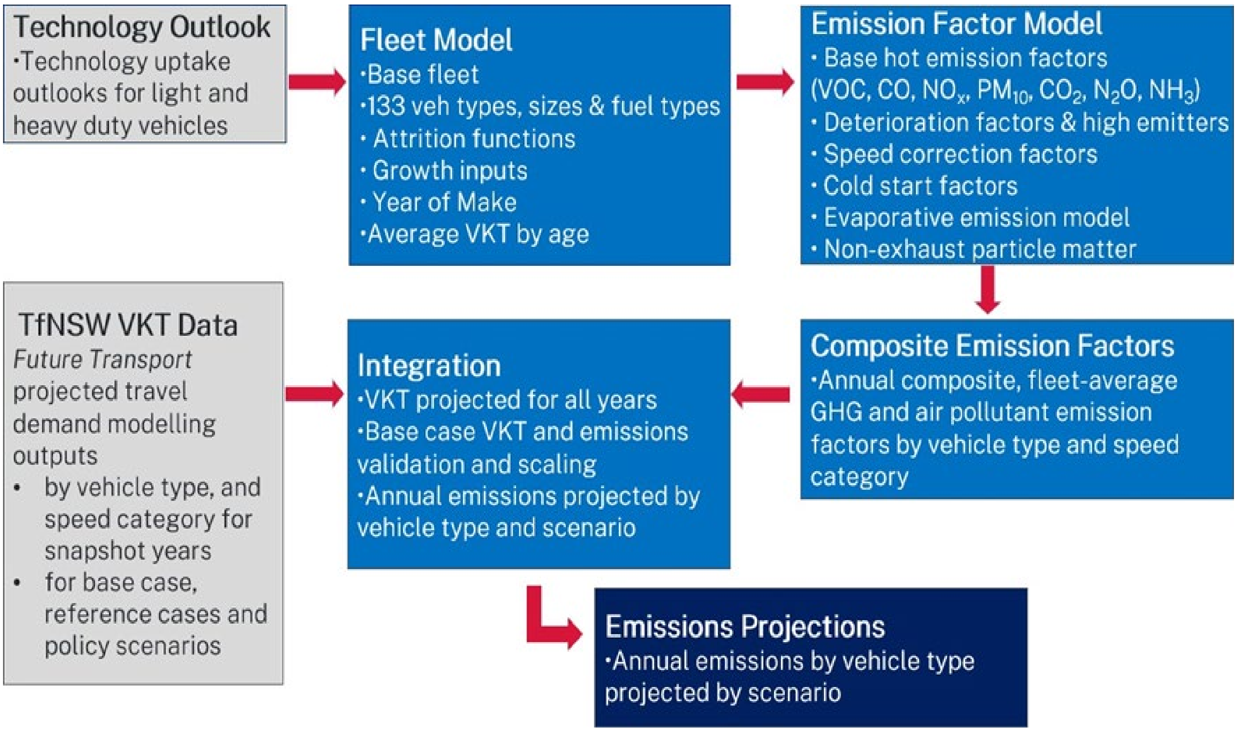


Figure 66: The DPE fleet and emission modelling methodology

Fleet growth estimations

Fleet attrition

Fleet attrition is modelled by analysing the year-on-year changes in the numbers of vehicles within each YOM cohort. Year-on-year survival rates of greater than 100%, where YOM cohort fleet number increases are observed in the raw data, were also attributed to the quality of data in the registration data base, inter-state registration transfers and changes in the nature of the freight task. Recent DPE analysis found that there was better agreement when omitting the year-on-year survival rates greater than 100% than retaining them.

Fleet annual vehicle kilometres travelled.

The DPE fleet model estimates the annual vehicle kilometres (VKT) travelled as a function of vehicle age, which is a process undertaken to distribute the total VKT predicted by transport models to YOM or age, and hence to the applicable vehicle emission standards (Australian Design Rule- ADR). However, when combined with the fleet number projections, the annual total fleet VKT is estimated independent of transport models.

The fleet average annual VKT is dependent on the fleet age profile, where new technologies which have a relatively young fleet will have a much higher annual average VKT than traditional technologies which have an established “natural” age profile.

The current fleet model only has one VKT as function of age curve applied for all sizes and fuel types for each vehicle type - it does not disaggregate vehicle types by size or fuel type/motive power.

4.1.4 DPE transport emissions model

The DPE transport emissions model generates fleet aggregate emission factors for CO_2, nitrous oxide (N_2O) and methane (CH_4) as greenhouse gases, and fine particulate matter ($PM_{2.5}$) and oxides of nitrogen (NO_x) to assess health impacts.

4.2 Heavy duty vehicle emission factors

DPE updated the NSW EPA Air Emissions Inventory motor vehicle emission model for NSW-wide application to generate fleet aggregate emission factors for CO_2, nitrous oxide (N_2O) and methane (CH4) as greenhouse gases, fine particulate matter ($PM_{2.5}$), oxides of nitrogen (NO_x) and other regulated exhaust pollutants, and fuel consumption for the BAU/CP and High/NZ scenarios.

The emission factors are derived from several sources and assumptions:

- The Australian Diesel National Environment Protection Measure (DNEPM) study which tested pre-ADR70 and ADR70 rigid and articulated trucks.
- The South Australian Test and Repair program which tested pre-ADR70, ADR70 (~Euro I- II) and ADR80/00 (Euro II) trucks.
- ADR80/02 (Euro IV) to ADR 80/04 (Euro VI) emissions and fuel consumption are estimated by reference to the European EMEP Guidebook which is the basis of the COPERT model and consideration of the historical Australian data.
- Euro VI is assumed to be adopted from 2027.

Zero-emission vehicle technology uptake rates

Used as a reference point, the DPE uptake rates of zero or low emission heavy vehicles as percentage of new vehicle sales, are estimated by consideration of projections from a range of sources including CSIRO for the 2022 AEMO Integrated System Plan[2] [3], Bloomberg New Energy Futures (BNEF) 2021 Electric Vehicle Outlook[4] and KPMG modelling for the NSW Hydrogen Strategy. Near term NSW/Australian trends are also informed by current announced policy and OEM announcements regarding supply of low/zero emission trucks to Australia. These uptake rates determine the baseline against which later analysis is evaluated.

DPE models uptake scenarios for a base case (business as usual) scenario and a current policy scenario (i.e., account for the EV strategy and Hydrogen strategy). Projections for a high tech or “net zero policy” were also made, however these are not considered in the current policy scenario. The outcomes of this study will help inform updates to the current policy scenario for DPE’s next update to their emission projections.

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[2] AEMO ISP 2021 Inputs Assumptions and Scenarios Report and Workbook, June 2021.

[3] Graham P and Havas, Electric Vehicle projections 2021, CSIRO, May 2021; Reed et al., multi-sector energy modelling, Climate Works Australia, July 2021

[4] https://about.bnef.com/electric-vehicle-outlook/

Uptake is allocated between the fleet model truck sizes considering the duty cycles (loads, trip distances and annual VKT) in relation to technology capability, as well as economic considerations which indicate BEVs will have significantly lower TCO compared to HFCVs for 10 to 15 years. It is assumed on this basis that HFCV will thus only be used in the near and medium term where BEV are not suitable in terms of range and charging times for the heavier long-haul operations.

Where published technology uptakes are projected as percentage of the total fleet stock, sales shares were estimated iteratively to match the fleet percentages. It was found that some of the published technology uptakes did not appear to be based on detailed fleet modelling including age-based attrition and the sales shares required to achieve the stock projections were not feasible or realistic in their trend.

For both rigid and articulated trucks, the small uptake rates of PHEV were adopted from the CSIRO modelling. The HFCV uptake were modelled next, and the BEV uptake was modelled last and capped to balance the total fleet technology sales shares to 100% (i.e., ICE trucks phased out).

4.2.1 Air pollution health costs

Reducing or removing tailpipe emissions from vehicles can generate significant health benefits for NSW, particularly for people living with respiratory health conditions like asthma or with a predisposition to cardiovascular conditions. About 70 premature deaths each year are associated with long term exposure to vehicle pollution in the NSW Greater Metropolitan Region with vehicle exhaust emissions contributing 69% of the fine particle exposures associated with these deaths (Broome R. , Powell , Cope , & Morgan, 2020).

4.2.2 Method for estimating health burden and benefits.

In the DPE models, health costs are calculated for exhaust emissions of oxides of nitrogen (NO_x) and fine particulate matter ($PM_{2.5}$) from petrol and diesel fuelled vehicles. $PM_{2.5}$ health costs are also calculated for non-exhaust emissions arising from tyre, brake, and road wear for both fossil fuel and battery electric vehicles.

Health costs are estimated using damage costs expressed as dollar per tonne of pollutant. $PM_{2.5}$ damage costs are estimated using the methodology proposed by PAEHolmes (PAEHolmes , 2013) which transfers health costs derived in the United Kingdom from full impact pathway health modelling, adjusted for Australian population densities, value of a life year, currency, and inflation.

The $PM_{2.5}$ damage costs used to estimate health costs for the transport fleet are adopted from the Marsden Jacobs Associates (MJA) draft Regulation Impact Statement (RIS) for the review of the NSW Protection of the Environment (Clean Air) Regulation 2010. MJA applied the PAEHolmes methodology to adjust the 2011 damage costs to 2017 dollars, and projected changes in population density by significant urban area (SUA). From the individual SUA damage costs, the MJA derived weighted damage costs for the NSW GMR and non-GMR areas of NSW.

The $PM_{2.5}$ damage costs weighted the MJA GMR and non-GMR damage costs to the whole of NSW and adjusted to 2019 Australian dollars. The damage costs are provided in **Table 12**.

Table 12: $PM_{2.5}$ and NO_x damage costs (2019 AUD per tonne emissions)

Year	$PM_{2.5}$	NO_x	Year	$PM_{2.5}$	NO_x
2021	$304,752	$6,457	**2035**	$368,121	$8,233
2022	$309,234	$6,556	**2036**	$372,742	$8,385
2023	$313,710	$6,659	**2037**	$377,423	$8,540
2024	$318,180	$6,765	**2038**	$382,163	$8,697
2025	$322,644	$6,876	**2039**	$386,963	$8,856
2026	$327,103	$6,992	**2040**	$391,825	$9,018
2027	$331,611	$7,113	**2041**	$396,749	$9,184
2028	$336,112	$7,239	**2042**	$401,736	$9,352
2029	$340,609	$7,370	**2043**	$406,787	$9,523
2030	$345,100	$7,508	**2044**	$411,902	$9,697
2031	$349,586	$7,648	**2045**	$417,082	$9,874
2032	$354,227	$7,791	**2046**	$422,328	$10,055
2033	$358,864	$7,936	**2047**	$427,641	$10,238
2034	$363,495	$8,083	**2048**	$433,022	$10,425

Source: Adopted from MJA

The NO_x damage costs estimates were developed by MJA for the Sydney GMR region drawing on a study that applied an impact pathway approach to estimating the health impacts and associated costs of NO_x and other emissions from transport in Sydney (DoEE, 2018). Recent international health impact studies were reviewed in the development of the NSW specific health costs.

The emissions, air modelling and health risk modelling are based on the national review of the Fuel Quality Standards Act 2000. Emissions were modelled using COPERT Australia. The potential for double counting of NO_x and PM impacts was considered, and a 20% reduction was applied to the NO_x health impacts to avoid double counting. The development of the NO_x damage costs is documented in an unpublished report to the NSW EPA.

4.2.3 Method for estimating GHG emissions costs.

The DPE emissions models form the basis for estimating the reduction in VKT and shift to LZEV for freight. The latter is operationalised through changes to growth and attrition and reflected in fleet composition. Changes in GHG emissions is established through changes in VKT and fleet composition.

The NSW Government Guide to Cost-Benefit Analysis (TPP17-03) advise that valuing the cost of carbon emissions should be based on market prices, assuming the price is unaffected by any interventions under consideration. There is, however, no market for carbon in operation in NSW. The NSW Interim Framework for Valuing Green Infrastructure and Public Places therefore recommends the use of the carbon price forecasted by the European Union Emission Allowance Units price based on futures derivatives published by the European Energy Exchange (NSW Department of Planning and Environment, 2022).

The DPE Emissions model provides multiple GHG emissions outputs and conversions to the CO_2-e metric. These conversions have been used in this study for the purpose of calculating both GHG emissions and the social cost/benefits associated with policy interventions based on the prevailing ETS CO_2 auction price. **Table 13** shows the prevailing ETU auction price. The carbon price in the table applies to both CO_2 and CO_2-e estimates.

Table 13: Market price of GHG from EU futures market (nominal price)

Year	€/tCO2	A$/tCO2
Dec-23	84.3	128.1
Dec-24	88.1	133.9
Dec-25	92.6	140.7
Dec-26	97.4	148.1
Dec-27	102.6	155.9
Dec-28	107.7	163.7
Dec-29	112.9	171.6
Dec-30	118.0	179.4
Dec-31	123.2	187.2

Source: https://www.eex.com/en/market-data/environmentals/futures

Note: 1€=1.52A$

Note: Following the agreement of GHG emissions costs, NSW Treasury

4.3 Modelling of baseline emissions scenarios

This section of the report presents the modelling of baseline emissions using the NSW DPE emissions model. The modelling results were extracted from a workbook provided by DPE that included annual emissions outputs and health impacts (up to 2061) based on several modelling scenarios. The data provided in the workbook were based on an established methodology described in the NSW Road Transport Emissions Modelling – State-aggregate Modelling Method [(NSW DPE, 2022a)]. The emissions models were used to support several key research tasks in this study which included modelling of baseline emissions (described in this section) representing two scenario settings. The same models were then used to model heavy vehicle emissions in the presence of key policy interventions.

4.3.1 Baseline modelling scenarios

The NSW DPE emissions baseline models analysed in this report include two uptake scenarios that were developed for heavy duty vehicles. These include:

- A current policy scenario based on zero-emission truck uptake rates for the AEMO 'Steady Progress' scenario with reference also made to the Bloomberg New Energy Futures (BNEF) economic transition scenario (ETS) which estimates uptake based on total cost of ownership and technology development projections under current policies.
- a high technology/net zero policy scenario based on BNEF's Net Zero scenario which estimates zero-emission truck uptake rates to achieve a 'net zero fleet by 2050' with the transition based on consideration of technology development and total cost of ownership projections and assumes that necessary policy support is provided.

These are represented in the DPE emissions model using the **'2022 current policy'** and **'High Tech'** scenarios. Each of these scenarios provides annual estimates up to 2061 and include:

- **2022 Current Policy**. This scenario includes the NSW Hydrogen Strategy (but excludes Net Zero Plan Stage 2 and 3 actions). It also includes the Zero Emission Buses Strategy and the Hydrogen Strategy for trucks.
- **High Tech**. This scenario assumes that Battery Electric Vehicles (BEVs) will represent 100% of all Light Duty Vehicle (LDV < 3.5 tonnes) sales by 2030. It also adopts the Bloomberg New Energy Finance (BNEF) Zero Policy uptake rates for Heavy Duty Vehicles (HDV > 4.5 tonnes)

4.3.2 Vehicle categories, model inputs and outputs

The DPE model provides emissions estimates for five categories of vehicle types including passenger vehicles, light commercial vehicles, buses, rigid trucks, articulated trucks. The focus of this research will be on the last two categories of rigid and articulated trucks.

The inputs to the NSW DPE emissions model include:

- **Vehicle-kilometre-Travelled (VKT)** by vehicle type. For LDV (passenger cars) and Light Commercial Vehicles (LCV), the VKT is based on TfNSW COVID Reference scenario as modelled by VLC 2021 for Future Transport (modelling conducted Oct 2021 – May 2022). For trucks, the VKT is based on BITRE 2021 projections for NSW (November 2021). For buses the VKT is based on TfNSW 2021 projections for NSW buses undertaken for the Zero Emissions Buses Strategic Business Case, September 2021.
- **Emissions factors for Internal Combustion Engine Vehicles (ICEV)**. These are based on the NSW fleet aggregate emission factors for ICEV from DPE fleet modelling (NSW Department of Planning and Environment (DPE), 2022). They are also based on NSW fleet aggregate fuel consumption factors for ICE vehicles from DPE fleet modelling, also May 2022.
- **VKT, fuel consumption and emissions data for verification**. These include data from the Sydney Motor Vehicle Survey including VKT millions by vehicle type for vehicles operated in NSW obtained from the 2016, 2018 and 2020 surveys.
- **Zero Emission Vehicle (ZEV) uptake estimates (% of Stock)**. For the '2022 Current Policy', these include estimates based on scenarios that include the Hydrogen Strategy (but excludes Net Zero Plan Stage 2 and 3 actions); Zero Emission Buses Strategy; and the Hydrogen Strategy for trucks. For the 'High Tech' scenario, the uptake estimates assume that BEVs will represent 100% of all LDV sales by 2030; and for HDVs assumes uptake rates from the Bloomberg New Energy Finance (BNEF) Zero Policy.

The DPE emissions modelling outputs include:

- CO_2-e emissions by scenario
- $PM_{2.5}$ emissions (exhaust, non-exhaust, total)
- NO_x emissions
- Monetised health costs
-

4.3.3 CO_2-e emissions

The Greenhouse Gas (GHG) emissions estimates provided by the DPE model are presented next. In the following diagrams, GHG outputs of multiple pollutants (e.g. Carbon Dioxide [CO_2], Methane [CH_4], Nitrous Oxide [N_20], Nitrogen Oxide [NO_x] etc) are expressed by a single metric – CO_2-e. **Figure 67** presents the total CO_2-e emissions for the '2022 current policy" scenario in the DPE model, which is comprised of the emissions from all vehicle categories. The diagram shows how this policy will reduce total emissions over the period 2022-2061. The diagram also shows that passenger vehicles will continue to make up the major proportion of the total emissions up to the late 2030s- mid 2040s.

Figure 67 also shows that articulated trucks contribute higher emissions than rigid trucks. In 2022, there were around 36,000 articulated trucks and 183,000 rigid trucks in NSW, but articulated trucks had a much higher VKT per vehicle than rigid trucks. In addition, fuel consumption (petrol and diesel combined) per 100 km for articulated trucks is nearly twice as high (51 litres per 100 km) as that of rigid trucks (28 litres per 100 km), resulting in much higher emission factors (1,427 g CO_2-e/km compared to 527 g CO_2-e/ km for rigid).

Figure 68 presents a more detailed view of the CO_2-e emissions by vehicle category. The diagram shows that emissions from passenger vehicles will continue to exceed emissions from other vehicle categories until the mid 2040s. The diagram also shows that articulated trucks and light commercial vehicles are the second and third strongest sources of transport CO_2-e emissions.

Similarly, **Figure 69** and **Figure 70** present the GHG emissions resulting from the 'High Tech' scenario which shows a more rapid decarbonisation pathway particularly from the late 2020s, which in turn would lead to realising accelerated benefits in terms of emissions reductions.

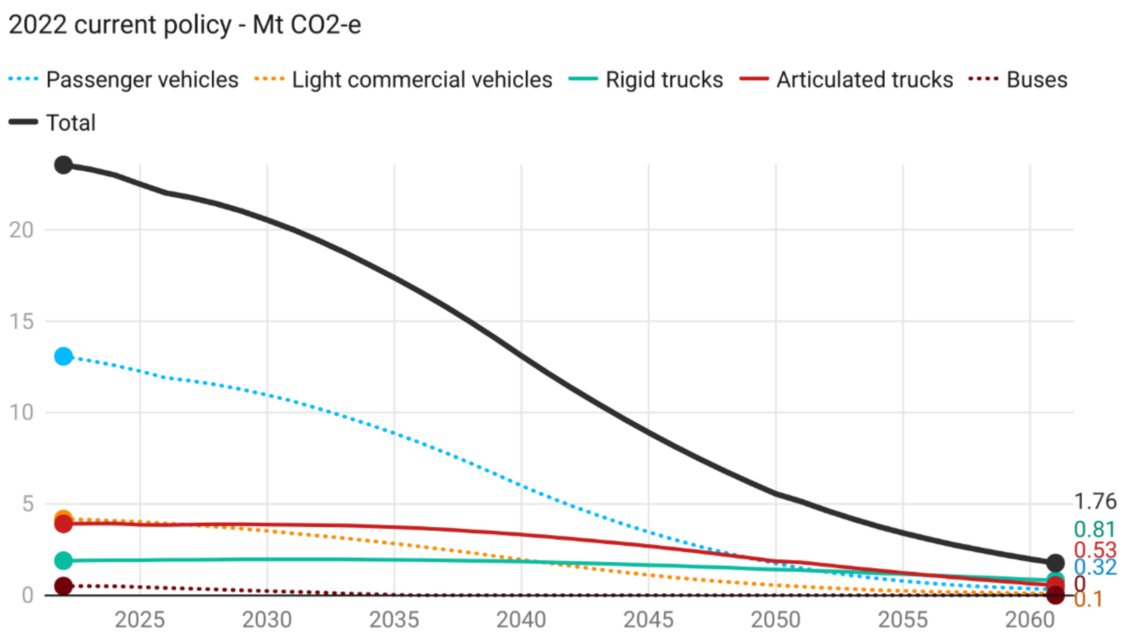


Figure 67: Total CO_2-e emissions for the '2022 current policy' in the DPE model

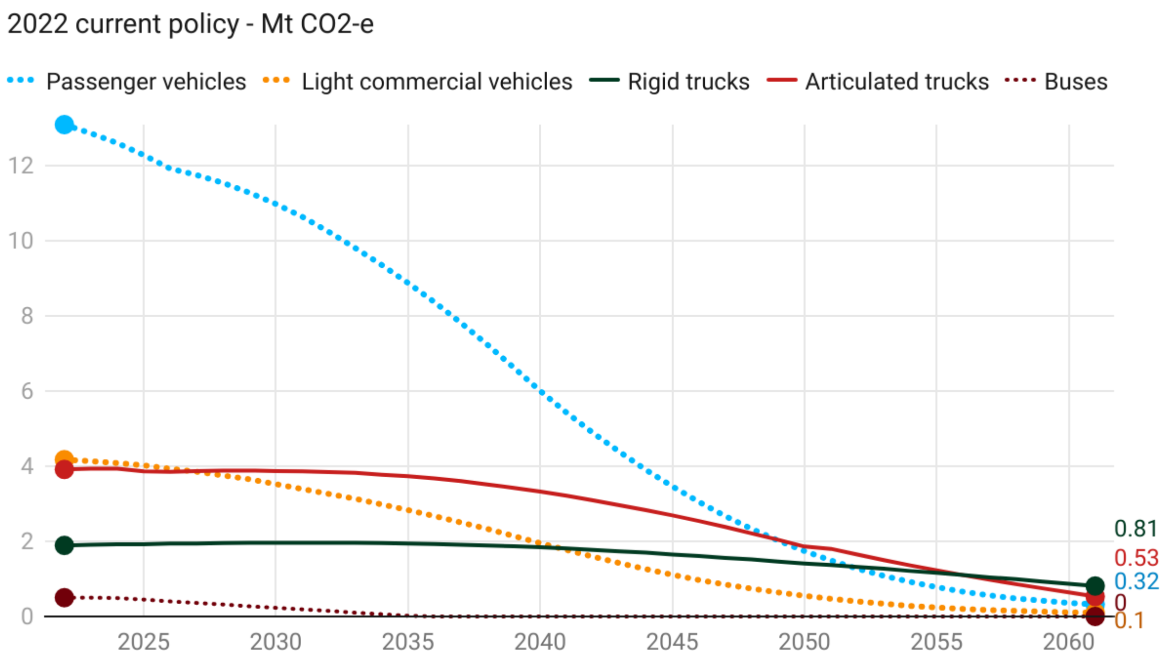


Figure 68: CO_2-e emissions for the '2022 current policy' for all vehicle categories

Both '2022 current policy' and 'High Tech' scenarios highlight the disproportionate contribution of passenger vehicles to CO_2-e emissions, compared to LCV, trucks and buses. While there are many opportunities available to reduce emissions from passenger vehicles[5], the decarbonisation of the freight fleet (especially rigid and articulated trucks) presents challenges and would require targeted interventions which will be the focus of this research.

[5] This included zero emissions vehicles but also established urban transport policies that reduce or avoid the need for car travel. This includes land-use transport integration, travel demand management, working from home, or using more energy efficient modes of transport such as active mobility and public transport.

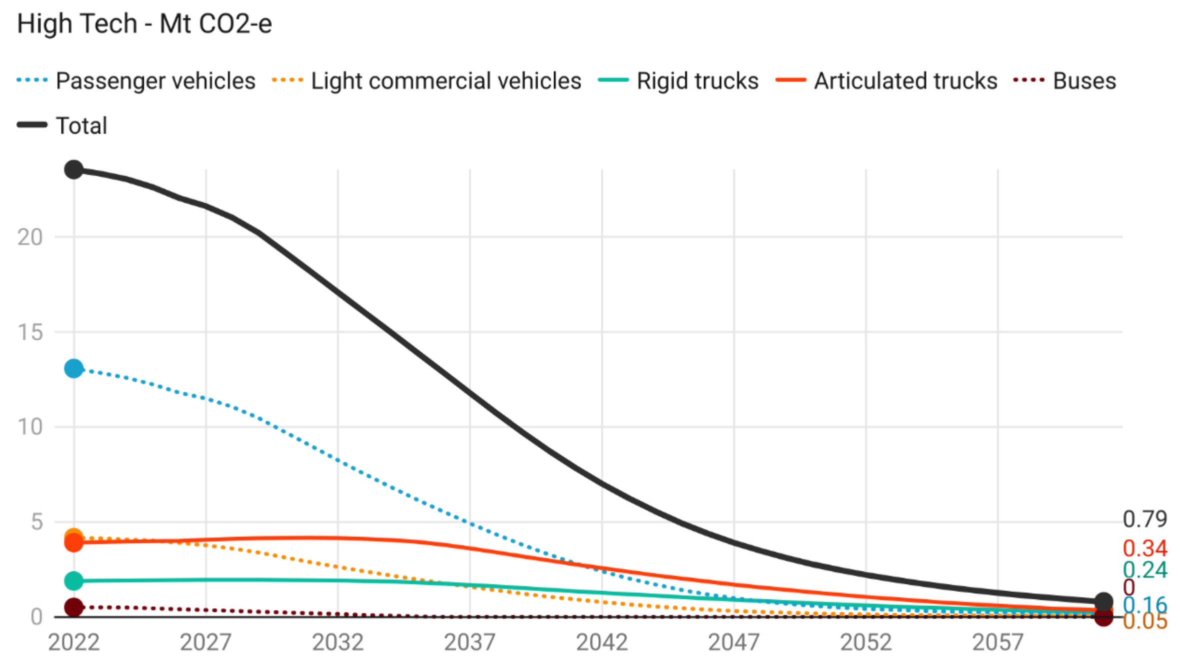


Figure 69: Total CO_2-e emissions for the 'High Tech' scenario in the DPE model

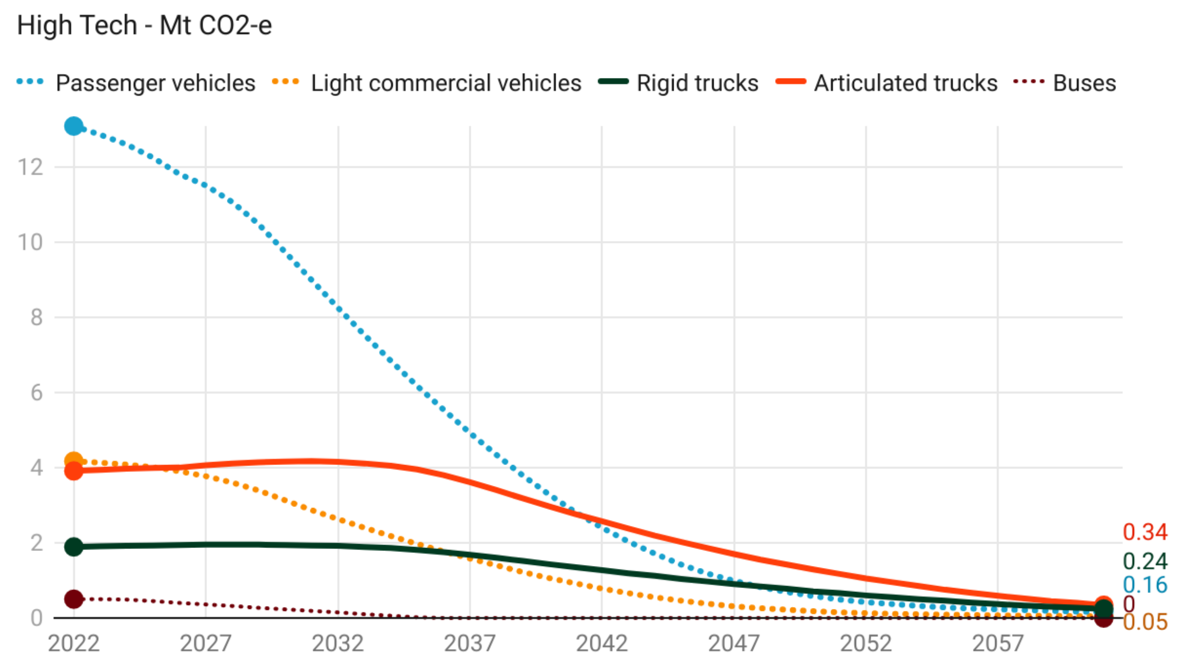


Figure 70: CO_2-e emissions for the 'High Tech' scenario for all vehicle categories

4.3.4 NO_x emissions

The NO_x emissions estimates provided by the DPE model are presented next. NO_x pollution contributes to the build-up of GHG in the atmosphere, but also air quality at ground levels.

Figure 71 presents the total NO_x emissions for the '2022 current policy" scenario in the DPE model, which is comprised of the NO_x emissions from all vehicle categories. The diagram shows how this policy will reduce total emissions over the period 2022-2061. It also shows that articulated trucks and light commercial vehicles will continue to be the highest sources of NO_x emissions up to the late 2030s-mid 2040s.

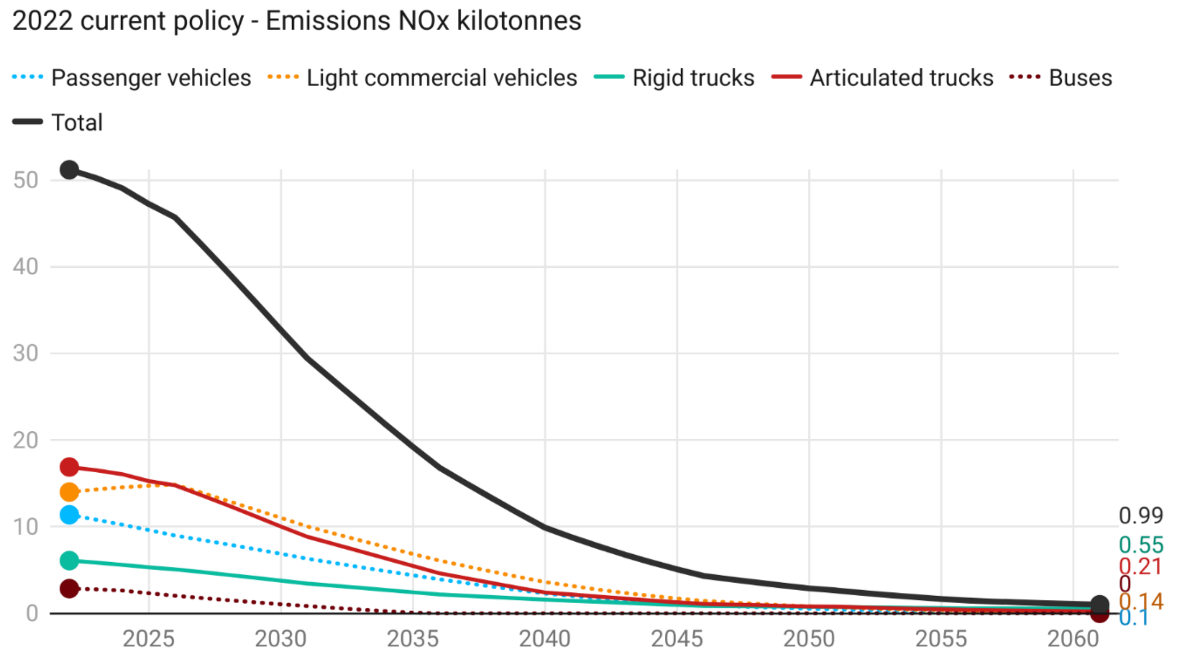


Figure 71: Total NO_x emissions for the '2022 current policy' in the DPE model

Figure 72 presents a more detailed view of the NO_x emissions by vehicle category. The diagram shows that emissions from articulated trucks and light commercial vehicles will continue to exceed emissions from other vehicle categories until the late 2040s. The diagram also shows that passenger vehicles and rigid trucks are the second and third strongest sources of transport NO_x emissions.

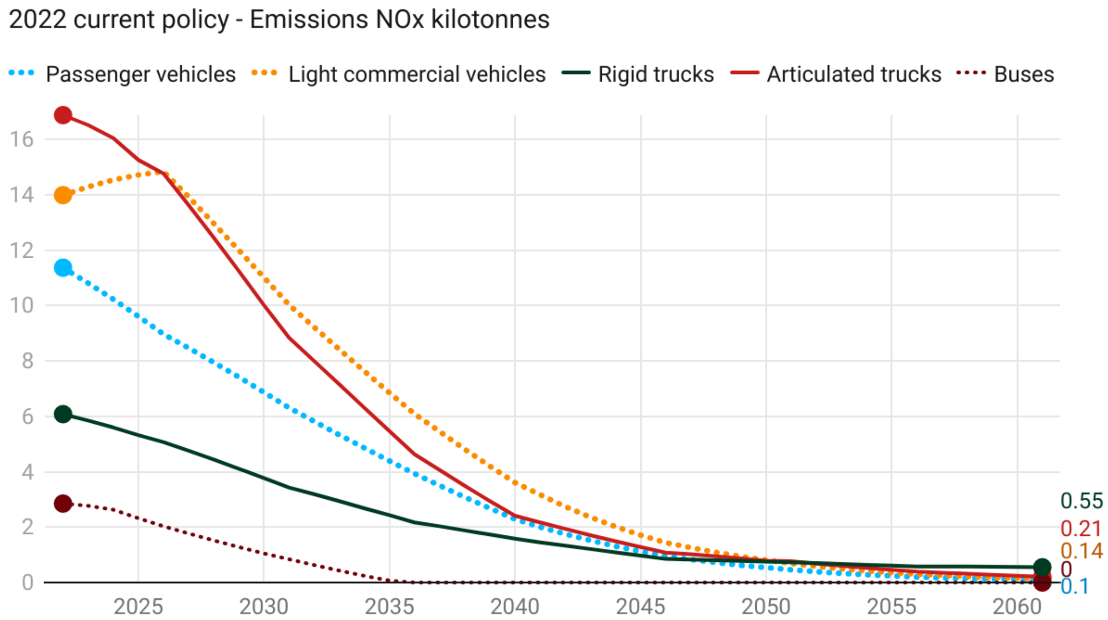


Figure 72: NO_x emissions for the '2022 current policy" for all vehicle categories

Similarly, **Figure 73** and **Figure 74** present the NO_x emissions for the 'High Tech' scenario which shows a more rapid decarbonisation pathway particularly from the late 2020s, which in turn would lead to realising accelerated benefits in terms of NO_x emissions reductions. Both sets of diagrams for the '2022 current policy' and 'High Tech' scenarios highlight the higher contributions of articulated trucks, light commercial vehicles, and passenger vehicles to NO_x emissions, compared to rigid trucks and buses.

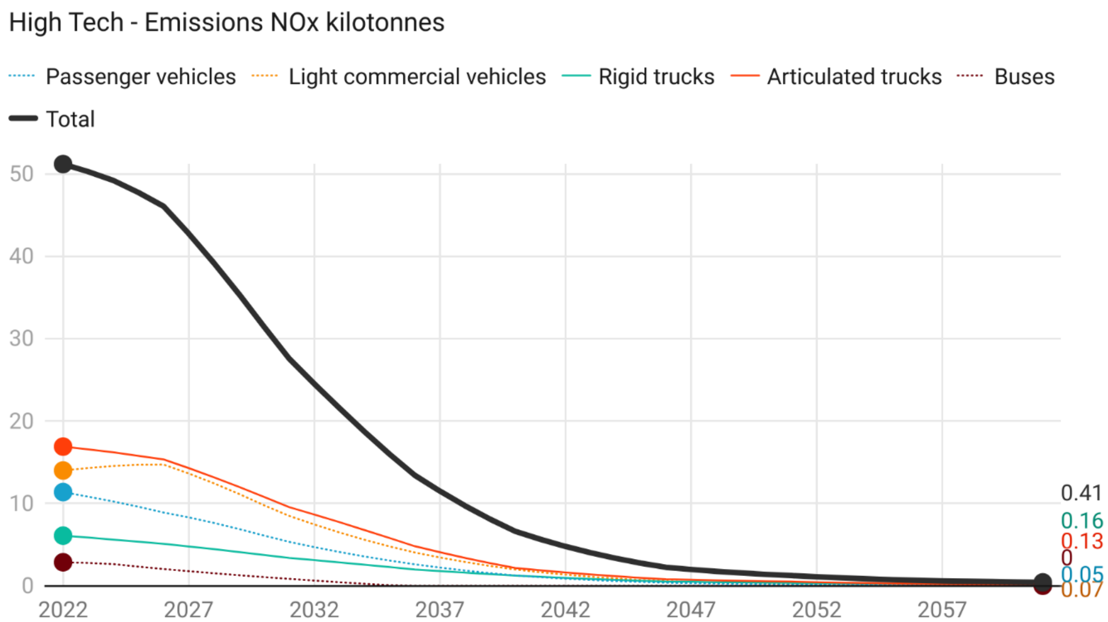


Figure 73: Total NO_x emissions for the 'High Tech' scenario in the DPE model

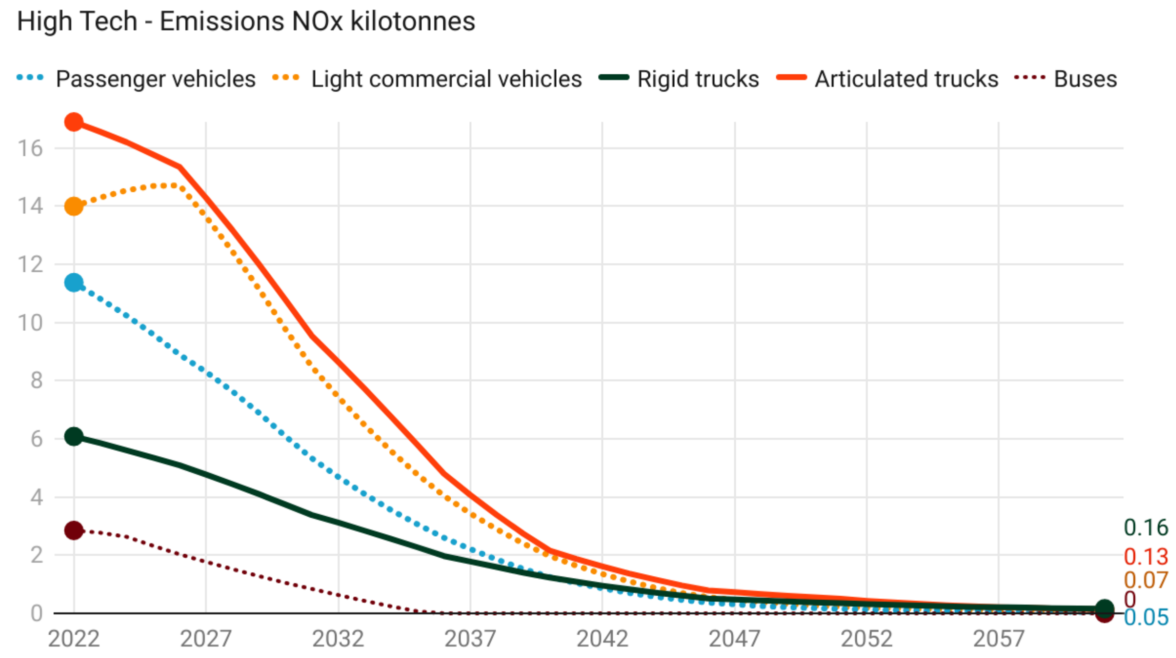


Figure 74: NO_x emissions for the 'High Tech' scenario for all vehicle categories

As noted above, both the '2022 current policy' and 'High Tech' scenarios appear to have a similar impact on reductions of NO_x from all vehicle categories with the biggest reduction impacts expected for articulated trucks and light commercial vehicles.

4.3.5 $PM_{2.5}$ emissions (exhaust)

The $PM_{2.5}$ exhaust emissions estimates provided by the DPE model are presented next.

Figure 75 presents the total $PM_{2.5}$ exhaust emissions for the '2022 current policy" scenario in the DPE model, which is comprised of the $PM_{2.5}$ exhaust emissions from all vehicle categories. The diagram shows how this policy will reduce total emissions over the period 2022-2061.

Figure 76 presents a more detailed view of the $PM_{2.5}$ exhaust emissions by vehicle category. The diagram shows that emissions from articulated trucks, rigid trucks, passenger vehicles and light commercial vehicles are the strongest sources of $PM_{2.5}$ exhaust emissions until the mid-late 2040s.

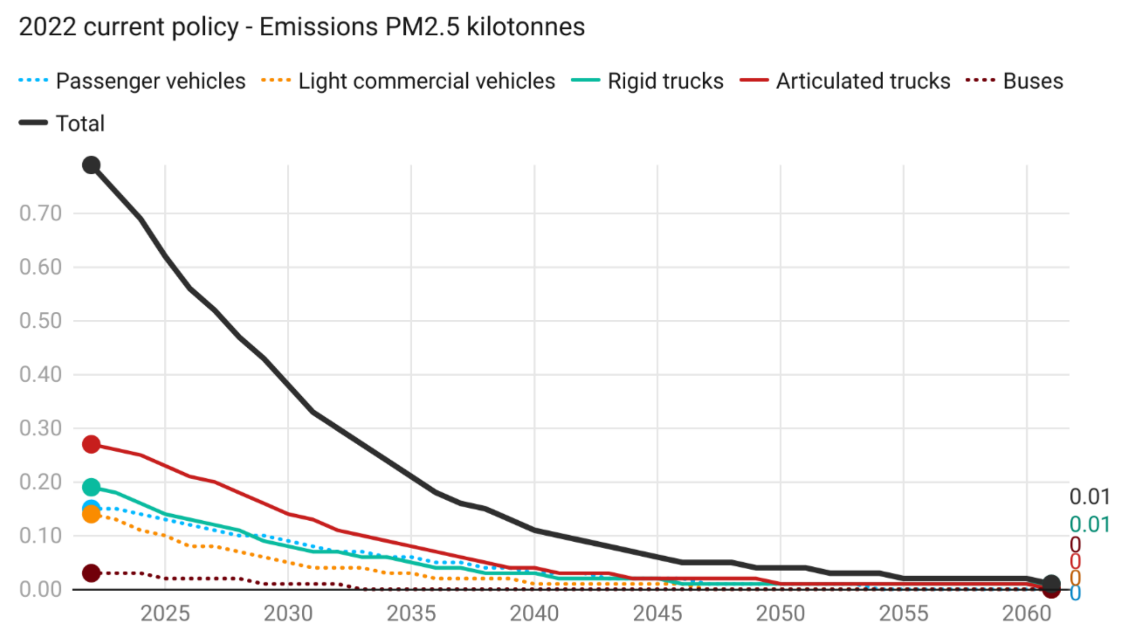


Figure 75: Total $PM_{2.5}$ emissions for the '2022 current policy' scenario

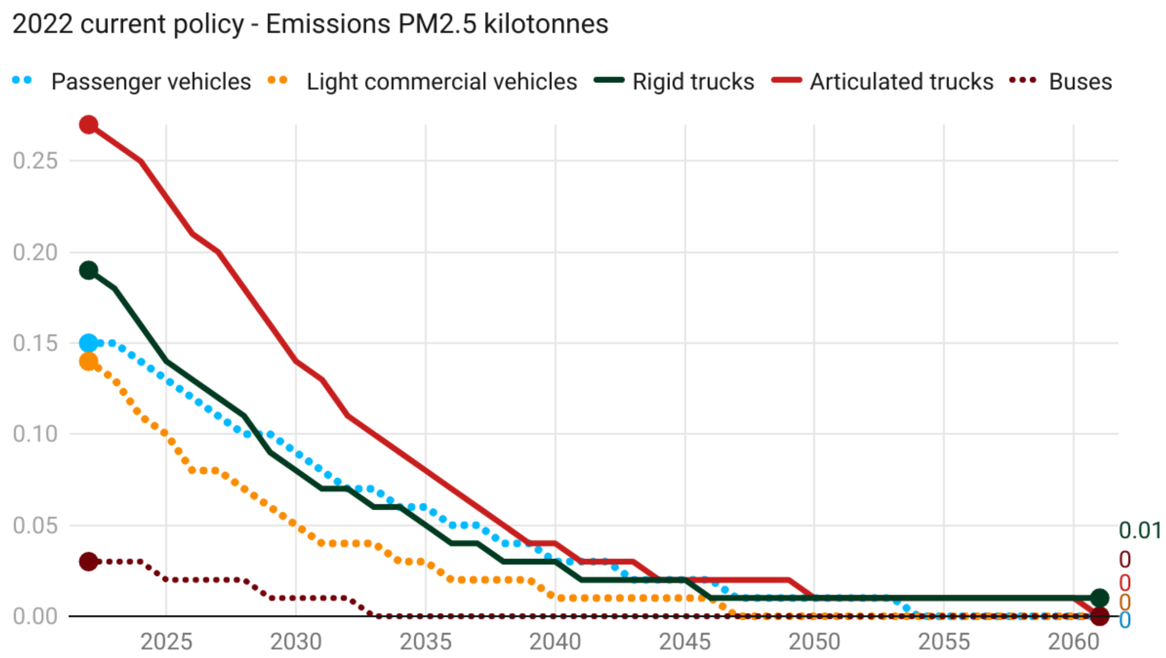


Figure 76: $PM_{2.5}$ exhaust emissions for '2022 current policy" scenario

Similarly, **Figure 77** and **Figure 78** present the $PM_{2.5}$ exhaust emissions for the 'High Tech' scenario which shows a more rapid decarbonisation pathway particularly from the mid-2020s, which would lead to realising accelerated benefits in terms of emissions reductions. Both sets of diagrams for the '2022 current policy' and 'High Tech' scenarios highlight the higher contributions of articulated and rigid trucks, passenger vehicles and light commercial vehicles compared to buses.

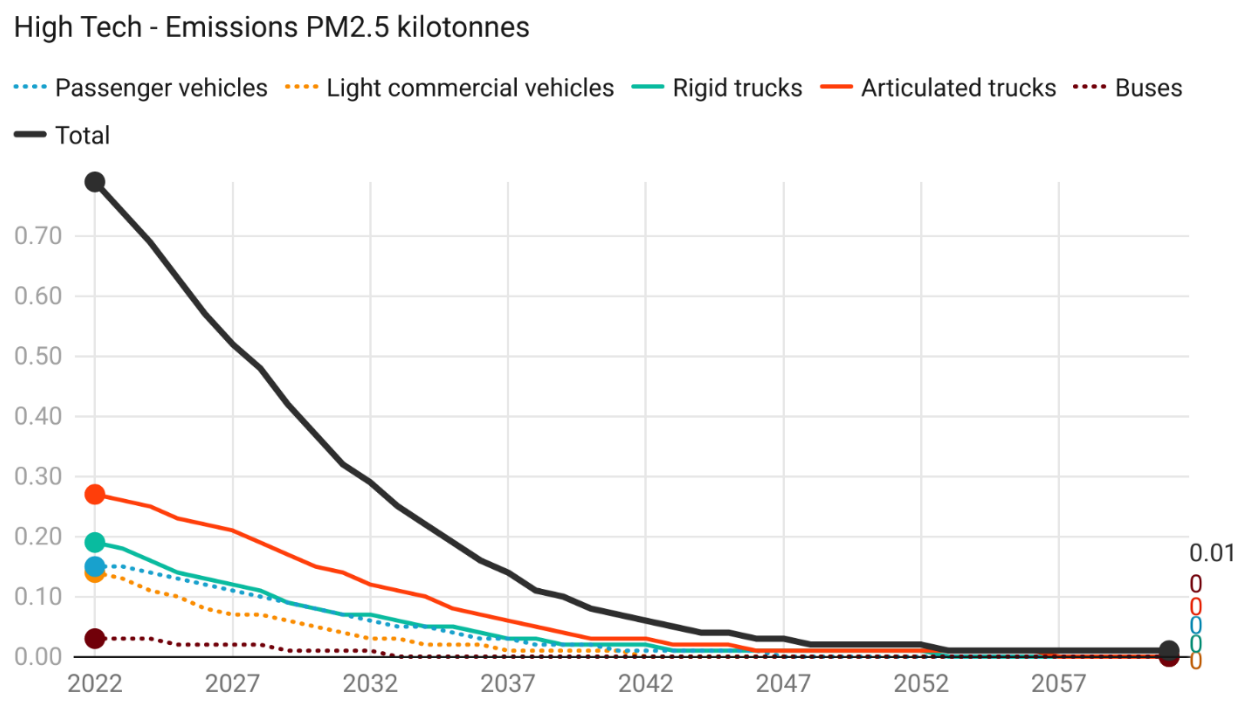


Figure 77: Total $PM_{2.5}$ exhaust emissions for 'High Tech' scenario in DPE model

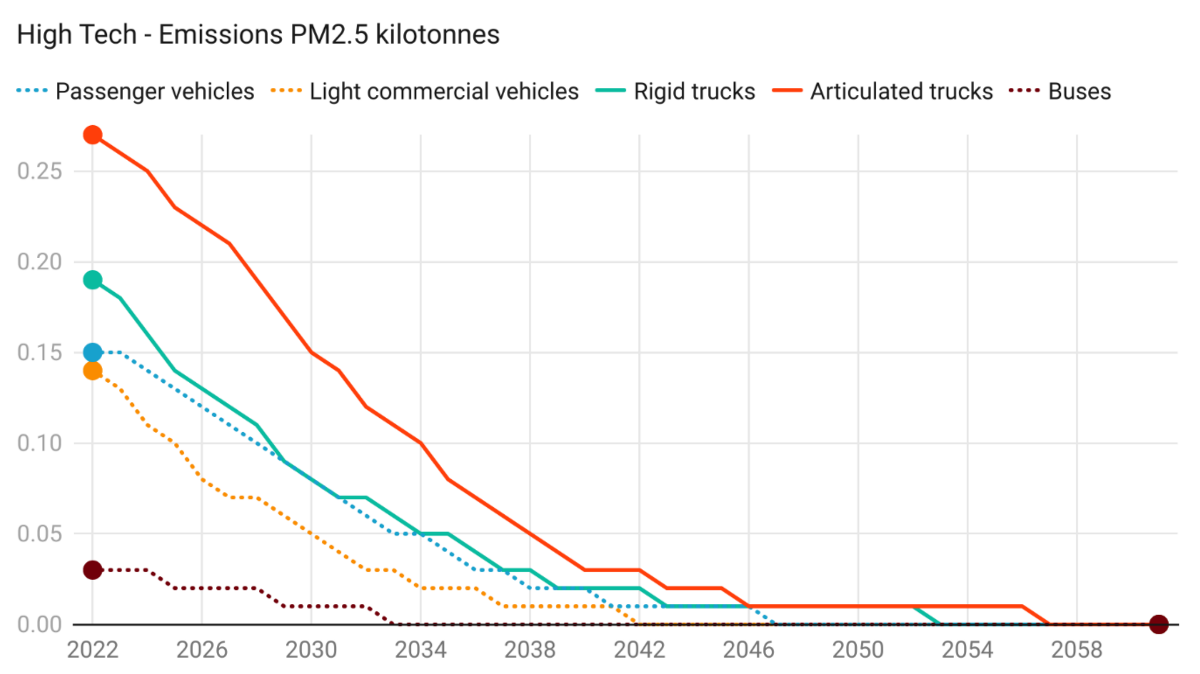


Figure 78: $PM_{2.5}$ exhaust emissions for 'High Tech' scenario

4.3.6 $PM_{2.5}$ emissions (non-exhaust)

Unlike tailpipe emissions, the $PM_{2.5}$ non-exhaust emissions are produced from the wearing down of brakes, tyres, road surfaces and resuspension of road dust. Exposure to these emissions is associated with a variety of adverse health outcomes, such as increased risks of cardiovascular, respiratory, and developmental conditions, as well as an increased risk of overall mortality.

It is noted that a shift of existing vehicle fleets to zero emissions vehicles won't contribute to reducing this type of non-exhaust emissions. Other established urban transport policies that aim to manage the demand for travel and reduce the number of vehicle trips would be required to ameliorate the expected increases in $PM_{2.5}$ non-exhaust emissions.

The $PM_{2.5}$ non-exhaust emissions estimates provided by the DPE model are presented next. The DPE modelling results show that the $PM_{2.5}$ non-exhaust emissions will continue to increase and are unlikely to be reduced with either the '2022 current policy' or 'High Tech' scenarios under consideration.

Figure 79 presents the total $PM_{2.5}$ non-exhaust emissions for the '2022 current policy" scenario in the DPE model, which is comprised of the $PM_{2.5}$ non-exhaust emissions from all vehicle categories. The diagram shows how the total $PM_{2.5}$ non-exhaust emissions will continue to rise over the period 2022-2061 due to increased vehicle kilometres of travel and that this scenario will not have any impact on ameliorating the $PM_{2.5}$ non-exhaust emissions. It also shows that passenger vehicles have the highest contributions to the total emissions.

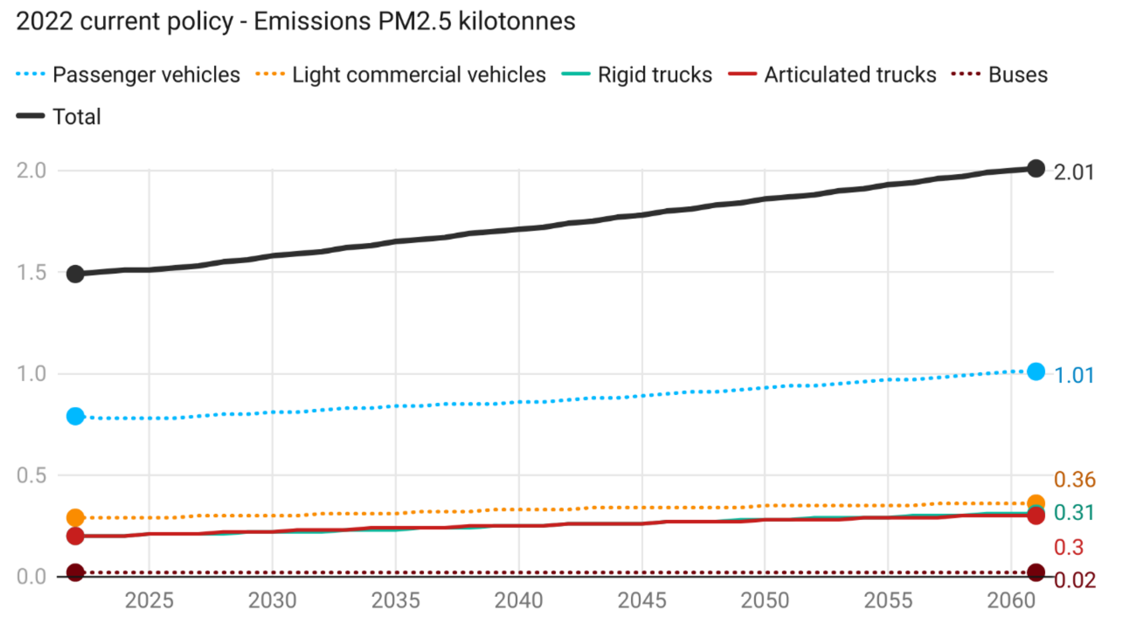


Figure 79: Total $PM_{2.5}$ non-exhaust emissions for '2022 current policy' scenario

Similarly, **Figure 80** presents the total $PM_{2.5}$ non-exhaust emissions for the 'High Tech' scenario in the DPE model. As expected, these diagrams provide identical information and confirm that neither of the two scenarios will reduce total $PM_{2.5}$ non-exhaust emissions over the period 2022-2060. These emissions will continue to grow in the future unless targeted urban policy interventions, such as the well-established "Avoid, Shift, Share, improve" strategies are implemented to manage travel demand.

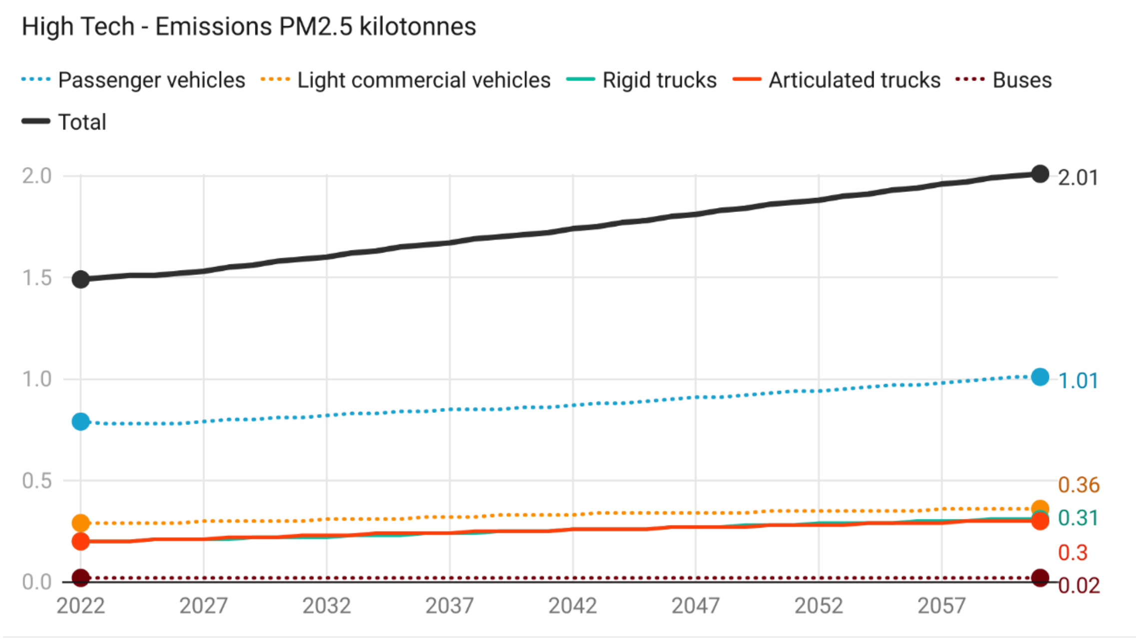


Figure 80: Total $PM_{2.5}$ non-exhaust emissions for 'High Tech' scenario

4.4 Modelling of health burden and impacts

All vehicles contribute to air pollution through road, brake, and tyre wear. The advantage of zero emission vehicles is that they also do not produce tailpipe emissions of particle and gaseous air pollutants like petrol and diesel vehicles.

Reducing tailpipe emissions from vehicles can generate significant health benefits for NSW, particularly for people living with respiratory health conditions like asthma or with a predisposition to cardiovascular conditions. It is estimated that about 70 premature deaths each year are associated with long term exposure to vehicle pollution in the NSW Greater Metropolitan Region with vehicle exhaust emissions contributing 69% of the fine particle exposures associated with these deaths (Broome R. , Powell , Cope , & Morgan , 2020).

When comparing health burdens over time, it is important to distinguish between the total GHG and air quality impacts generated by all freight vehicles and the GHG and air quality impact of individual vehicles. The two are connected, but even if the impact of individual vehicles declines, the impact generated by all vehicles combined may still increase. The DPE model focuses on total GHG and air quality impacts. Over time the total GHG and air quality impact of freight is a function of:

- Technology: this is the GHG and air quality impact of each individual freight vehicle.
- Usage: this is distance travelled, but also speed and other driving characteristics.
- Number of vehicles: a growing freight fleet may increase GHG and air quality impacts even if the impact per vehicle declines.
- Social cost of emissions: NSW guidance on monetising GHG and air quality impact assumes the social cost of emissions increases over time (NSW Treasury 2023), resulting in an increased health burden also under a no change scenario.

4.4.1 Method for estimating health burden and benefits.

The DPE model produces estimates of Nitrogen Oxides (NO_x) and fine particulate matter ($PM_{2.5}$) from petrol and diesel fuelled vehicles. The DPE model also produces estimates of $PM_{2.5}$ for non-exhaust emissions arising from tyre, brake and road wear for fossil fuel and battery electric vehicles. These estimates can be used to calculate the potential health cost value arising from reduction in petrol and diesel fuelled cars on NSW roads.

Monetising $PM_{2.5}$ impacts.

To monetise $PM_{2.5}$ health costs the DPE model utilises a damage cost approach developed by PAE Holmes for the NSW EPA (PAEHolmes, 2013). This methodology transfers health costs derived in the United Kingdom from full impact pathway health modelling, adjusted for Australian population densities, value of a life year, currency, and inflation.

The $PM_{2.5}$ damage costs used to estimate health costs for the transport fleet are adopted from the Marsden Jacobs Associates (MJA) draft Regulation Impact Statement (RIS) for the review of the NSW Protection of the Environment (Clean Air) Regulation 2022 (NSW Environmental Protection Agency, 2022). MJA applied the PAEHolmes methodology to adjust the 2011 damage costs to 2017 dollars and adjust for projected changes in population density by significant urban area (SUA). From the individual SUA damage costs, MJA derived weighted damage costs for the NSW GMR and non-GMR areas of NSW.

The $PM_{2.5}$ damage costs applied in DPE modelling utilises a weighted average of the MJA's Greater Metropolitan Region (GMR) and non-GMR damage costs to the whole of NSW, adjusted to 2019 Australian dollars.

Monetising NO_x impacts

To monetise NO_x health costs the DPE model also uses a damage costs approach. The NO_x damage cost approach is adopted from those used by MJA for the Clean Air Regulation RIS. The NO_x damage costs estimates were developed by MJA for the Sydney GMR region drawing on a study that applied an impact pathway approach to estimating the health impacts and associated costs of NO_x and other emissions from transport in Sydney. Recent international health impact studies were also reviewed in the development of the NSW specific health costs.

The air pollution related health costs associated with transport emissions are estimated in the DPE model and are presented next. The aggregate over-time trends for each vehicle category, reflect the four determinants of health costs that were previously set out.

Health impacts DPE model

Figure 81 presents the health costs for the '2022 current policy' scenario in the DPE model, which is comprised of the health costs for all vehicle categories. The diagram shows how this policy impacts health costs over the period 2022-2060. The aggregate health impacts in **Figure 81** reflect trends in the four determinants (technology, usage, number of vehicles and social costs of emissions) for each vehicle type and combined. In the DPE models the monetised health burden initially declines, before rising again after 2040/2045.

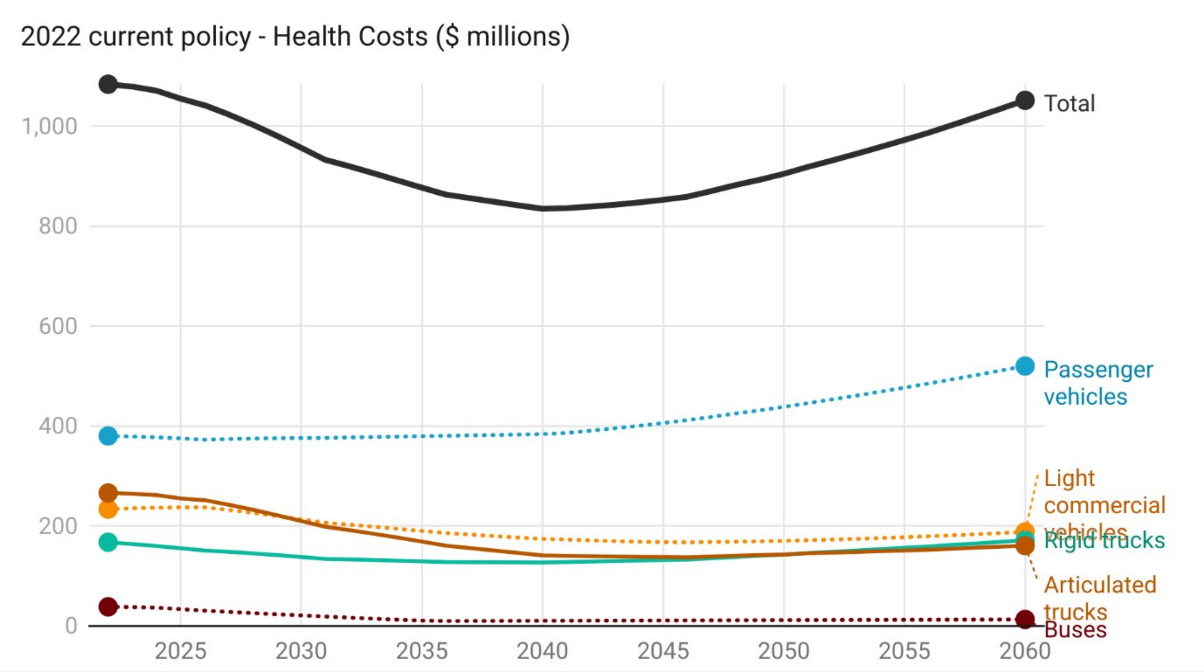


Figure 81: Health burden (monetised, AUD 2021) for DPE '2022 current policy' scenario

Figure 82 presents the health costs for the 'High Tech' scenario in the DPE model, which is also comprised of the health costs for all vehicle categories. The diagram also shows how this policy impacts health costs over the period 2022-2060.

In both the '2022 current policy' and 'High Tech' scenarios, passenger cars contribute the most to the health costs followed by articulated trucks, light commercial vehicles, and rigid trucks.

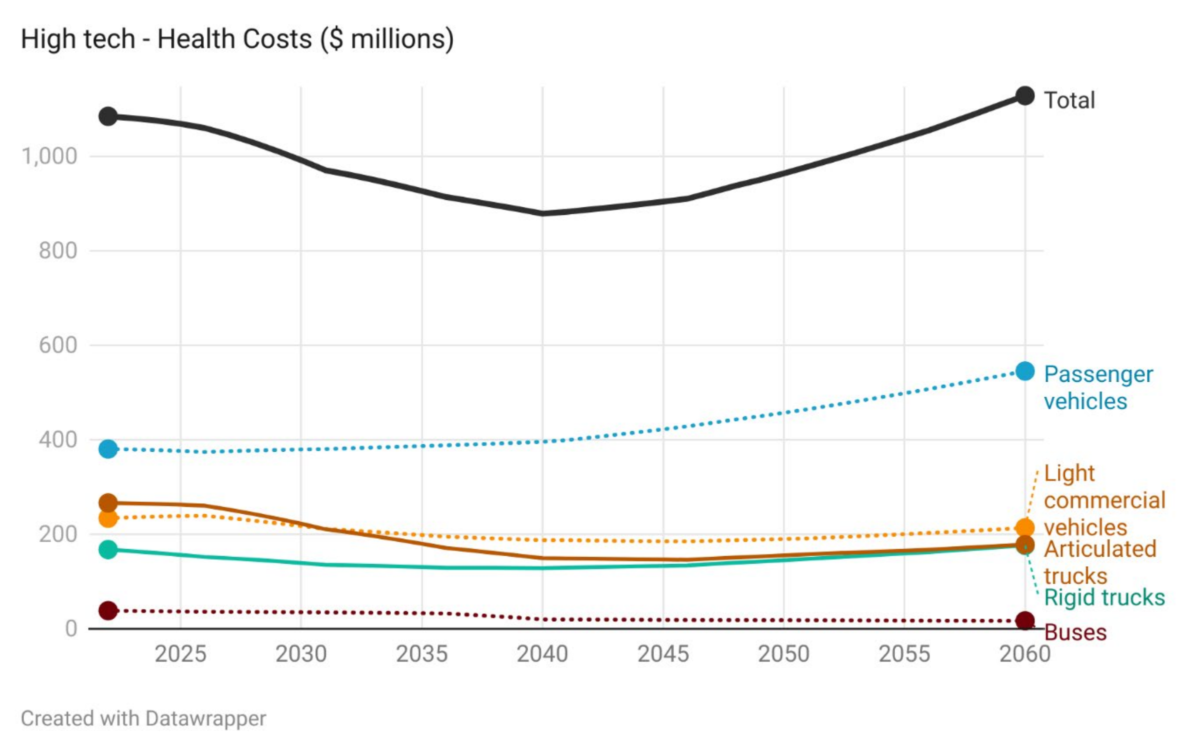


Figure 82: Health burden (monetised, AUD 2021) for DPE 'High Tech' scenario

4.5 Summary baseline emissions/health costs by type

This section of the report provides a more detailed view of the emissions by truck type focusing on articulated and rigid trucks.

4.5.1 CO_2-e emissions

Figure 83 provides a comparison of CO_2-e emissions for the '2022 Current Policy' and High Tech' scenarios for both rigid and articulated trucks. The diagram highlights how GHG emissions from these two vehicle categories will generally remain steady until the mid-to-late 2030s, assuming no further policy interventions. The diagram also highlights the marked differences in emissions between these two truck categories, and how the 'High Tech' scenario, which assumes increased adoption rates of zero emissions trucks, will accelerate the emissions reductions from both truck categories, compared to the '2022 current policy' scenario.

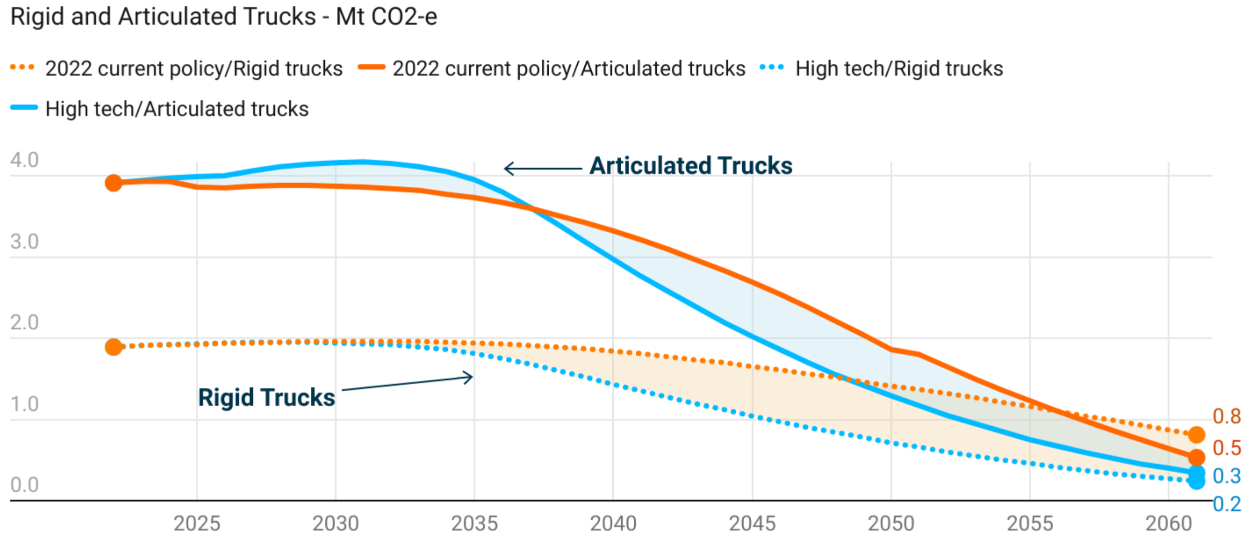


Figure 83: Comparison of CO_2 impacts of DPE scenarios

4.5.2 NO_x emissions

Figure 84 provides a comparison of the NO_x reductions resulting from the '2022 Current Policy' and 'High Tech' scenarios for both the rigid and articulated truck vehicle categories. The diagram shows no marked difference in the impacts on NO_x reductions for trucks resulting for the two scenarios.

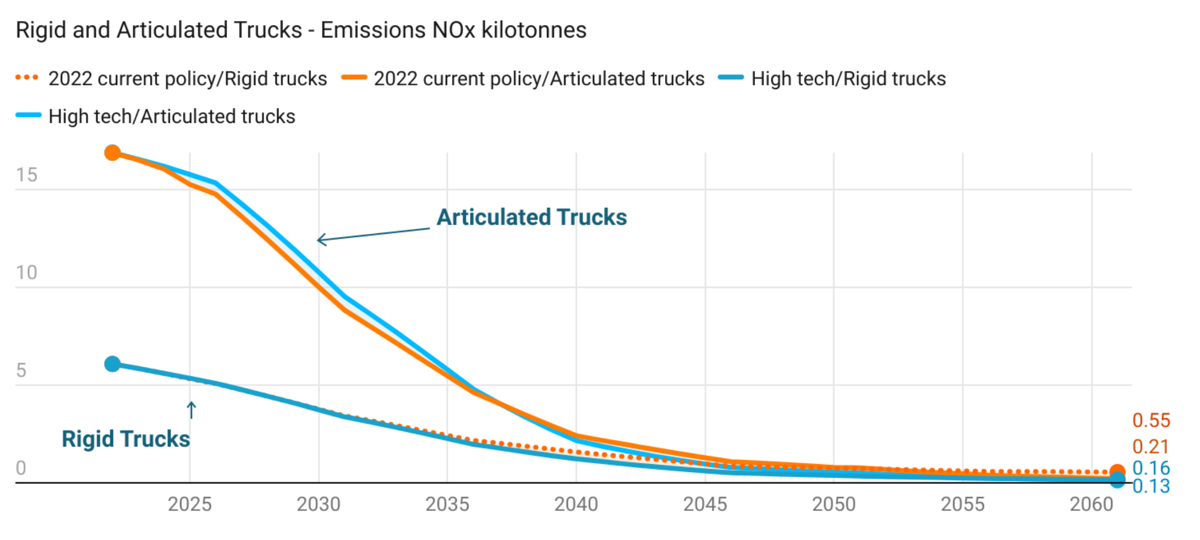


Figure 84: Comparison of NO_x impacts of DPE scenarios

4.5.3 PM2.5 (exhaust) emissions

Figure 85 presents the $PM_{2.5}$ (exhaust) emissions from the '2022 Current Policy' scenario for both the rigid and articulated truck vehicle categories. The diagram shows a marked impact of this scenario in reducing $PM_{2.5}$ (exhaust) for rigid and articulated trucks.

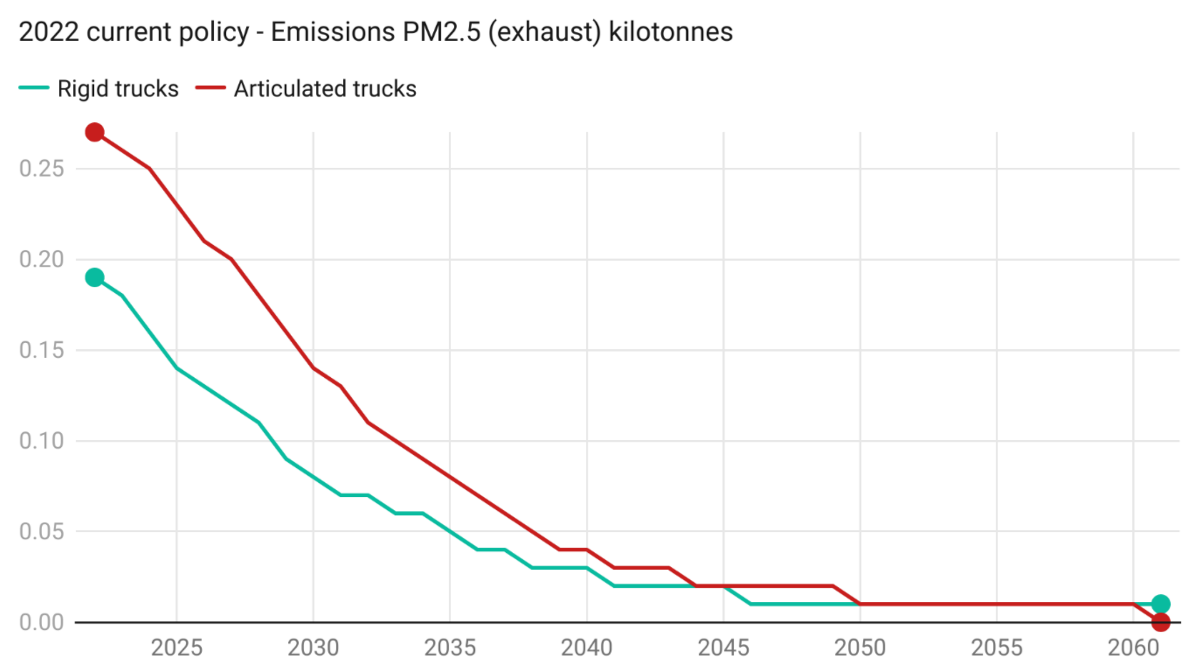


Figure 85: $PM_{2.5}$ emissions (exhaust) for the '2022 Current Policy' scenario

Similarly, **Figure 86** presents the $PM_{2.5}$ (exhaust) emissions from the 'High Tech' scenario for rigid and articulated trucks. The diagram also shows the marked impact of this scenario in reducing the $PM_{2.5}$ (exhaust) emissions for the two truck categories.

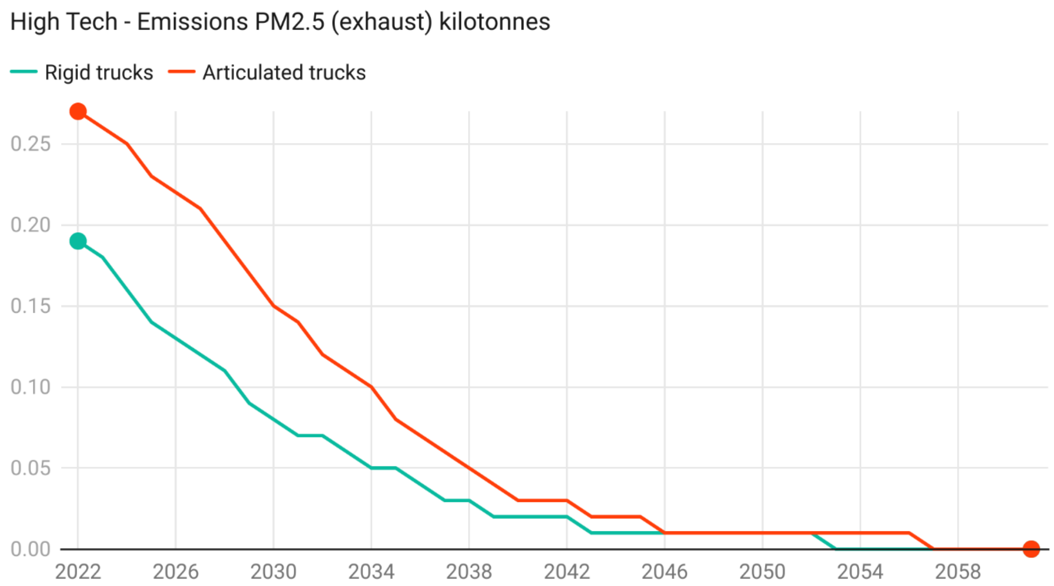


Figure 86: $PM_{2.5}$ emissions (exhaust) for the 'High Tech' scenario

4.5.4 $PM_{2.5}$ (non-exhaust) emissions

Figure 87 presents a comparison of the $PM_{2.5}$ (non-exhaust) emissions for rigid trucks resulting from both the '2022 current policy' and 'High Tech' scenarios. The diagram shows that the impacts from the two scenarios are identical because neither scenario can lead to reduction of this type of emissions as discussed earlier.

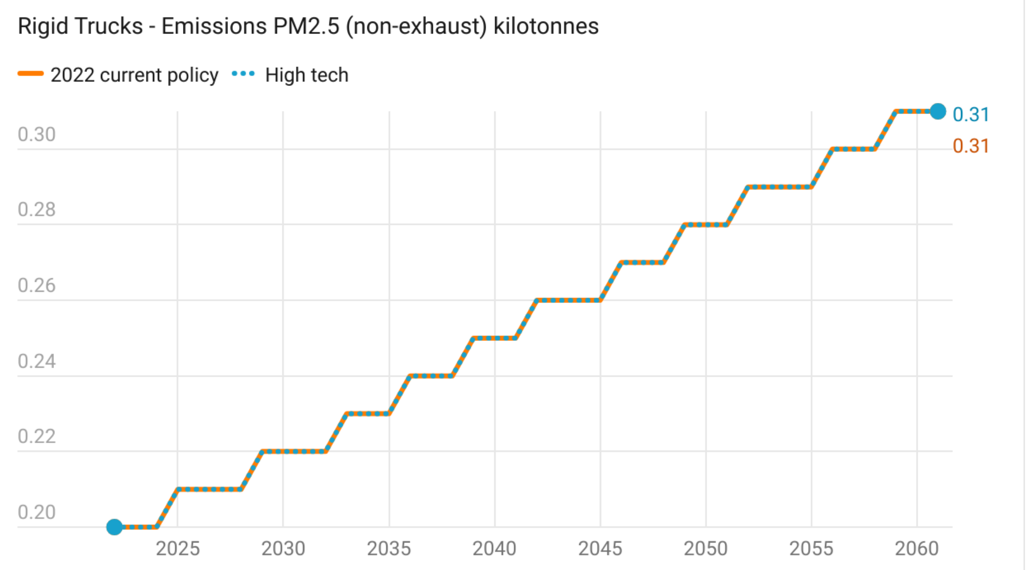


Figure 87: Comparison of $PM_{2.5}$ emissions (non-exhaust) for DPE scenarios

Similarly, **Figure 88** presents a comparison of the $PM_{2.5}$ (non-exhaust) emissions for articulated trucks resulting from both the '2022 current policy' and 'High Tech'' scenarios. Like previous discussions for rigid trucks, the diagram shows that the impacts of the two scenarios are identical and that they won't reduce the $PM_{2.5}$ non-exhaust emissions which will continue to rise due to increased VKT.

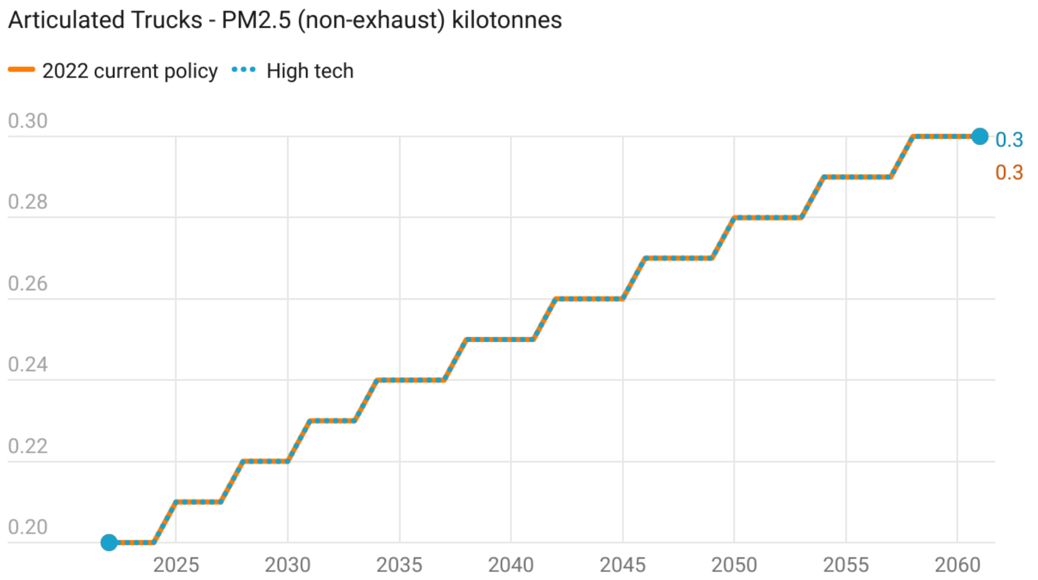


Figure 88: Comparison of $PM_{2.5}$ emissions (non-exhaust) for DPE scenarios

4.5.5 $PM_{2.5}$ total (exhaust and non-exhaust) emissions

Figure 89 presents a comparison of the $PM_{2.5}$ total (exhaust and non-exhaust) emissions for both the rigid and articulated truck categories resulting from both the '2022 current policy' and 'High Tech' scenarios. The diagram does not show a marked difference in the impacts of the two scenarios in reducing $PM_{2.5}$ total emissions for each of the truck categories.

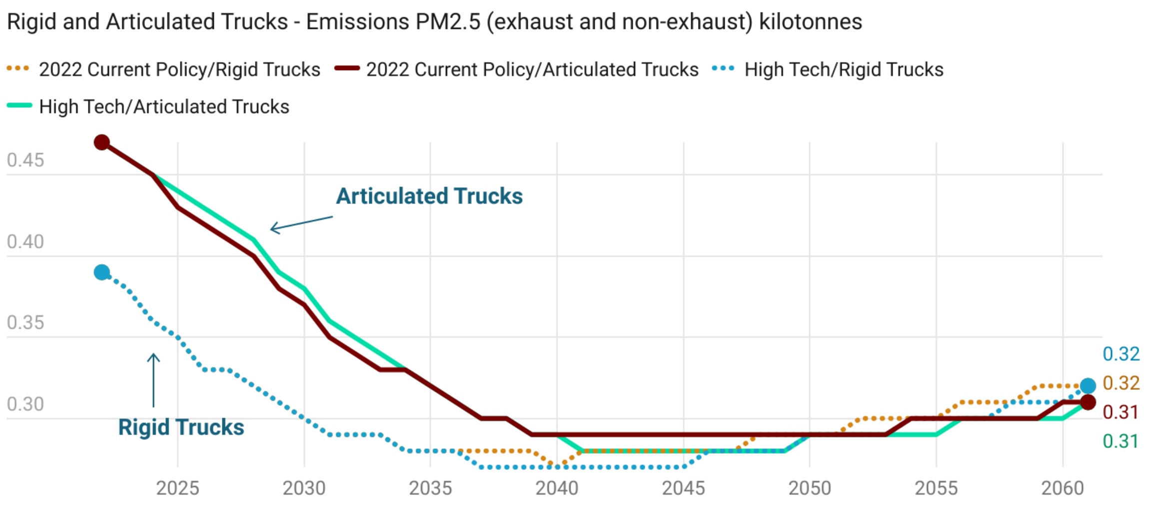


Figure 89: Comparison of total $PM_{2.5}$ emissions for DPE scenarios

Figure 90 and **Figure 91** provide a summary of the different emissions for rigid and articulated trucks, respectively.

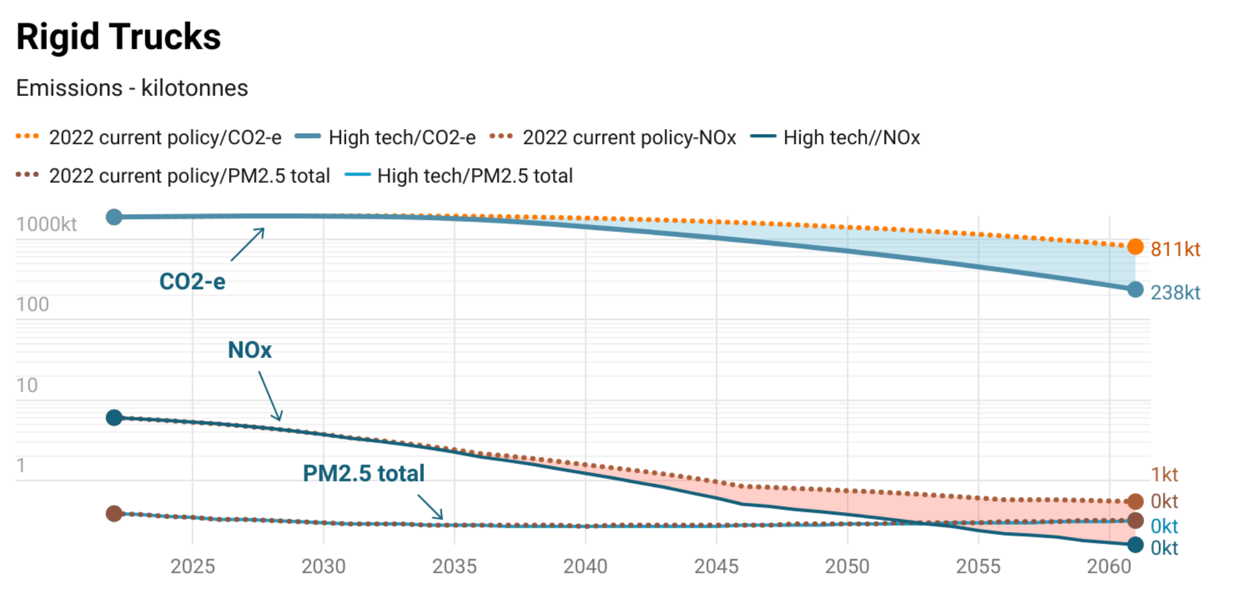


Figure 90: Summary of emissions for rigid trucks for DPE scenarios

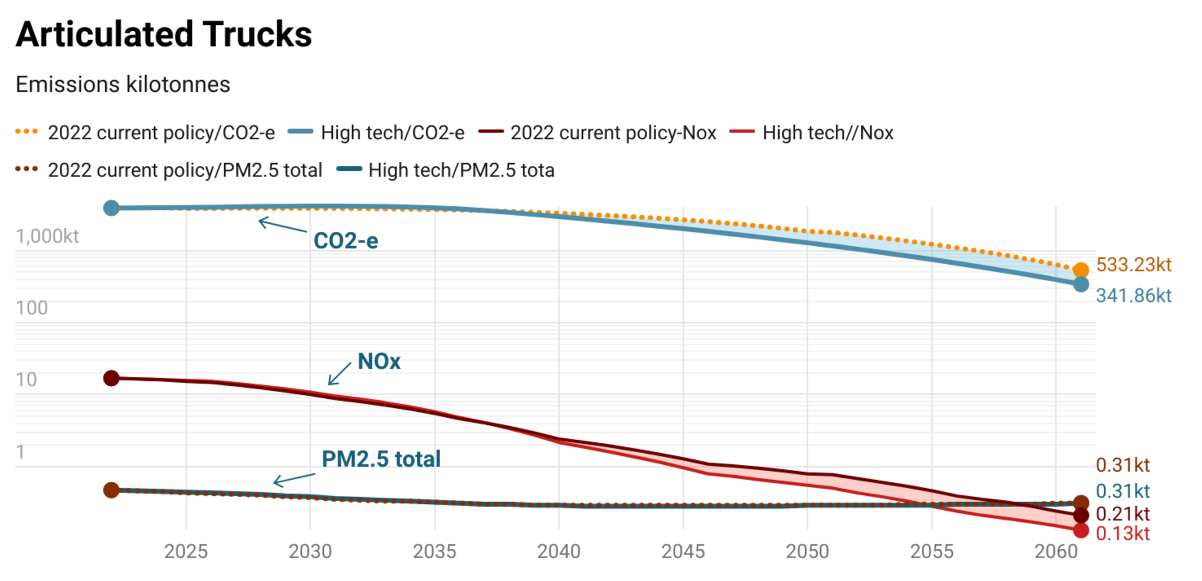


Figure 91: Summary of emissions for articulated trucks for DPE scenarios

Finally, the next diagrams (**Figure 92, Figure 93, Figure 94** and **Figure 95**) provide representations for the health burdens for rigid and articulated trucks, broken down by scenario and type of vehicle, demonstrating the impact of each scenario on health costs.

In the DPE models the monetised health burden of rigid and articulated trucks is determined by the four factors set out earlier (technology, usage, number of vehicles and social cost of emissions). Over time these do, however, not individually show the same trend – technology improves (e.g., adoption of ZEVs), but number of vehicles and social cost of emissions increase. The total health burden therefore initially declines, before rising again after 2040/2045.

Beyond 2040-45 the monetised health burden begins to increase again, reflecting the overall growth in trucks on NSW roads, as well as an increase damage cost per tonne of emissions (air quality). For instance, while tailpipe $PM_{2.5}$ emissions declines with the shift to ZEVs, more freight vehicles in total also translates into increased non-tailpipe $PM_{2.5}$ emissions. The increased volume of trucks and damage cost per tonne of emissions over time thus combine to raise the monetised health burden.

The difference in health burden trends between rigid and articulated trucks is reflective of how the four determinants of the health burden vary by vehicle class. For instance, the DPE model assumes that by 2061 the market penetration rates of ZEVs for both types are high, but somewhat higher for articulated trucks (rigid 71%, articulated 91%). Technological evolution is similar – declining emissions factors until 2040. However, over the same period the number of rigid trucks is projected to increase by some 100,000 vehicles, compared to 17,200 articulated trucks. The combination of somewhat lower ZEV market penetration for rigid trucks and the much greater number of additional (projected) vehicles results in quite different health burden profiles over time.

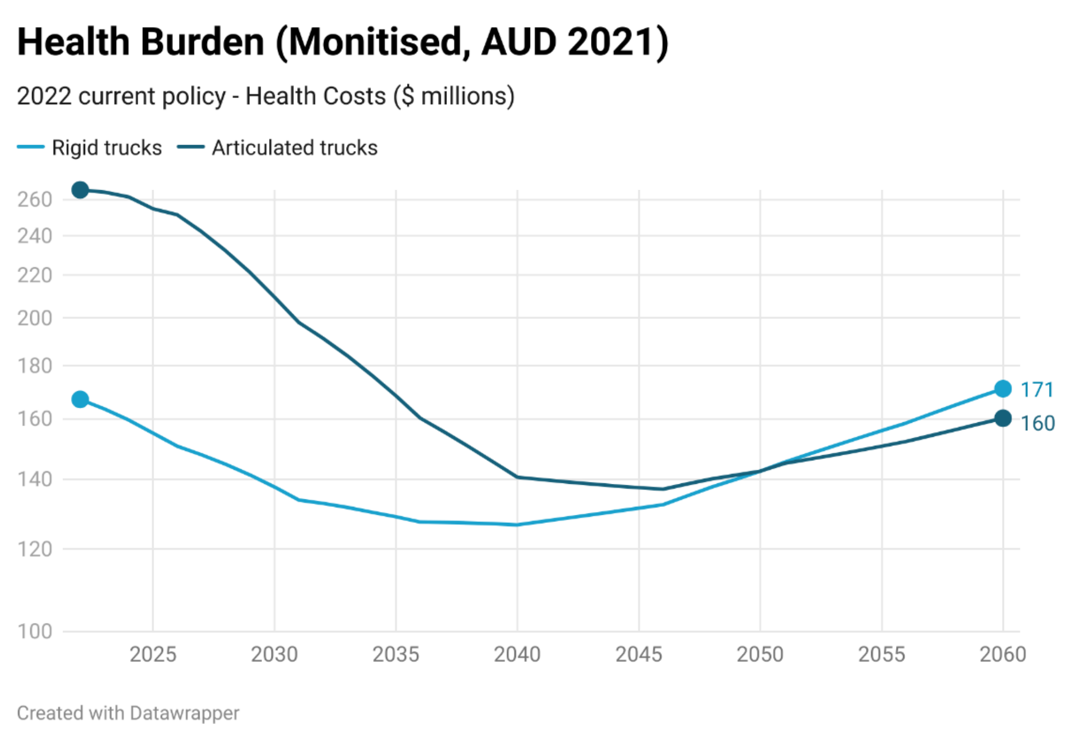


Figure 92: Summary of health burden from trucks under '2022 current policy' scenario

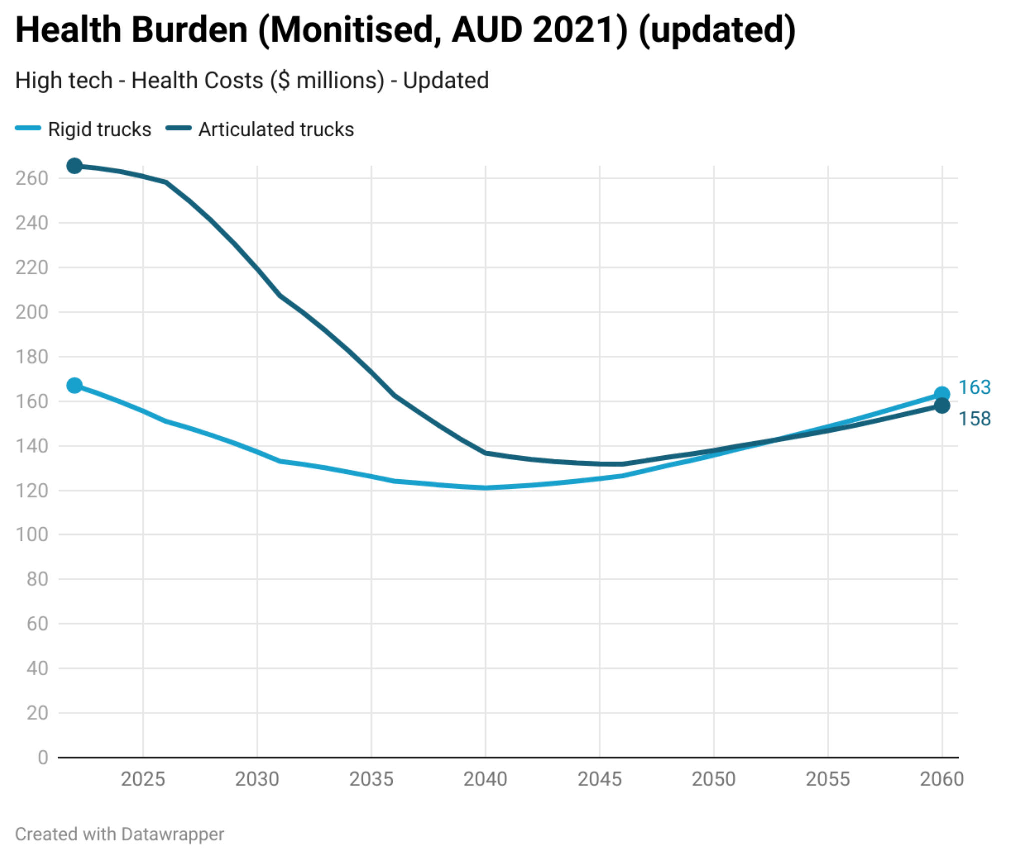


Figure 93: Summary of health burden from trucks under 'High Tech' scenario

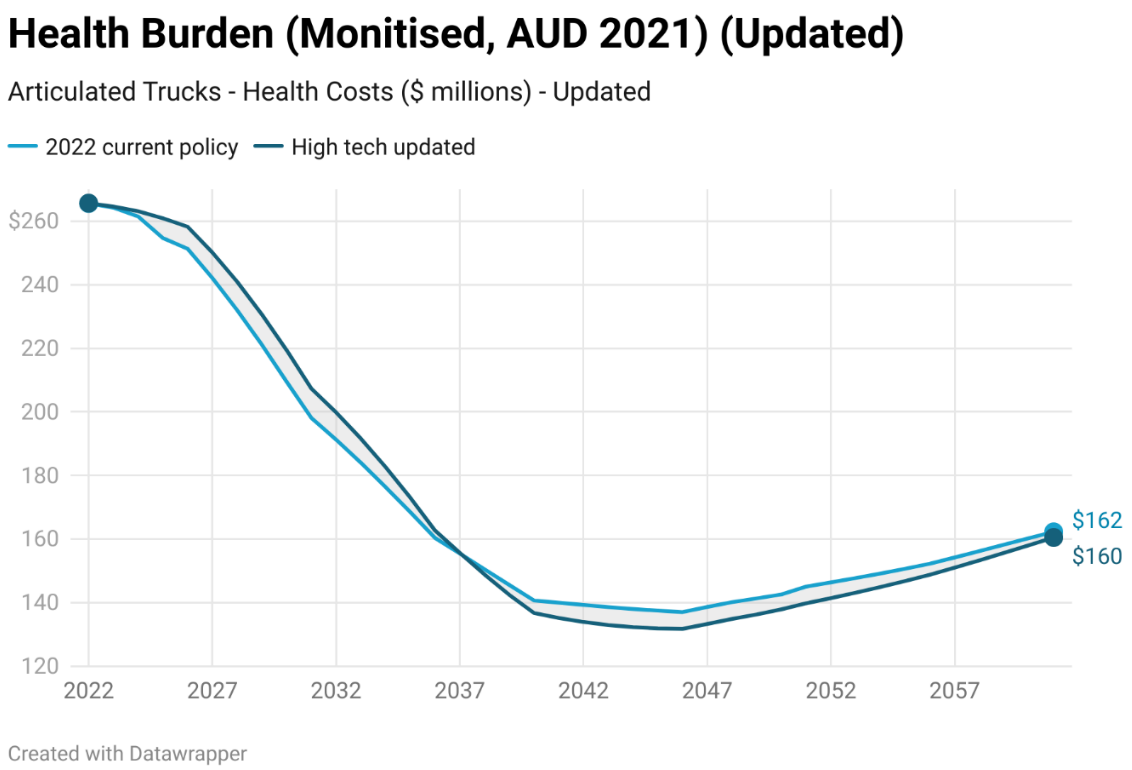


Figure 94: Health burdens from articulated trucks under DPE scenarios

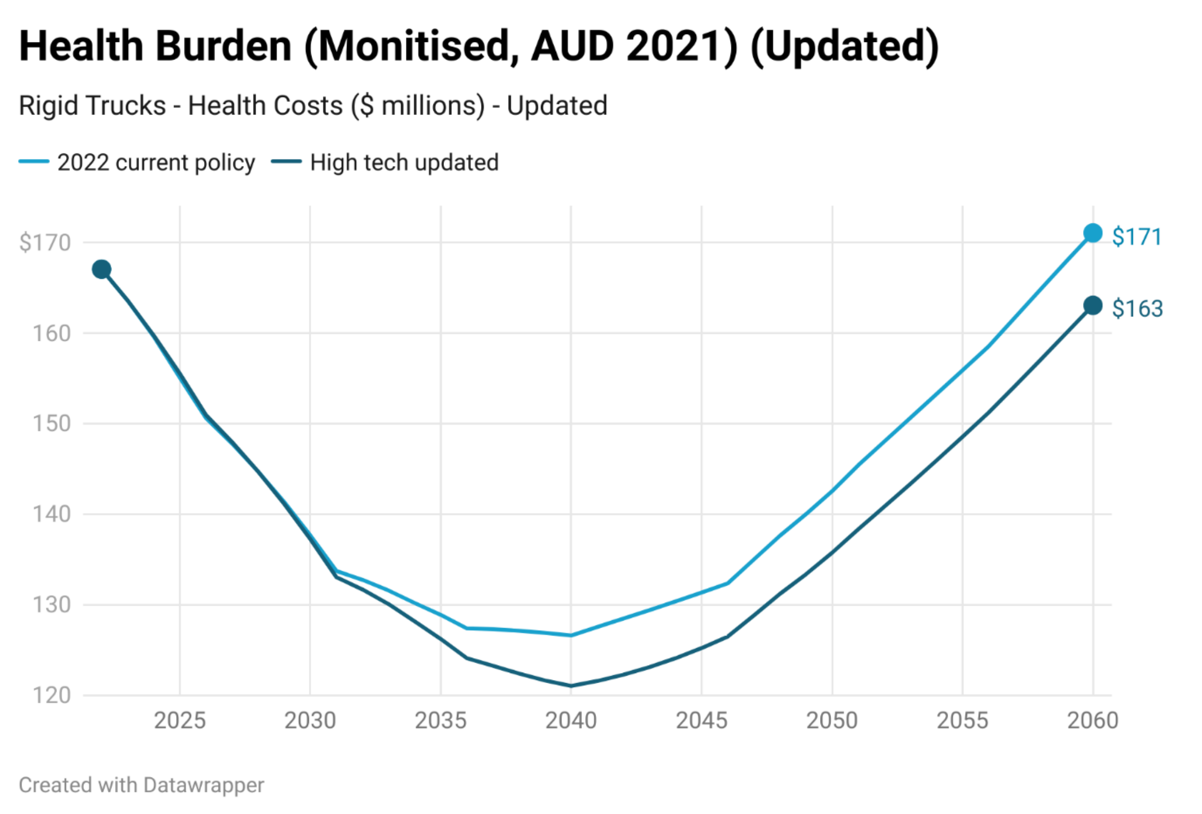


Figure 95: Health burdens from rigid trucks under DPE scenarios

Assessment of Interventions

5. Assessment of Emissions Reductions Interventions for NSW

TfNSW provided an assessment of policy levers that were considered suitable in principle, and for the research team to assess each lever for its viability to be modelled for emissions reduction impact as well as cost/benefit (**Table 14**). These are detailed below, including a literature scan of known interventions in other jurisdictions.

5.1 Financial incentives

Policies that reduce the financial cost of acquiring LZETs are designed to incentivise individuals and businesses to purchase these vehicles by lowering the upfront cost. Such policies typically come in the form of government subsidies, grants, tax benefits, or low-interest loans that can reduce the initial purchase cost of these vehicles. These policies can also support reduced total cost of ownership by promoting the use of more fuel-efficient, cleaner, and cheaper-to-maintain vehicles over their lifetime. For example, electric vehicles tend to have lower fuel and maintenance costs than traditional fossil-fuel vehicles. By lowering the initial cost of purchasing an electric vehicle through subsidies or tax benefits, governments can help make it more attractive for consumers to invest in these vehicles, and by extension, help to promote a shift towards cleaner, more sustainable modes of transport.

Under the NSW Climate Change Policy Framework 2016 (NSW Government, 2016), the NSW Government has set objectives to achieve net zero emissions by 2050. The Net Zero Plan Stage 1: 2020–2030, released in March 2020, is the foundation for NSW's action to reduce emissions, reach targets of net zero emissions by 2050 (NSW Government: Department of Planning, Industry and Environment, 2020). NSW introduced financial incentives for battery electric and hydrogen fuel cell light vehicle purchasers through rebates and exemptions from stamp duty. Heavy vehicles over 4.5t such as trucks and buses are not eligible for this rebate.

Intervention 1: Offering incentive payments or interest-free loans to decrease the upfront cost difference between LZETs and ICE trucks.

Individual businesses face increased upfront costs for purchasing LZETs (both BETs and HFCTs) as a significant barrier to decarbonise their fleet. This issue was raised during Transport for NSW's freight industry consultation in developing the draft Towards Net Zero Freight Emissions Policy. The EVC-ATA report (ATA and EVC, 2022) similarly states that this issue was consistently raised by participants and members during their workshop. Some freight operators also report higher insurance costs, and changes to electric truck utilisation based on their route charging requirements, cargo capacities, etc., which can have significant impacts on a trucking business. Industry confidence could also be improved by providing grants, rebates, or co-investment initiatives (like the rebates introduced for light EVs). According to the QTLC report (QTLC, 2022), upfront costs for zero emission trucks will continue to be a barrier for some time and a contestable fund for competitive grants could support new zero emission truck rollouts.

Examples include California Air Resources Board's (CARB) Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), which offer vouchers and incentives for the purchase of zero-emission and hybrid trucks and buses (California Air Resources Board, n.d.). Another example is the Enova SF program in Norway. Through this program, businesses can receive a grant of up to 40% of the additional cost of purchasing a zero-emission truck compared to a conventional diesel-powered truck, up to a maximum of NOK 150,000 (approximately AUD 21,300) per vehicle (Enova, 2020).

Table 14: Intervention assessment criteria

Assessment criteria for different policy categories		
Demand	Impact on short-term and long-term ZEV adoption	Policies that increase demand for ZEVs are likely to have a positive impact on adoption rates
Supply	Effect on the supply side of the market for ZEVs	Policies that incentivize or otherwise support the production and sale of ZEVs are likely to have a positive impact on adoption rates
Public support	General public support	Policies that are widely supported by the public are more likely to be effective in driving ZEV adoption
Industry support	Known position from industry specific groups like the Australian Trucking Association (ATA), the Electric Vehicle Council (EVC), on a given policy	Policies that have strong industry support are more likely to be effective in driving ZEV adoption
Implementation	Indicative difficulty to implement for government in terms of set-up, monitor, enforce, and adjust the policy overtime	Policies that are easy to implement and monitor are more likely to be effective in driving ZEV adoption
Funding	Funding requirement	Policies that require significant funding are likely to be more challenging to implement, but may also have a greater impact on ZEV adoption
NSW influence	State authority to enforce and implement a policy	Policies that can be enforced and implemented at the state level are more likely to be effective in driving ZEV adoption because they can be tailored to the specific needs and conditions of the state, and can be more easily monitored and adjusted over time to ensure that they remain effective

Intervention 2: Introduce a temporary exemption/discount/rebate to support operational costs for LZETs until sales reach set target.

Heavy vehicle charges aim to recover heavy vehicle related expenditure on roads from heavy vehicles operators. This allows governments to invest in building and maintaining productive and safer roads. The level of heavy vehicle charges is underpinned by the principle of full cost recovery from heavy vehicle road users and are set nationally.

Heavy vehicle charges are made up of the Road User Charge (RUC), administered by the Australian Government through the fuel excise system and state-based registration fees. The RUC contributes approximately 50 per cent to heavy vehicle charges and being a fuel-based excise LZETs currently have a cost advantage over ICE vehicles.

To further encourage the adoption of LZETs, an intervention could be a temporary exemption to NSW registration fees until sales reach a set target. This would mean LZETs would have a significant coat advantage over ICE vehicles particularly as it is expected that the RUC will be increasing over the short to medium term (currently increasing annually at 6 percent).

In the longer term, the increasing uptake of LZETs will reduce the RUC and adversely affect the recovery of the heavy vehicle share of road expenditure. As such, it will be necessary to move away from a fuel excise and explore a road user charging reform program such as distance-based charging across all heavy vehicles where charges would be based on the actual consumption of road services rather than a vehicle’s fuel type.

However, to make sure that any move away from fuel excise does not work as a disincentive for operators to decarbonise their fleet, the introduction of distance-based charging for LZETs could be exempt for a period, imposed at a reduced rate to the RUC or until sales reach a set target.

In New Zealand, for example, heavy electric vehicles (buses and trucks) are exempt from paying RUC, distance, and mass-based charges, until 31 December 2025 (Waka Kotahi NZ Transport Agency , n.d.). The NZ Government will then consider whether this RUC exemption should be changed as part of the planned consultation on a wider package of amendments to RUC legislation.

Intervention 3: Introduce fee exemptions or discount periods on registration, stamp duty, and tolls for LZETs until sales reach set target.

This intervention aims to incentivise individuals and companies to invest in LZETs by reducing the financial burden of owning and operating these vehicles. The set target provides a clear goal for the policy and ensures that the exemptions or discounts are not a permanent feature, but rather a temporary measure to encourage the uptake of zero emission vehicles.

California offers a reduced vehicle registration fee for eligible zero-emission and plug-in hybrid heavy vehicles (US Department of Energy, n.d.). In Norway, the government has implemented a policy that exempts zero emission trucks from toll fees on public roads and bridges, as well as from municipal road taxes. This policy contributed to a significant increase in the adoption of zero emission trucks in the country.

Intervention 4: Introduce a Feebate (fee + rebate) scheme to increase the cost of ICE trucks (extra fee) and reduce the cost of LZETs (rebate)

The Feebate scheme, also called bonus-malus, is a policy tool that introduces a charge on high-emitting ICE vehicle purchases and allocates the revenue as rebates to encourage the purchase of low or zero emitting vehicles. This method enables governments to promote the shift towards zero emission vehicles while discouraging the acquisition of ICE vehicles. Unlike incentive-based programs, feebates can be structured to maintain revenue neutrality, as discussed in (Fridstrøm, 2021). Ideally this would be implemented nationally, given some heavy vehicles are registered nationally, but in the absence of this, some form of financial support / penalty should be considered for NSW.

Sweden implemented a bonus-malus system for new vehicles in 2018, covering cars, motorhomes, light trucks, and light buses. The system rewards buyers of vehicles with zero CO_2 emissions, offering a bonus of SEK 70,000 (AUD 9,950), while buyers of vehicles with emissions between 1 and 60 g CO_2/km receive a decreasing bonus of SEK 44,400 (AUD 6,300) to SEK 10,000 (AUD 1,420). Fossil fuel powered vehicles, including hybrid electric vehicles, are subject to increased vehicle ownership tax during the first three years of ownership, with diesel vehicles paying higher rates. From June 2022, malus rates increased linearly starting at official emission values of 76 g CO_2/km (ICCT, 2022).

Assessment of the implementation of these financial incentives in NSW based on the discussed metrics are outlined below in **Table 15.**

5.2 Set LZET targets and ICE bans

Setting zero emission truck targets (e.g., percentage of fleet, percentage of sales, and number of vehicles) provides a clear goal for governments and companies to work towards and can help to drive the adoption of cleaner vehicles in the freight sector. Procurement policies can be an effective tool for achieving these targets by creating a market for LZETs and driving the development and deployment of these vehicles.

Intervention 5: Set zero emission truck targets of 30% by 2030 and 100% by 2040.

The Global Memorandum of Understanding (MoU) for Zero-Emission Medium and Heavy-Duty Vehicles was announced in November 2021 at the Conference of Parties (COP26). It is the first ever global agreement for zero emission trucks and buses and sets a sales goal of 30% by 2030 and 100% by 2040 (Global Drive to Zero, n.d.). The MoU has been endorsed by national governments, sub-national governments, manufacturers, fleets, and other industry bodies.

State Governments should raise this MoU with other jurisdictions at national transport meetings and encourage the Australian Government to adopt the target set under this MoU. The NSW government can work with manufacturers, fleets, and industry bodies to develop a plan to achieve this goal, which could include implementing procurement policies that prioritize the purchase of zero-emission trucks, providing incentives for the adoption of these vehicles, and investing in charging infrastructure. Performance against set goals can be regularly measured to calibrate the policy settings such as levels of assistance provided on purchase costs of vehicles and charging infrastructure. The sales goals would also support the net zero commitment of all Australian governments. The QTLC report (QTLC, 2022) also states that the government should develop a clean energy plan for transport and take a clear stance on heavy vehicle emission standards to provide industry confidence.

Assessment of the implementation of this intervention in NSW based on the discussed metrics are outlined below in **Table 16.**

Table 15: Assessment of financial incentive interventions in NSW

Assessment Criteria	Likely implementation and expected outcome
Demand	• Increased demand for zero emission trucks • Likely positive as heavy vehicle operators are sensitive to price. • Analysis indicates that financial incentives can help to expand adoption into rural areas (Wappelhorst, Beyond major cities: Analysis of electric passenger car uptake in European rural regions., 2021)
Supply	• Likely positive, policy may provide a more attractive market for suppliers due to potential increase in LZET demand. • Increased supply of zero emission trucks
Public support	• Infrastructure Victoria's community panel revealed that financial support had significant public support (Capire Consulting Group, 2021). This is supported by (Long, Axsen, & Kitt), which estimated that most survey respondents (70%) were supportive of EV subsidies. • Increased public support for zero emission trucks
Industry support	• The EVC-ATA report recommends incentive payment to reduce the upfront purchase price and stamp duty exemption for zero emission trucks. • Financial incentives recommended by QTLC include incentives to reduce capital costs (tax offsets, grants, rebates, and co-investment initiatives) and operating costs (fee exemptions or discount periods in registration, stamp duty, and tolls)
Implementation	• Upfront financial incentives are a one-time (non-recurring) incentive; this method reduces ongoing monitoring and enforcement, requiring less resources to manage however, determining policy condition may be difficult. • For road pricing or fee-bate schemes, it is difficult to determine most suitable or publicly acceptable introduction and implementation methods
Funding	• Requires direct government investment to fund (Slowik, Hall, Lutsey , & Nicholas, 2019) • Financial incentives likely need highest direct government investment of all LZET policies (Melton, Axsen, & Moawad, 2020)
NSW influence	Can be implemented directly via state, as in other international jurisdictions

Table 16: Assessment of implementation of LZET targets / ICE bans initiatives in NSW

Assessment Criteria	Likely implementation and expected outcome
Demand	Likely a positive, indirect benefit to demand due to market signal, and given manufacturers may have incentive to make LZET offerings more attractive to consumers (higher impact closer to an ICE ban date)
Supply	Likely positive as a strong supply side policy that provides clear signal to that a region aims to only allow LZET sales / use by a certain year. It will create a market for LZETs in NSW, which will attract suppliers and manufacturers to provide new and innovative LZET solutions. This will lead to increased competition and drive down the cost of LZETs over time. Further, (Morfeldt, Davidsson , & Johansson, 2021) found that annual CO_2 emissions were estimated to decrease with introduction of an ICE sales ban
Public support	Supply-side policies typically receive higher levels of public support but have low awareness (Long, Axsen, & Kitt). This is supported by (Capire Consulting Group, 2021), the Victorian survey suggests that the over three-quarters of respondents supported the end of ICE vehicles by 2030
Industry support	• One of the policy levers recommended by the EVC-ATA report. • The QTLC report states that there is a lack of clarity on how to reduce transport emissions and there is a need for National collaboration on emissions targets
Implementation	• Many regions have introduced bans or targets (primarily for light vehicles); however, few have taken legislative action and those which have are generally non-binding (Burch & Gilchrist, 2018) • The implementation of this policy will require significant coordination and planning from the government and stakeholders. • Bans sensitive to implementation date, particularly with delayed stock turnover effects (Fulton, Jaffe, & McDonald)
Funding	Funding expected to be limited with no direct fiscal cost (Slowik, Hall, Lutsey , & Nicholas, 2019). However, will need to be implemented with other policies that achieve target
NSW influence	Within jurisdiction, if successful, this policy could influence other states to adopt similar policies, leading to a wider transition to LZETs across the country

5.3 Regulatory interventions

Regulatory policies for LZET transition involve aligning and harmonising regulations and standards to increase technology availability and wider uptake of LZETs. Access concessions can also be introduced for LZETs, such as exemptions from truck curfews, access to special-use lanes, and night-time delivery permits. These measures can help to incentivise the adoption of LZETs and facilitate their operation in urban areas.

Intervention 6: Concessions for width and mass of trucks: exemptions from Design Rules for LZETs

Australian Design Rules (ADR) and standards for truck width rules, steer axle mass, and fuel standards are not aligned with international regulation. As a result, LZETs manufactured overseas are not directly compatible for the Australian market, reducing model availability. Australia's truck width rules, at 2.5 metres, are out of step with the standard in Europe (2.55 metres, with 2.6 metres for refrigerated vehicles) and North America (2.6 metres) (ATA and EVC, 2022). The *Heavy Vehicle Productivity Plan 2020-2025*, published by the National Heavy Vehicle Regulator (NHVR), identifies the Australian width limit of 2.5 metres as a constraint restricting the availability of heavy vehicles designed for the US and EU markets (NHVR, 2020). In February 2022, there was in principle consensus from all Australian jurisdictions to increase truck width limits from 2.5 metres to 2.55 metres for trucks fitted with advanced safety features. In October 2022, the Australian Government announced that a new ADR (80/04 based on the Euro 6) will be phased in for newly approved heavy vehicle models that are supplied to Australia from November 1, 2024. This also includes existing heavy vehicle models that are still being supplied to the Australian on or after November 1, 2025. NHVR suggests the use of safety technology, such as lane departure warning systems and cameras to provide the confidence that vehicles wider than 2.5 metres can remain in lane and not compromise road safety. Also, Australia's steer axle mass limit is 6.5 tonnes, which is lower than major supplier economies such as Europe. However, the weight of batteries can have a significant impact on LZETs and a minimum one tonne concession for steer axle mass is needed to deploy more LZET models in Australia.

If possible, standards should be aligned to allow LZET models from compatible markets to be imported to Australia. However, it is important to note that the current ADR mass and dimension regulations are due to the nature of the infrastructure in Australia and a comprehensive research review is required to understand the difference in mass and dimensions of LZETs compared to equivalent ICE trucks and how this different design of LZETs impacts road assets and associated costs in maintenance and rehabilitation. In addition to the impact on pavement wear, any mass and dimension concessions may have implications on structures, road management and HV licensing. There is research underway to test the potential impact of different mass and dimensions of LZETs on pavements using Australian Road Research Board's (ARRB) Accelerated Loading Facility (ALF). ALF measures the direct impact on the pavement resulting from axle load, tyre width, tyre pressure and other variables. While international harmonisation is a good objective it is not always feasible in the short term in Australia, without resolving the infrastructure vulnerability and safety issues. Austroads upcoming project, *NEF6392: Future freight vehicles and buses – implications for road managers* (Austroads, n.d.), will also provide guidance on the impacts of higher axle masses of LZETs compared to ICE heavy vehicles. Transport for NSW has also recently initiated a Network Impact Analysis study that will consider the impact of LZETs on the NSW state road network.

Also, consideration could be given to including vehicle emissions as part of the National Heavy Vehicle Accreditation Scheme (currently includes mass, maintenance, and fatigue management modules).

Intervention 7: Introduction of low and zero emission zones in urban areas with specific truck emissions categories and corresponding charges

This policy involves creating zones within urban areas that are restricted to LZETs. These zones could be areas with high levels of air pollution or congestion, such as city centres or residential neighbourhoods. Within these zones, trucks would need to meet specific emissions categories to be allowed to operate; for example, BETs and HFCTs with zero tailpipe emissions would be allowed to operate without any restrictions.

To enforce the policy, corresponding fee rates would be set for each emissions category. Trucks that do not meet the emissions standards for the zone would need to pay a fee to enter the zone, while LZETs would be exempt from the fee. The fees could be used to fund the development of LZET infrastructure or to incentivise the transition to LZETs.

Sweden implemented low emission zones for heavy vehicles prior to introducing light vehicles emissions zones (Government Offices of Sweden, 2018). The Zero Emissions Delivery Scheme (ZEDs) in London, launched in 2018, encourages businesses to use zero-emission vehicles for deliveries in London by offering discounted parking and other benefits. It aims to reduce air pollution and improve the efficiency of freight deliveries in the city. Implementing these zones would directly improve awareness and education of LZETs by penalising the externalities of ICE vehicles (i.e., air and noise pollution within emission zones).

This policy could be implemented after a set target percentage of new truck sales are LZETs, such that there are enough freight vehicles around to make deliveries in this transition period and delivery charges remain reasonable.

Intervention 8: Exemptions for LZETs from truck curfews and provision of access concessions, including night-time delivery and special use lanes.

Transitioning to electric trucks in NSW could mean reducing noise, congestion, and pollution on suburban and city streets. Truck curfews could be lifted for these LZETs allowing night-time deliveries. Currently, diesel trucks face curfews in some areas to limit noise pollution at night. According to SEA Electric, electric trucks are much quieter than diesel trucks, making them ideal for much quieter deliveries at night and if electric trucks were exempt from these curfews, more businesses would add them to their fleets (Agius, 2022). The EVC-ATA report (ATA and EVC, 2022) states that curfew-free operations of freight trucks could create benefits for operators by optimising fleet operations and to the community through reducing peak hour traffic and congestion.

Delivery curfews in Australia were temporarily lifted during the COVID-19 pandemic allowing heavy vehicle drivers to make deliveries outside of peak hour times when the roads are crowded; however, these curfews have been reimposed (NATROAD, 2021). In NSW, the National Road Transport Association (NatRoad) successfully lobbied for the extension of the lifting of curfews providing enough time for the NSW Government to research the appropriate conditions to be in place for a possible permanent removal of curfews in NSW (ATA and EVC, 2022) (NATROAD, 2021). A review of this exemption showed improved productivity and efficiency, flexibility to respond to surges in demand, reliability for consumers, fewer visible heavy vehicles at peak times and improvements to road safety (NATROAD, 2021).

Assessment of the implementation of these regulatory interventions in NSW based on the discussed metrics are outlined below in **Table 17.**

Table 17: Assessment of LZET regulatory interventions in NSW

Assessment Criteria	Likely implementation and expected outcome
Demand	• Likely positive, studies suggest significant impact to demand / market share. • Businesses / fleets have increased model availability to effectively transition fleets
Supply	Likely positive in line with business / fleet demand
Public support	• Likely negative, with inability to drive high-polluting ICE heavy vehicles in low / zero emissions zone likely to be perceived negatively by businesses / fleets who have invested in those vehicles. • However, public may support as these policies aim to reduce air pollution and improve the environment. Public support can further incentivise the transition to LZETs
Industry support	• The regulatory policies recommended by EVC-ATA include ADR alignment with international standards (Intervention 6) and exemption of LZETs from curfews (Intervention 8) • Interventions 6, 7, and 8 are all recommended by QTLC
Implementation	• Provided road infrastructure vulnerability and safety issues being resolved, NHVR and state could provide concessions for mass and licencing to offset the loss of payload in LZETs. • Low / zero emission zone enforcement may require telematics in vehicles or additional enforcement measures. • Another option could be automatic number plate recognition (ANPR) to send out a penalty notice for a non-compliant vehicle. • The successful implementation of these policies will depend on effective enforcement mechanisms and cooperation between regulatory agencies, industry stakeholders, and other stakeholders involved
Funding	• Considerable administrative costs (Slowik, Hall, Lutsey , & Nicholas, 2019) • Low/zero emission zone policies may be designed to be revenue generating or neutral dependent on non-compliance fees (Slowik, Hall, Lutsey , & Nicholas, 2019)
NSW influence	Can be implemented directly via state or even local government with guidance from the state

Uptake Rates

6. Estimation of LZET Uptake Resulting from Policy Interventions

This section of the report presents the research tasks undertaken to estimate potential uptake of LZETs resulting from the proposed policy interventions. The activities that were completed to estimate the potential uptake of policy interventions required:

- Primary data including the Drives Data that describes all the vehicles that are currently in the Fleet Stock, as well as Choice Experiment Data to establish parameters that feed into the equations that will be used to estimate decisions to adopt zero/low emissions vehicles.
- Definition of assumptions and methodology for calculating/estimating total cost of ownership, which includes scenarios for future electricity, hydrogen, and diesel prices as well as future prices of vehicles of different types.
- Setting up a simulation framework that utilises adoption equations as well as survival functions and VKT functions, to estimate adoption of different vehicle types over time.
- Obtaining research ethics approval and clearance to commence data collection for the Choice Experiment. The data was collected through a Panel Survey company (The ORU).
- Reviewing a large body of literature on the various types of adoption models that are available in relation to low emissions vehicles, to identify useful international data and approaches to use, to complement the data to be collected in this research. Most importantly, a key article (Cantillo, 2022) has been identified and used to construct a prototype simulation model.
- A simulation model was developed to provide adoption probabilities up to 2050 for Diesel, BEV, HEV, and Hydrogen vehicles.

6.1 Factors influencing adoption

Based on review of literature, the following factors that are likely to influence adoption of low emission trucks have been identified:

- Access to makes and models on the market.
- Financial parameters, i.e., purchase price and ongoing cost.
- Perceived added (or reduced) value of trucks using alternative fuels.
- Government policies and capacity building.

The first factor mainly relates to the opportunity to purchase vehicles, whilst factors 2-4 relate to the preference for low emission trucks over the alternatives.

6.1.1 Access to makes and models

It is reported in several studies that the limitations on the diversity of makes and models available on the market significantly impact on the decision to purchase an EV truck (Imre, 2021)(Cantillo, 2022)(Quak, 2014). It is notable that this was reported in diverse jurisdictions, such as Colombia, Turkey, and Europe. Based on a report by an industry task force in California (US), the poor vehicle quality and support from suppliers was mentioned as the second most important factor limiting adoption of e-trucks (Brotherton, 2016).

Based on demonstration projects in Europe, freight operators noted that a key issue for them is the limited available leasing options for freight vehicles (Quak, 2014). This can be addressed by capturing the carbon credits and community value in the lease price, and if the NSW government collaborates with lease service providers.

It is also revealing that in a Choice Experiment study in Colombia it was found that engine power, and range were significant factors in the choice of vehicle, when looking at willingness to pay (Cantillo, 2022). The authors also found that 37% of respondents considered the manufacturer and 39% the available technical support to be highly important factors in the choice of a vehicle (71% and 89% respectively thought these factors were important). This compares to 83% who considered cost a highly important factor (and 95% considered cost to be an important factor).

In another study (Imre et al, (2021)) also noted that limited access to efficient after-sales support is among the main weaknesses in the transition to LZEVs. They also note that the "offering of OEMs of line-produced vehicles is limited". They note that there needs to be a stronger role for manufacturers and/or leasing companies to guarantee the value of vehicles, as there is clearly a perception of risk of LZEVs due to low value (or at least uncertain resale value, and therefore high rates of depreciation), and therefore potentially losing their value more quickly (Imre, 2021).

6.1.2 Financial parameters

The overall whole-of-life cost and benefits of LZEVs can be competitive, as illustrated by this quote from a freight operator in Stockholm, Sweden (Melander, 2022):

> *"You have to look at the overall cost. If someone asks me what the vehicles cost to buy, then sure, LZEVs are more expensive than diesel vehicles. But, when I look at the total cost, including subsidies, taxes, and fuel, then that is no longer true."*

Along the lines of this thinking also, a California e-truck task force identified (upfront) cost as the most important barrier to adoption (Brotherton, 2016).

In a Delphi study with experts in the German freight business community (Anderhofstadt, 2019), they considered the key cost factors that would impact the future adoption of Electric Vehicles (EVs) in the freight sector to be (in order of importance – average Likert scale response in brackets):

- Future trends in fuel costs (6.27)
- Current fuel costs (6.27)
- Purchasing price for a vehicle (5.9)
- Depreciation / resale value (5.6)
- Service and maintenance costs (5.3)
- Expense for repairs (5.1)
- Taxes and insurance (4.1)

It should be noted that these factors generally rated lower than operational factors like reliability (6.95), access to charging infrastructure (6.82), service quality of manufacturers (6.1), maximum payload capacity (6.1), manufacturer's warranties (6.1), etc. Such factors are primarily associated with operational advantages and access to good vehicles to purchase.

For light commercial vehicles, Lebeau et al (2019) identified the following policy approaches to improving cost effectiveness of EVs over conventional vehicles:

- Penalise conventional vehicles based on one or both of kilometre-based charge or reduced fiscal incentives.
- Second life applications for batteries to ensure they receive a higher residual value.
- Ability to deduct expenses on EVs over and above those of conventional vehicles.

In China, the following costs were highlighted for commercial vehicles (Hao, 2022):

  - purchase cost and subsidies.
  - Insurance costs: but the insurance costs do not vary considerably as a function of powertrain.
  - Energy costs
  - Implicit cost: covering range anxiety, alternative vehicle cost, and repower annoyance cost.
  - Maintenance and repair: for alternative powertrains, this is derived as a ratio of costs of ICE vehicles.
  - Tax and fees: including tax on commercial vehicles, and road tolls.

The relative fuel costs of driving an LZEVs versus an ICE truck for 100 kms in different jurisdictions is shown in **Figure 96**. These costs were based on numbers provided by Noll et al as well as snapshot estimates of Australian 2023 prices of electricity at 28.66 c/kWh and $1.94 for a litre of diesel. Fuel efficiencies of 28 litres per 100 km, and 1.1 kWh per km were assumed, based on data from Volvo on similar vehicle types.

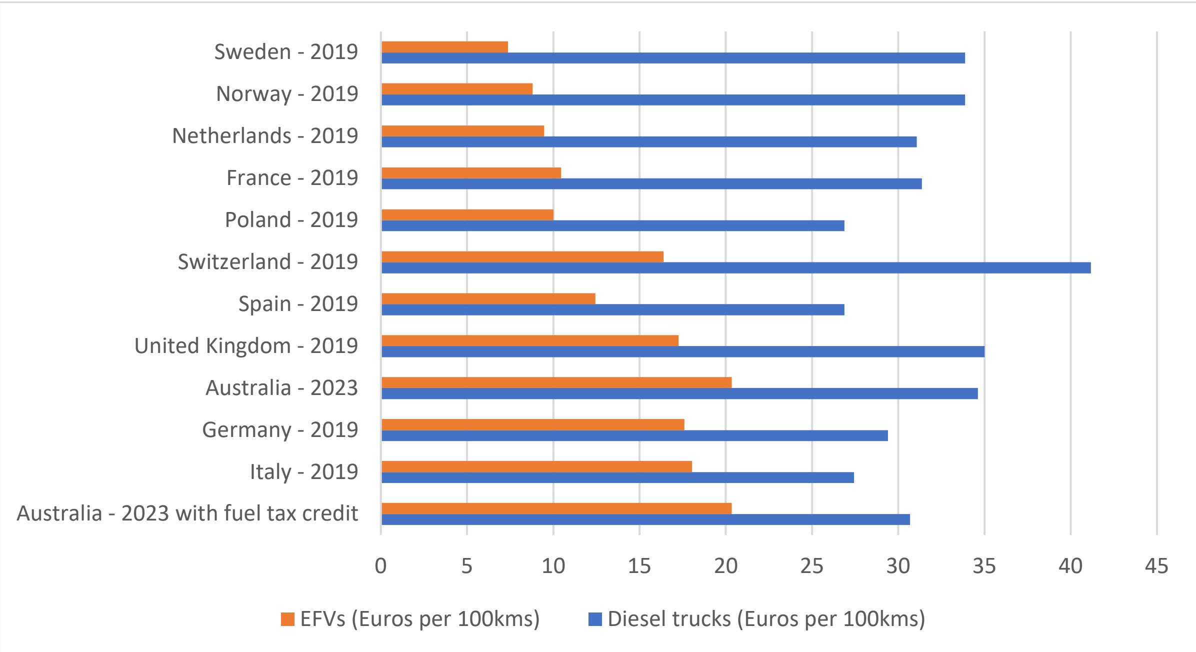


Figure 96: Relative fuel costs for driving a truck for 100 kms

Source: Data from Noll et al (2022), complemented with a snapshot of 2023 fuel prices in Australia.

It is worth noting that electricity can be sourced much cheaper than this if produced for example using solar panels - (with prices as low as 6 c/kWh for example) or based on cheaper deals. The price of diesel also seems to be trending upwards so this may be an underestimation of the fuel costs into the future. Importantly, however, many freight operators receive a fuel tax credit that currently returns 22 cents per litre of diesel[6]. Australian electricity as a fuel is the least competitive compared to all other jurisdictions, with this fuel tax credit.

Projections of fuel prices are hard to come by, but some have attempted, such as (Guerrero De La Pena, 2020), illustrated in **Figure 97.**

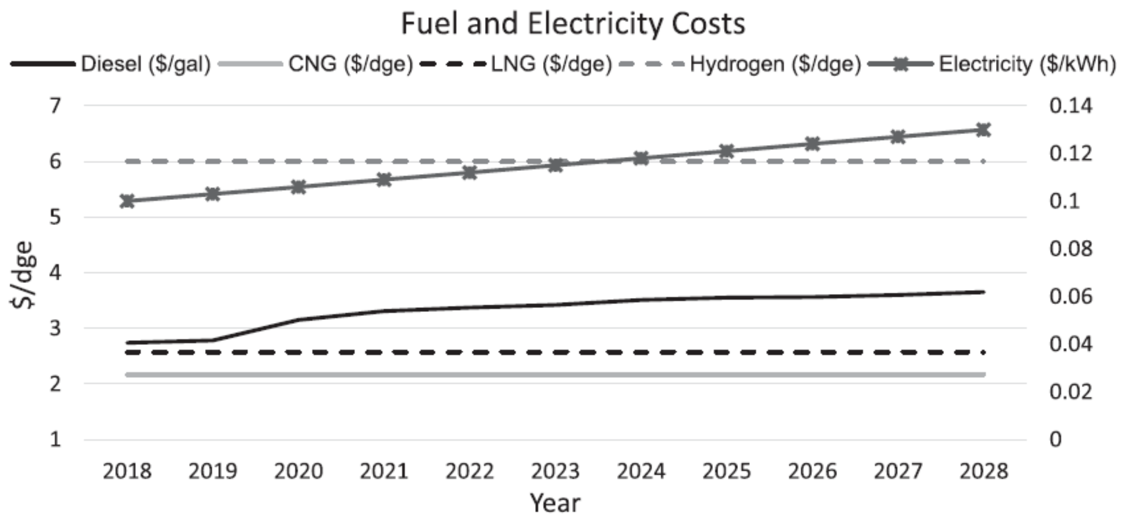


Figure 97: Assumed projections of fuel prices in 2020

Source: (Guerrero De La Pena, 2020)

The purchase price of low emission trucks is also thought to converge towards that of ICE trucks, as shown in **Figure 98.**

Hao (2022) has also shown that better battery economics has the potential to swing the scales in favour of LZEVs. For example, battery swapping techniques could help to reduce this cost and causes a big problem in terms of annual cash flows.

6.1.3 Added value of low emission trucks

Interviews of five freight firms in Sweden found the following perceived benefits of LZEVs (Melander, 2022):

- Building a brand (based on importance of sustainability in the community):

  “a way for us to differentiate ourselves from our competitors and strengthen our brand – not only as a supplier but also as an employer, to show that we take our responsibility seriously.”

  “We want stakeholders to be aware that our brand is highly engaged in these issues and that we are innovative and part of these future sustainability developments”.

  “We have some customer segments that want us to transition to LZEVs; many public customers are pushing hard. Some private customers are also interested, but they are still few”.

- Access to public organisations (via procurement rules):

6 https://www.ato.gov.au/Business/Fuel-schemes/Fuel-tax-credits---business/Rates---business/From-1-July-2022/

"Public organizations face demands on how deliveries are conducted, whether you use delivery sharing, the types of vehicles you use and so on. These demands are increasing. Also, private customers have started having similar demands. It's right on time."

"Public procurement has started to include clear demands for fossil-free transport. It is a starting point in public procurement nowadays."

"It is becoming more and more a standard in public procurement that you need to promise a certain percentage of fossil-free transport. Previously, this was something that you could say was difficult to accomplish, and contractors would let you get away with not fulfilling it. But today, it is becoming a non-negotiable demand. It has moved up the priority list and become the most important thing."

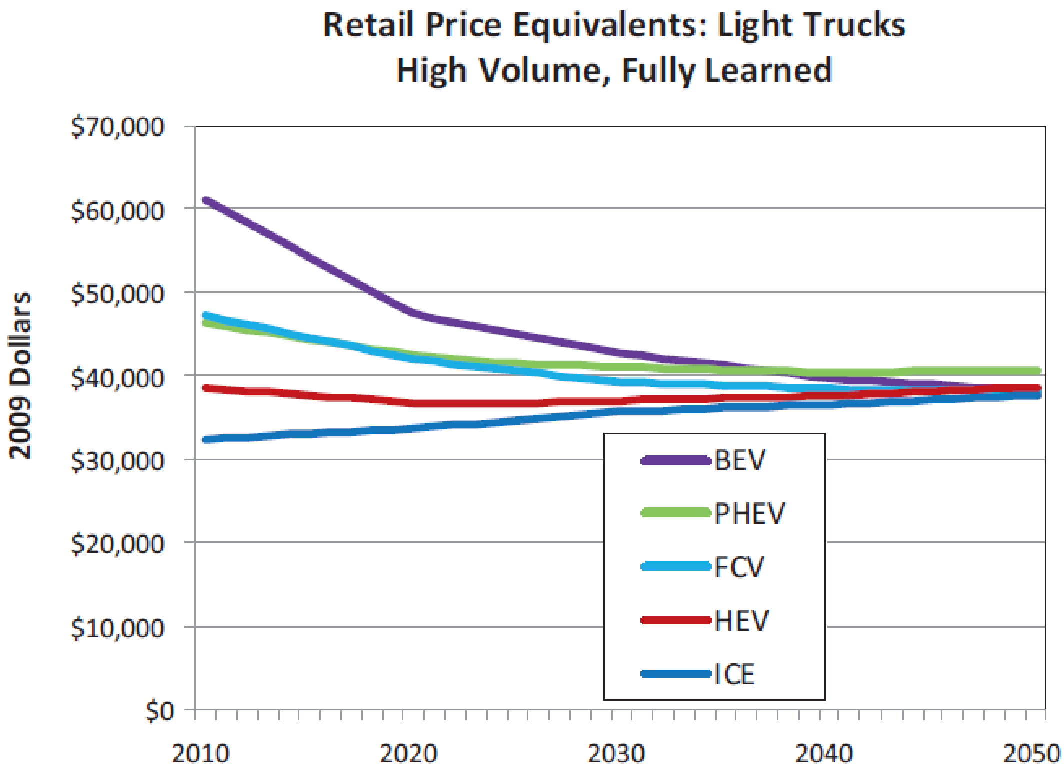


Figure 98: Assumed changes in upfront price of trucks

Source: (Greene D. L., 2014)

6.1.4 Government support and capacity building

Based on interviews of freight operators in Sweden, Melander et al (Melander, 2022) reported the following:

> *"We need to relearn everything, how the trucks work, how the charging works; we need to learn how to build our routes. There are a lot of new things to consider, and we need to learn how to get our customers to accept this and to share the costs."*

To run a fleet of trucks on electricity (or other low-emission fuels) will require a change of logistical practices, especially because of the different charging/fuelling requirements compared to an ICE vehicle, as well as the different profile of weight and haulage volume of Low and Zero Emissions Vehicle (LZEV). This means that over time, freight fleet operators will need to build the competencies and update their practices to allow this to happen. There could be a role in government in providing training and guidance during this transition stage, as well as aligning regulations to be better suited to new vehicle fleets. It is however expected due to the slow attrition rate of old vehicle fleets that this will be a slow process, and EVs are likely to find niche applications during the early years of uptake. Quak and Nesterova (2014) report on demonstrator projects across Europe and note several potentially useful policy interventions:

- In Amsterdam, setting up (low) emission zones, use of bus lanes, parking at non-loading areas, wider time road access restrictions, and possibilities to enter pedestrian zones resulted in operational advantages for LZEVs. This had a positive effect on logistics operations, especially in terms of time savings, associated with loading/unloading, as well as driver walking times, and ease of planning deliveries.
- It was also found during the early stages of adoption in these demonstrator projects that the certification of vehicles was a problem where regulatory support is necessary when vehicle types come in small batches. This is because the requirements are strict: all vehicles, like these, tend to be tailor-made and with specifications that slightly differ in batches, and therefore they must be tested to get a certificate. This indicates a higher certification cost.
- They also found that drivers are not concerned about range issues if there is a stable and predictable daily delivery environment with which they know their vehicles will be able to cope.

Similar sentiments were noted by Melander and Nyquist-Magnusson (Melander, 2022) based on interviews with a set of five freight operating firms in Stockholm, Sweden. They identified the following competencies that need to be built:

- There is a need for rethinking distribution with LZEVs, not possible to use the old ways of optimizing distribution.
- There are currently no available route planning programs that allows planning for charging during the route – at least in Stockholm.
- It is often more stressful for drivers to reload (not required with a diesel vehicle).

A key suggestion from the study by (Lajevardi, 2022) is that a key driver for adoption is the infrastructure roll-out scenarios. Based on a set of assumptions on these issues, they were able to estimate the breakdown of market share under several different scenarios.

6.1.5 Summary

The review of policy options here, to formulate key options for policy makers in Australia and New South Wales, that could be used for promoting the adoption of LZEV trucks:

- The reviewed literature identifies that access to vehicles that have all the right performance metrics is probably the most important factor impacting on adoption of LZEVs. This relates to the engine's power, and range, but also to the quality-of-service providers for maintenance etc. It also shouldn't be under-estimated that uncertainty about performance can be a sticking point, i.e., unless you have already incorporated a LZEV truck into your fleet, there is likely to be some risk aversion. A way to overcome this issue is to heavily subsidise the first few vehicles in a fleet.
- The second most important issue is the financial performance of LZEV trucks, although it is noted that LZEVs are soon likely to be performing well, at least on a Total Cost of Ownership (TCO) basis. The high purchase price will remain a key consideration well into the future, and this can be alleviated through supporting more leasing options. Embedded within the financial performance is the key issue about the cost of fuels, and it was noted

that diesel is relatively cost-competitive vis-à-vis electricity in Australia, at least when accounting for the current fuel subsidies for diesel. Recent price rises on Diesel is likely to impact on uptake of LZEVs, and there are potential opportunities in ensuring access to cheap electricity for LZEV trucks.

- International evidence appears to indicate that at least some freight operators consider there to be additional business value associated with purchasing and operating LZEV trucks. International evidence highlights the value for the brand, as well as access to customers (esp. government clients) who demand environmentally friendly services.
- Finally, and importantly, the transition to LZEVs is likely to involve many teething issues, and government can help by supporting education, training, and capacity building, as well as the developing of logistical support tools (for scheduling etc) and to support demonstrator project. International evidence also suggests that providing road access to special lanes or zones accessible only for LZEVs, can support the transition.

6.2 Survey and choice experiment

A Choice Experiment (CE) and associated survey was undertaken to collect evidence on:

- Responsiveness of technology uptake to the purchase price and ongoing cost.
- Extent by which freight operators are willing to pay extra for low emission trucks.
- Potential impact of certain non-financial policy interventions.
- Impact on decisions, of access to charging and refuelling infrastructure.

A CE is a "stated preference" survey approach designed to elicit consumer preferences based on hypothetical markets (Mariell, 2021). Respondents are required to choose between multiple types of goods - in the current study, different types of trucks. It is a method widely used by economists, especially for establishing "non-market" values. Within the CE, participants were confronted with "choice cards", as shown in **Figure 99**, where they were asked to choose between multiple options, with variable attributes on types of trucks. For each choice card, there are three options (varied systematically according to an experimental design), as well as the option of a "protest choice" which in this case is a status quo option, i.e., a diesel truck.

To make it a substantive choice in the Choice Experiment, it was assumed that all vehicle types are available for purchase, but we note that for LZEV trucks this is not yet the case. For example, there are not yet any large articulated hydrogen fuel cell electric trucks on the market in Australia. This means that respondents are choosing in a hypothetical scenario and may have limited experience and knowledge about new technologies (i.e., LZEVs). Normally, and this has been the case in previous Choice Experiments in other locations, there is a systematic bias against new technologies, but this was not observed here.

6.2.1 Data collection and respondents

The survey data collection occurred during late April and early May 2023. Recruitment was completed using a certified survey panel company, The ORU (https://www.theoru.com/). Survey panel members sign up to be a member, and the recruitment occurs through offline strategies (print ads, telephone, postal). The survey included 28 survey questions, and 12 Choice Experiments questions. Screening criteria for inclusion in the survey were:

- Being at least 18 years of age.
- Working for an employer that provides any road freight, (road) transport, and/or (road) postal services.

- Making strategic decisions within the business that they work for. Examples provided include involvement in logistics or supply chain coordination, transport planning, route planning, insurance, fleet acquisition or management, executive management, or owner-operators.

	Option 1	Option 2	Option 3	Diesel truck
Power train	Hydrogen fuel cell (400 km range and fast refuelling)	Battery electric (300 km range)	Battery electric (300 km range)	I would choose a regular Diesel vehicle instead ($100,000 purchase price, $25,000 annual cost, 400 km range, and your preferred make and model)
Charging/refuelling stations for each diesel station	25% as many as for diesel/petrol stations	As many as for diesel/petrol stations	As many as for diesel/petrol stations	
Make and model	Not your preferred choice	Not your preferred choice	Your preferred choice	
Ongoing costs incl. insurance etc (per 100 km)	$100	$40	$15	
Purchase price (after any subsidies, and with a 5% interest loan)	$200,000	$200,000	$200,000	
Buy-back scheme for vehicle/battery at end of life (20% of purchase price at end of life)	Yes	Yes	No	
Low-emission access package (i.e. reduced night time restrictions, access to special lanes, and access to low emission zones in urbanised areas)	No	Yes	Yes	
Annual cost (ongoing plus finance)	$39000	$21000	$22500	
	○	○	○	●

Figure 99: An example of a choice card in the CE survey

Note: Each survey respondent was confronted with 12 choice cards.

After the survey was completed, a set of respondents were removed for the following reasons:

- Non-sensical or obvious repeat responses
- Filled out the survey too quickly.
- Protest bids (i.e., always chose the diesel truck and noted in the follow up responses that this was because they were not basing their choices on facts)

Several unrelated job roles (chef, nurse, social services, etc) were also removed.

After responses were collected, and inappropriate responses removed, there were 199 responses left, exceeding the 140 target which was identified based on the design of the experiment. A summary of the characteristics of these respondents is shown in **Table 18.** Respondents were from across all Australian states and territories. 92% of respondents were from the south-eastern states and territories, as per **Figure 100**. The age distribution of participants is shown in **Figure 101.**

Table 18: Summary statistics describing the responses of survey participants. N=199

Q12. What is the size of the fleet (number of trucks) of the company that you work for?		Q10 - What's your role in the company you work for? Categorised.	
1-5	66%	Management	30%
6-10	17%	Owner	27%
11-49	11%	Director	22%
50 or more	6%	General staff	13%
		Analyst	8%
Q14 - What proportion (approximately) of the goods that your company transports, is delivered within a metropolitan area such as Sydney?		Q13 - What proportion (approximately) of the goods that your company transports, is refrigerated or perishable?	
None	16%	None	56%
Some	26%	Some	16%
About half	17%	About half	11%
Most	26%	Most	11%
Nearly all	16%	Nearly all	6%

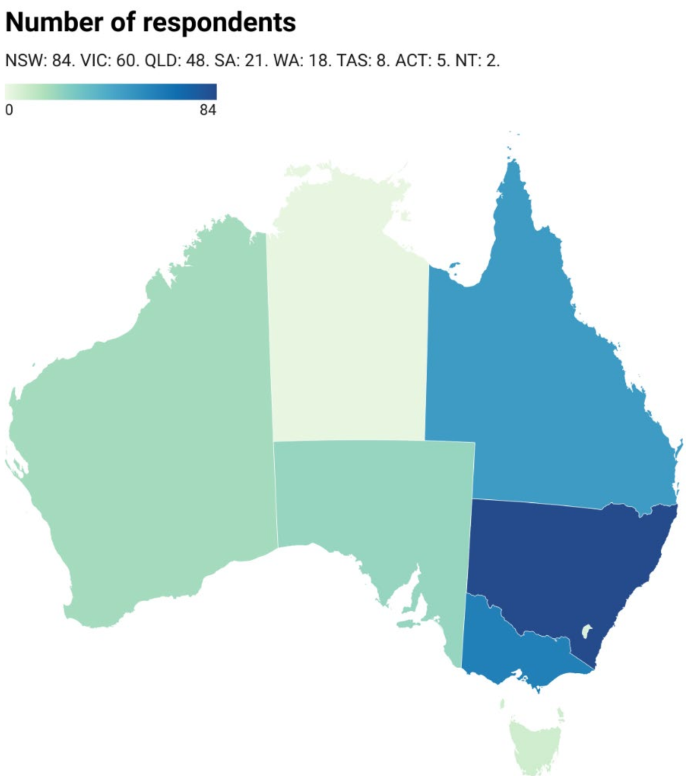


Figure 100: Distribution of survey participants across Australian states and territories

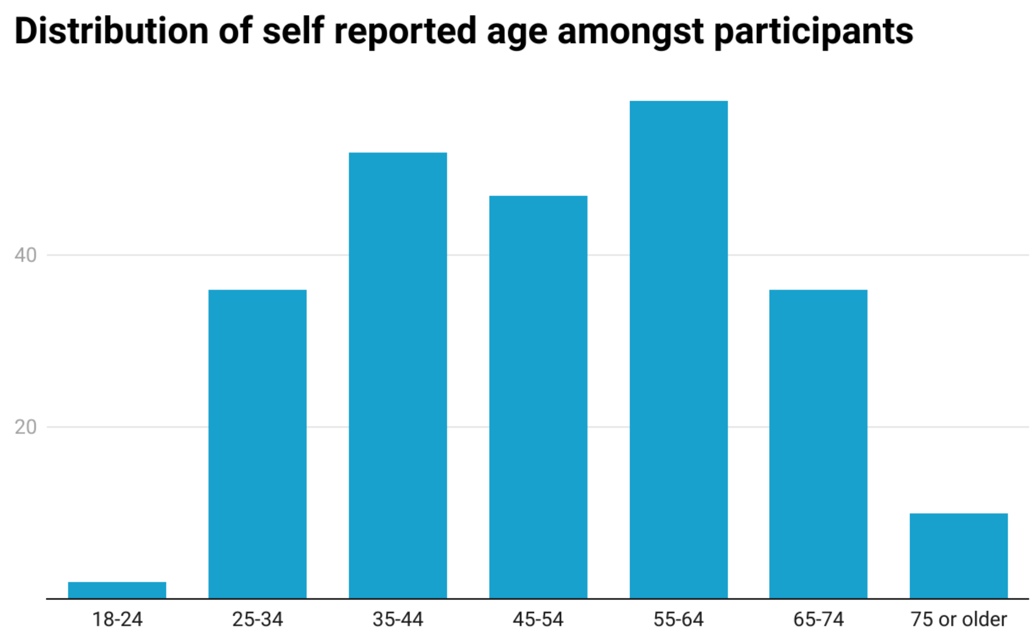


Figure 101: Participant age distribution

6.2.2 Attitudes towards decarbonisation/climate change

Participants were asked three questions relating to decarbonisation and climate change with the summary of responses shown in **Table 19** and **Table 20.**

Table 19: Summary of respondents' attitudes towards decarbonisation

Q38 - How important do you think it is that the freight sector rapidly reduces its emissions in Australia? N=199.		Q39 - How do you feel about suggestions that the freight industry needs to decarbonise? N=199.	
Not at all important	4%	Extremely negative	3%
Slightly important	23%	Somewhat negative	8%
Moderately important	30%	Neither positive nor negative	34%
Very important	27%	Somewhat positive	41%
Extremely important	17%	Extremely positive	15%

It could be assumed that an important underlying factor in relation to the attitudes towards decarbonisation is the participants beliefs about climate change, and therefore the survey asked a question to better understand and benchmark such beliefs against previous studies. The results of this question, as well as a comparison with results from a CSIRO 2010 study, using the same survey instrument but different recruitment methodologies, are shown in **Table 27**. It is noted that the survey participants in the current study had similar, albeit somewhat more sceptical views on climate change, when compared to a sample of the Australian population in 2010 (Leviston, 2011). It is also noted that the Australian community's level of concern about climate change has risen sharply since 2010, as shown through polling by the Lowy institute, although this study used a different methodology (Lowy Institute, 2023).

Table 20: Beliefs about climate change

Given what you know, which of the following statements best describes your thoughts about climate change? Tick one box only.		
Statement	**% of survey respondent in this survey. N=198.**	**% of survey respondents in large survey by the CSIRO in 2010. N=5036.**
I think that climate change is happening, and I think that humans are largely causing it.	49%	50%
I think that climate change is happening, but it's just a natural fluctuation in Earth's temperatures.	33%	40%
I have no idea whether climate change is happening or not.	12%	4%
I don't think that climate change is happening.	6%	6%

6.2.3 Insights about policy

Although the survey did not aim to gauge preferences on policies, a couple of insights could be made based on the results. Firstly, options for leasing BEV trucks could make them more attractive, as shown in **Figure 102**, at least for about half of participants. Also, there was some broad level of preferences for waiving road tolls, road access to special lanes, increased mass limits, and even low-emission zones or removed noise curfews (see **Table 21**).

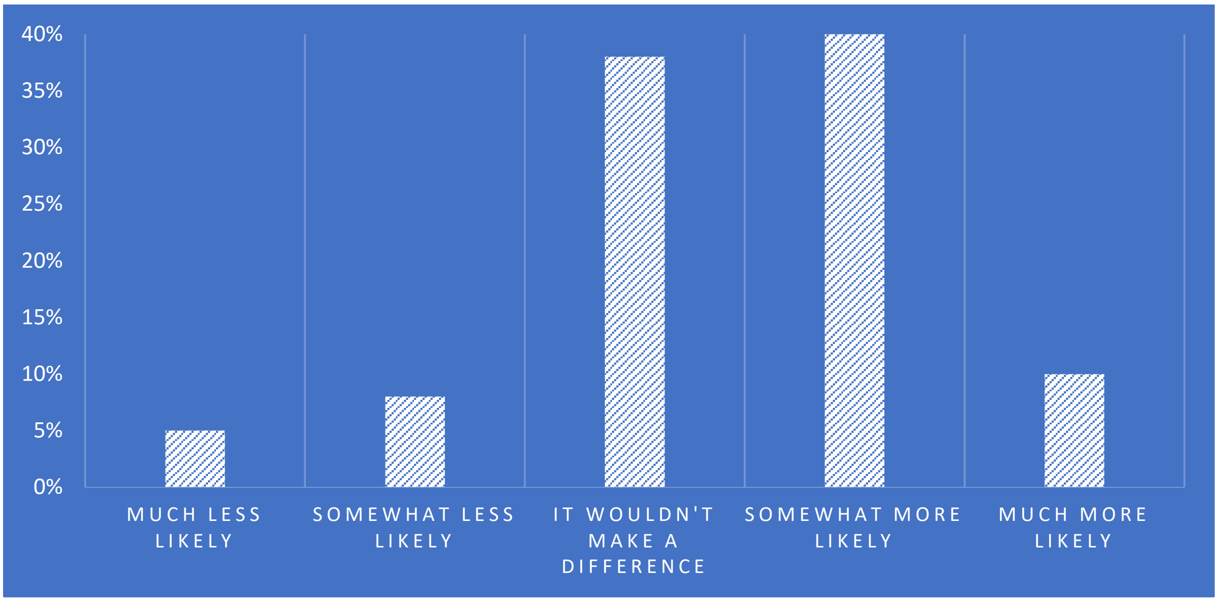


Figure 102: Responses to the impact of leasing options on uptake of electric trucks

Note: N=199

Table 21: Summary of responses for preferences on low emission policy incentives

N=194.

Q34 - Which parts of the low emissions access package do you think are the most appealing to the business you work for? Choose the preferred options in the list below. You may select multiple options.	% of responses
Waived road tolls: removing the need to pay road tolls for trucks that use low emission technologies.	46%
Access to special lanes: lanes, like bus lanes, on key roads, designated for low-emission trucks (electric, hydrogen, etc)	38%
Increased mass limits: applied to low-emission trucks to allow for heavier vehicles on the road.	25%
Low-Emission Zones: parts of Sydney and other urban areas to be designated as low-emissions zones where diesel trucks are prohibited.	24%
Remove noise curfews: allowing (electric or hydrogen) trucks to deliver goods during night-time in areas where curfews currently exist due to noise restrictions.	17%

6.2.4 Conjoint Analysis results

The influence of the following attributes was being explored in the CE, i.e., the:

- Price of the truck.
- Type of truck (i.e., FCEV, BEV, or ICE truck)
- Ongoing cost (per 100 kms) of the truck.
- Choice of preferred make and model of truck.
- Buy-back scheme for the battery (for BEVs and FCEVs)
- Low emissions road access to zones, special lanes, and night-time freight, etc.
- Access to charging/refuelling infrastructure.

Qualtrics software was used for undertaking Conjoint Analysis, which uses a hierarchical Bayesian algorithm to estimate respondent-level utility scores (i.e., how much each respondent value different attributes). Analysing the results of the CE based on Conjoint Analysis (Raghavarao, 2010), helps to determine the "utility" (value) that an individual assigns to a particular truck that they are presented with is determined by the characteristics of the attributes and individual specific characteristics. The functional form of this utility for individual i of option j is shown in the following equation:

$$V_{i,j} = \beta_{fueltype\ j} + g(purchase\ price) + f(ongoing\ cost) + \gamma(charging\ access) + \alpha(policy)$$

The values, including the functions g, f, γ, and α are determined based on the statistical analysis of the survey data. It is noted that the functions g, f, and γ are all linear or piecewise linear functions with intercepts and gradients in **Figure 103, Figure 104** and **Figure 105**. The function α is based on the presence (or not) of road access to low emission zones, lanes and loosening of night-time restrictions for zero emissions vehicles. If so, it's +0.08, and if not available the value is -0.08.

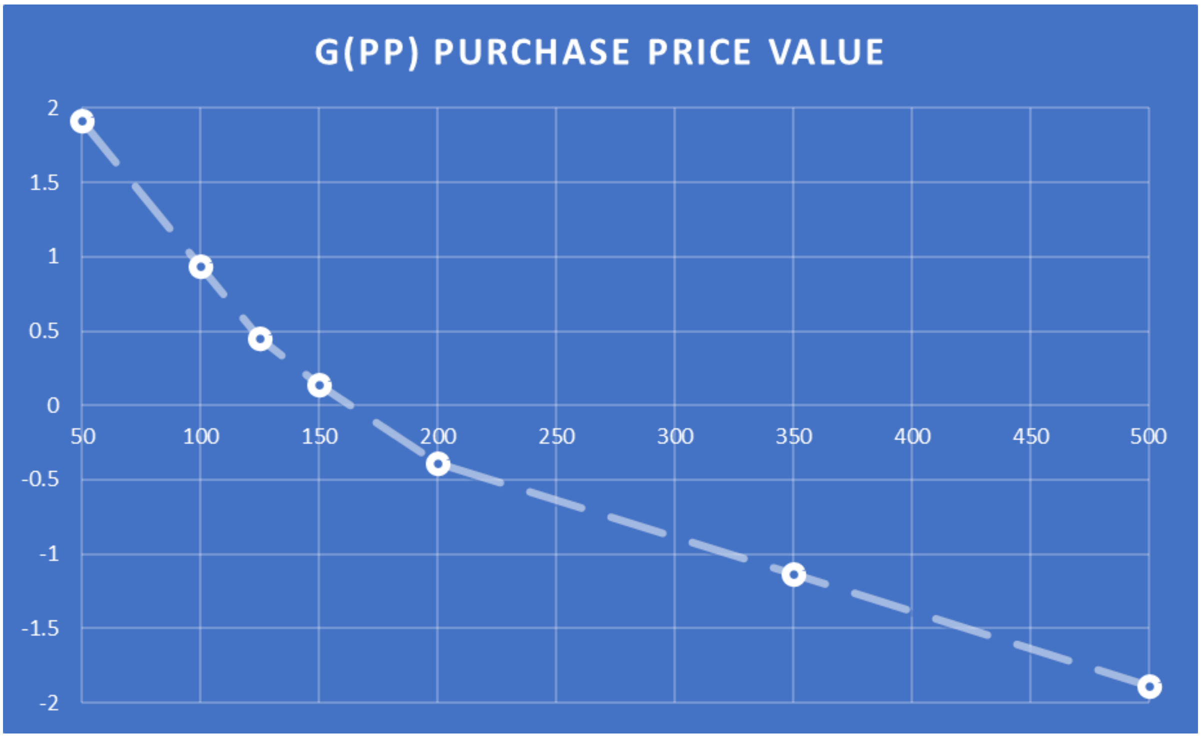


Figure 103: Assigned value as a function "g" of purchase price

Note: A piecewise linear function where x-axis shows the purchase price normalised (so that 100 represents the price of a diesel truck in 2023). Y-axis shows the value for equation 1.

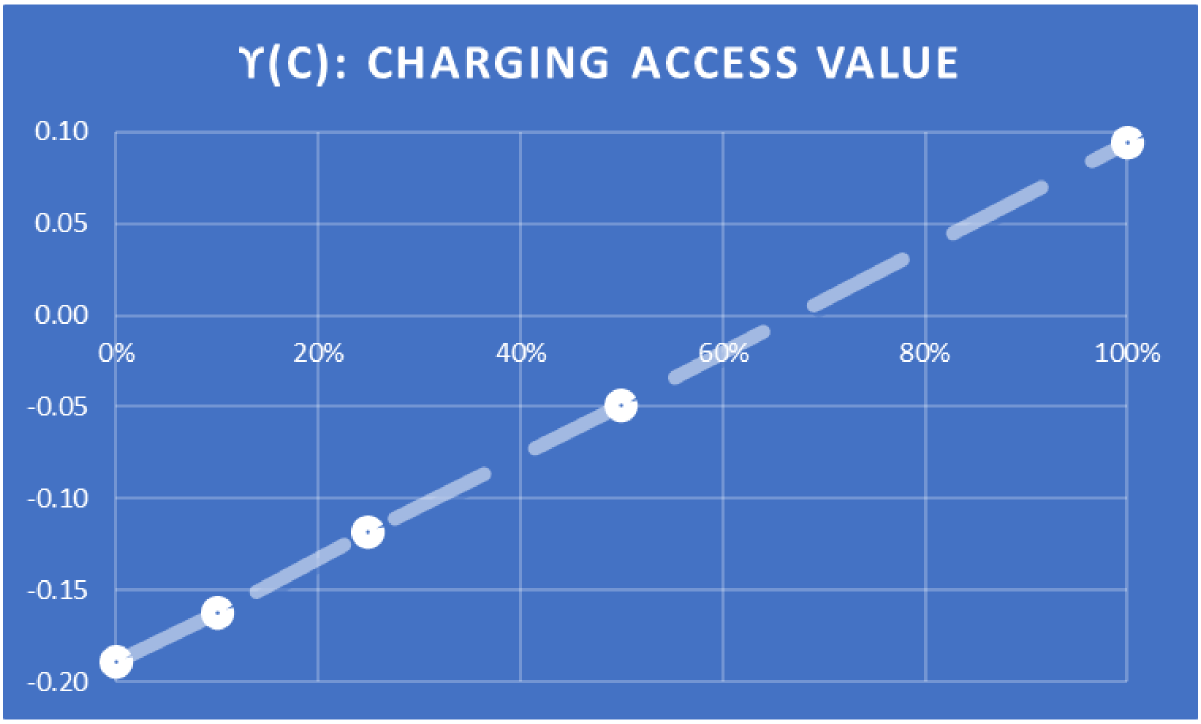


Figure 104: Assigned value as a function gamma of the charging access available

Note: A linear function where the x-axis is showing the percentage access. The y-axis shows the value that goes into equation 1.

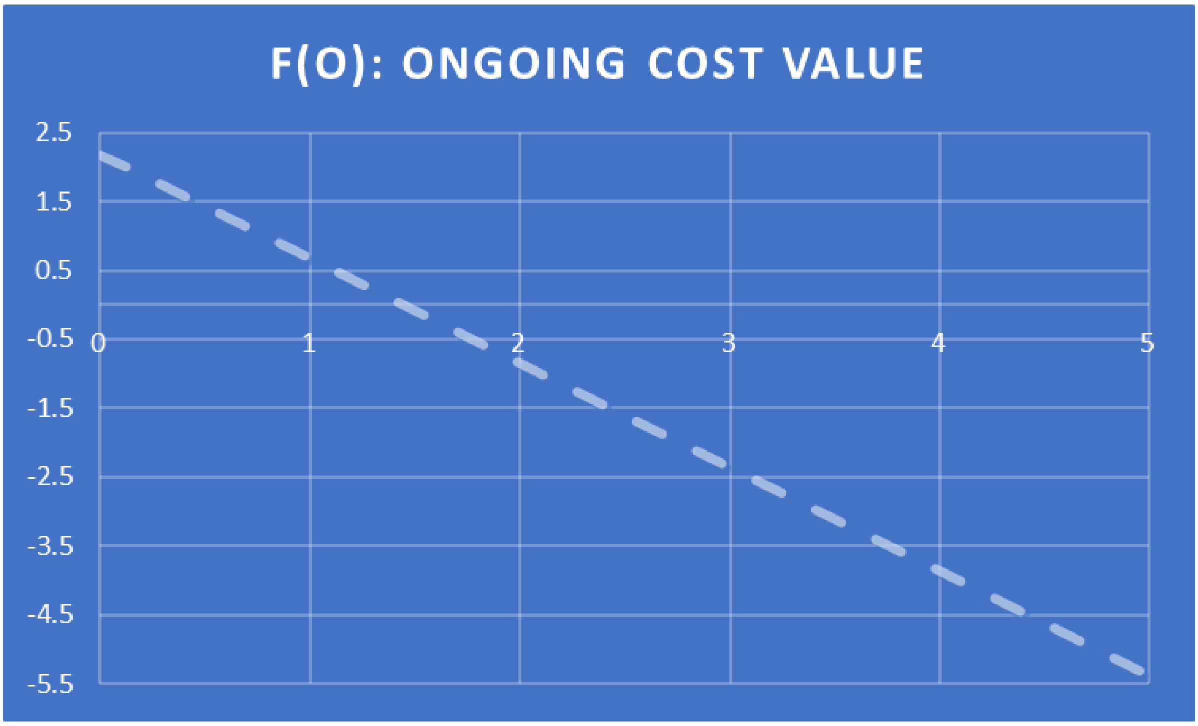


Figure 105: Assigned value as a function of f(o) of the ongoing cost (per 100 kms)

Note: A linear function where the x-axis is showing the normalised ongoing cost, where 1 represents the cost for a Diesel truck in 2023.

An important focus of the survey was to evaluate the extent by which freight companies might be happy to pay extra for a BEV or FCEV. The answer, according to the CE, is yes, they are, with the estimated values associated with fuel types shown in **Table 22**. The relative value of a BEV is smaller than the relative value of the FCEV. A lower value in **Table 22** indicates a lower relative preference for this type of technology (i.e., fuel type) and these values are incorporated into the equation at the start of the modelling chapter, through the exponential function.

Table 22: Values associated with different fuel types

Fuel type	Value	Exp(value)
Battery Electric Vehicle	-0.30	0.74
Fuel Cell Electric Vehicle	1.28	3.6
Diesel Vehicle	-1.46	0.23
Hybrid Electric Vehicle	0.48	1.6

6.2.5 Adoption preferences clusters

Amongst the survey participants, two clusters were identified, based on their distinctly different preferences. Cluster 1, has a relatively strong preference for low emission trucks whilst cluster 2, representing the remainder of participants has a relatively strong preference for diesel trucks. Key differences in responses between two clusters are shown in **Table 23.** Simulating the preferences of the two clusters in a hypothetical scenario of a diesel truck ($100,000 purchase price and $40 per 100 km ongoing costs) vs a battery electric truck ($200,000 purchase price and $40 per 100 km ongoing costs) with current limited levels of access to charging infrastructure, Cluster 1 (progressives) would select the BEV truck 66% of the time, whilst Cluster 2 would select the BEV truck only 4% of the time.

Table 23: Patterns of responses amongst the two clusters

Key area of difference	Cluster 1: "Progressives"	Cluster 2: "Conservatives"
Age profiles	Younger. Median age 35-44	Older. Median age 45-54.
Fleet size	Generally larger, with 49% having 6 and more vehicles.	Generally smaller, with 72% smaller having 1-5 vehicles.
% that expect that freight will shift to electric by 2030	40%	6%
% positive or neutral about decarbonisation in the freight sector	63%	46%
% of all participants in the survey as they were classified into these clusters	57%	43%

Cluster 1 would be happy to pay extra for a BEV (over a diesel truck) whilst cluster 2 would be happy to pay extra for a diesel truck (over a BEV truck). Interestingly, both clusters put a relatively high value on FCEV trucks, which therefore appears to be an option that both clusters can agree on.

Some of the concerns raised about BEV trucks, especially amongst cluster 2 were:

- BEV trucks are too expensive (61%).
- The BEV technology is too new and untested (33%).
- There is a risk of fire in the BEV truck batteries (27%).
- There aren't enough good (BEV) vehicles to choose from (24%).
- The BEV trucks are too heavy (18%).
- There is nowhere to buy BEV trucks (10%).

Another concern raised is about access to charging stations as illustrated by this quote:

> *"Most charging stations are out of service. As a logistics operator, time is of essence. In every scenario, if you have equal or same number of charging stations, better range and slightly more expensive than diesel, then I would opt for an electric truck. However, refuelling is a time-consuming exercise, so if you limit the number of refuelling sites, you make diesel very attractive."*

A concern is also about the range of BEV trucks as illustrated by this quote:

> *"BEVs don't have sufficient range for any but small courier type operations or local deliveries as yet."*

6.2.6 Commentary on current perceptions

We note that in the survey and choice experiment, participants were presented with a range of options on types of trucks that are currently not yet widely available on the market. This is important because the survey captures views and preferences at a particular moment in time. At the time of the survey, there is seemingly limited understanding of new truck types (see section on stakeholder consultations), and there is always an expected inertia where some resist change or new technologies.

Here, indeed we did find that there is a group of freight operators that are still very much resisting any type of change. We did, however, also find that there is a relatively large group of participants with a positive view on both BEVs as well as FCEVs, but the positive views on FCEVs were more widely held. This is consistent with what seems to be a general mood, where limitations and concerns have been raised about BEVs, in relation to range, fire risk, and cost. Such concerns have not yet been widely raised about FCEVs, but this may simply be due to limited understanding of the technology which is still evolving towards becoming mature enough for the current market. There are also significant questions about the emissions impacts of FCEV and to what extent they can form the basis of an appropriate emissions reduction strategy (Camacho et al., 2022). They would also require high initial investments in infrastructure (Camacho et al., 2022). Regardless, it is important to understand that perceptions of these options are dynamically dependent on the understanding and knowledge about technologies which are rapidly changing. This indicates the need to monitor such views over time.

We also note that in the presented options within the Choice Experiment, the BEVs were presented as having a lower range (300 kms) than the FCEV or diesel trucks (400 kms). Range is a known factor in the choice of trucks (but not included in the Choice Experiment), The lower range for BEV trucks compared with FCEV or diesel trucks is consistent with current performance but may not be consistent with future performance.

6.3 Modelling future adoption

A common approach for modelling the future uptake of LEVs is based on the optimisation of Total Cost of Ownership (Guerrero De La Pena, 2020)

(Zhou, 2019) adopted a social science methodology based on surveying delivery drivers in China about the intention and use of EVs for their trips. This was based on a questionnaire and structural equations analysis, and the resulting model is described in **Figure 106**.

A common approach for modelling the future adoption of emerging technology is to use econometrics, that consider both financial and non-financial considerations, for example using Choice Experiments as we have in this study (Lajevardi, 2022); (Cantillo, 2022). In this section we further describe the econometric approach we have used in this study.

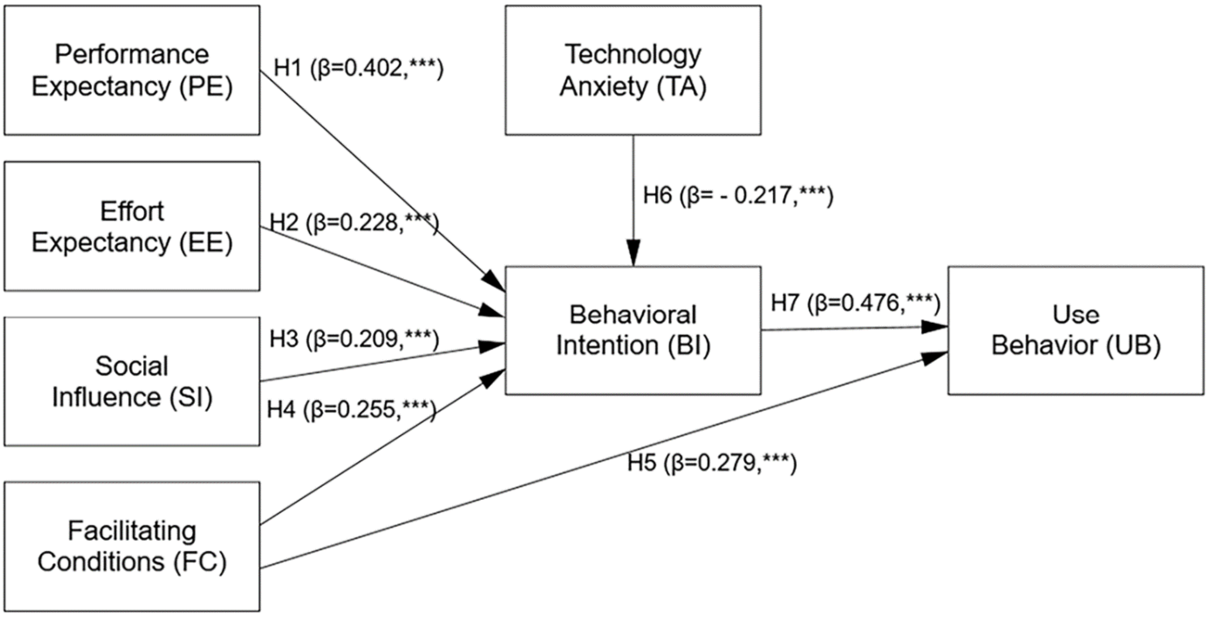


Figure 106: Structural Equations Model: intention and use of EVs for urban deliveries

(Lajevardi, 2022); (Cantillo, 2022)

6.3.1 Method

This research applies an econometric approach, using a choice experiment and conjoint analysis, combined with estimations of costs and prices, within a choice model framework. To model fleet transition, the Choice Experiment results plus assumptions, were embedded into a model that has a fleet turnover component. Every time a vehicle is purchased, a decision is being made which has two components: (1) access and opportunity to purchase a LZEV is dependent on assumptions on when vehicles will enter the market, and (2) Preference for LZEVs based on a choice model framework.

At each decision point, there is a probability of access for each of the vehicle types, i.e., the probability of access to a diesel truck for purchase p_d, the probability of access to a BEV truck for purchase p_{bev}, and the probability of access to a FCEV truck for purchase p_{fcev}. Using Bayes formula for conditional probabilities (considering 7 different access scenarios), the preferences in each scenario are estimated based on the standard choice model formula shown in the following equation:

$$P(i) = \frac{\exp\,(x_i'\beta)}{\sum_{j=1}^{n} \exp\,(x_j'\beta)}$$

The seven scenarios and associated conditional probabilities are shown in **Table 24**. The resulting adoption probabilities are aggregated by a sum over probability of each scenario multiplied by the probabilities of uptake as per equation 2, as per Bayes formula.

Table 24: Vehicle availability scenarios

Scenario	Choices modelled by equation 2	Probability of scenario
1	Diesel only	$p_d \cdot (1-p_{bev}) \cdot (1-p_{fcev})$
2	Diesel vs BEV	$p_d \cdot p_{bev} \cdot (1-p_{fcev})$
3	Diesel vs FCEV	$p_d \cdot (1-p_{bev}) \cdot p_{fcev}$
4	Diesel vs BEV vs FCEV	$p_d \cdot p_{bev} \cdot p_{fcev}$
5	BEV only	$(1-p_d) \cdot p_{bev} \cdot (1-p_{fcev})$
6	BEV vs FCEV	$(1-p_d) \cdot p_{bev} \cdot p_{fcev}$
7	FCEV only	$(1-p_d) \cdot (1-p_{bev}) \cdot p_{fcev}$

6.3.2 Fleet changes

The modelling described in this report is based on modelling of the fleet dynamics, and the slow change of composition of diesel, BEV, and FCEV trucks over time. As the fleet starts with only 117 BEV trucks, and 89 HEV trucks, this represents a mere 0.1% of the total truck fleets. For the purpose of modelling, trucks are categorised into 8 classes, as shown in **Table 25**, broadly on the basis of Gross Vehicle Mass (GVM) (with some exceptions), with key numbers extracted from the New South Wales vehicle registration database. It is noted that the larger vehicles tend to drive significantly more kilometres than the smaller vehicles, on average, and this translates to a higher turnover of vehicles.

Table 25: Extract of data on different truck classes

Vehicle type	Approximate GVM range (tonnes)	Number of vehicles in 2022	Average age of vehicle	Average annual VKTs (kms)	Average odometer reading
RIG-S	4.5-5.5	23,586	10	44,087	173,156
RIG-SM	5.5-7.5	15,081	16	30,651	227,991
RIG-M	7.5-12.5	48,095	16	71,228	286,943
RIG-ML	12.5-20.5	17,459	17	63,505	338,604
RIG-L	>20.5	22,210	12	161,752	263,631
ART-S	<= 31.5	1,030	12	196,997	468,995
ART-M	31.5-42.5	15,370	14	292,844	547,564
ART-L	> 42.5	11,204	8	310,766	363,852

In **Table 32**, the average age, annual average VKTs, and average odometer readings are estimated after some data cleaning (e.g., removing from the analysis vehicles with manufacturing years registered as zero, and odometer readings less than 100 kms). The average annual VKTs is calculated based on two successive years of registration data (2021, and 2022) and the average increase in odometer readings within each class (after removing outliers such as extremely high and extremely low odometer readings or negative changes in odometer readings between successive years). For modelling purposes, the proportion of fleet retired each year needs to be established and number of new vehicles purchased in each of these classes. The research interrogated consecutive years of registration data and estimated renewal, retirement, and net growth rates for each of class as shown in **Table 26.** The renewal rate is estimated based on number of new vehicles in the register, compared to previous year's vehicle register. This represents the number of new vehicles being purchased each year. The retirement rate is estimated based on number of vehicles removed from the register from one year to the next. This represents the number of vehicles that are being retired every year. The net change rate is the change in total number of vehicles between two years, i.e., generally a growth in total number of vehicles.

Table 26: Change in vehicle fleet for articulated and rigid truck categories (2021-2022)

Vehicle type	Renewal rate	Retirement rate	Net change rate
Rigid	5.04%	3.17%	1.87%
Articulated	5.75%	3.53%	2.23%

6.3.3 Purchase prices and costs

Purchase prices (capital expenditure) and costs (operating expenditure) are key considerations in the choice of which truck to purchase. In the modelling, estimates of current prices for Diesel, BEV, and FCEV trucks are used (see **Table 27**), as well as their fuel economies. A range of sources were used to come up with these estimates (Sharpe, 2022); (Berglas, 2022); (World Economic Forum, 2021); (Grattan Institute, 2022) as well as online material available on the sales of trucks, and manufacturers websites and their specifications[7].

Table 27: Representative purchase prices for different types of trucks in 2023

Vehicle type	Diesel truck	BEV truck	FCEV truck	Equivalent diesel models
RIG-S	$60,435	$110,306	$152,963	Isuzu NNR 45-150
RIG-SM	$91,528	$167,057	$231,660	Isuzu NPR 75-190
RIG-M	$120,188	$219,367	$304,199	Isuzu F Series FRR110-260
RIG-ML	$197,050	$359,656	$498,739	Isuzu FVD 165-3OO
RIG-L	$226,714	$413,799	$573,819	Isuzu FXZ 240-350
ART-S	$241,990	$441,681	$612,483	Fuso Shogun FV74 460
ART-M	$250,000	$456,300	$632,757	Iveco Stralis X-Way AT450
ART-L	$284,900	$520,000	$721,090	Iveco Stralis X-Way 550

This study used representative fuel economies for different types of trucks (**Table 28**) and fuel costs based on current prices (**Table 29**)

[7] Examples of sources include: https://www.trucksales.com.au/, https://freightmetrics.com.au/truck-operating-cost-calculator-trial/ , https://www.atap.gov.au/parameter-values/road-transport/5-vehicle-operating-cost-voc-models , https://www.volvotrucks.com/en-en/trucks/trucks/ , https://www.fuso.com.au/range/electric/

Table 28: Representative fuel economies for different types of trucks in 2023

Vehicle type	Diesel truck (l per 100 kms)	BEV truck (kWh per 100 kms)	FCEV truck (kg per 100 kms)	Equivalent BEV models
RIG-S	15	51.7	2.1	FUSO eCanter
RIG-SM	19	65.5	2.3	FUSO eCanter
RIG-M	21.5	74.1	3.5	Freightliner eM2 106, 2024 KENWORTH K270E
RIG-ML	24.9	85.9	3.7	PETERBILT 220EV
RIG-L	29	100	8	Tesla: Semi, Futuricum DPD
ART-S	24.3	140	10	Volvo FMX
ART-M	44	150	12	Volvo FM Electric, Kenworth T680E, Peterbilt 579EV, BYD TT
ART-L	55	170	14	Volvo FM Electric, Nikola TRE

Table 29: Fuel costs (in $s per 100 km) based on current fuel and energy prices

Vehicle type	Diesel truck ($s per 100 kms)	BEV truck ($s per 100 kms)	FCEV truck ($s per 100 kms)
RIG-S	26	14	38
RIG-SM	33	18	41
RIG-M	37	20	63
RIG-ML	43	24	67
RIG-L	50	27	144
ART-S	42	38	180
ART-M	76	41	216
ART-L	95	47	252

It is acknowledged that there are currently not many available models of BEV and FCEV trucks in Australia for these categories. For the diesel trucks, representative trucks and their associated current prices are readily available. For the FCEV trucks, the research used data from the International Council on Clean Transportation (Sharpe, 2022) as demonstrated in **Figure 107**, **Figure 108** and **Figure 109.**:

- FCEV trucks are now a factor of 2.53 times more expensive than equivalent diesel trucks.
- The price of BEV trucks will reduce by about 40% by 2030 due to technological improvements and increased sales volumes. Another 5% reduction expected by 2040, achieving parity with diesel trucks around 2040.
- The price of FCEV trucks will reduce by about 23% by 2030, and this trajectory of cost reduction will continue until 2040.

The operating expenditure (per 100km of travel) includes insurance, maintenance and finance costs which are a function of the purchase price, although the maintenance cost is assumed 21% higher for FCEVs than for the equivalent diesel or BEV trucks (Hao, 2022).

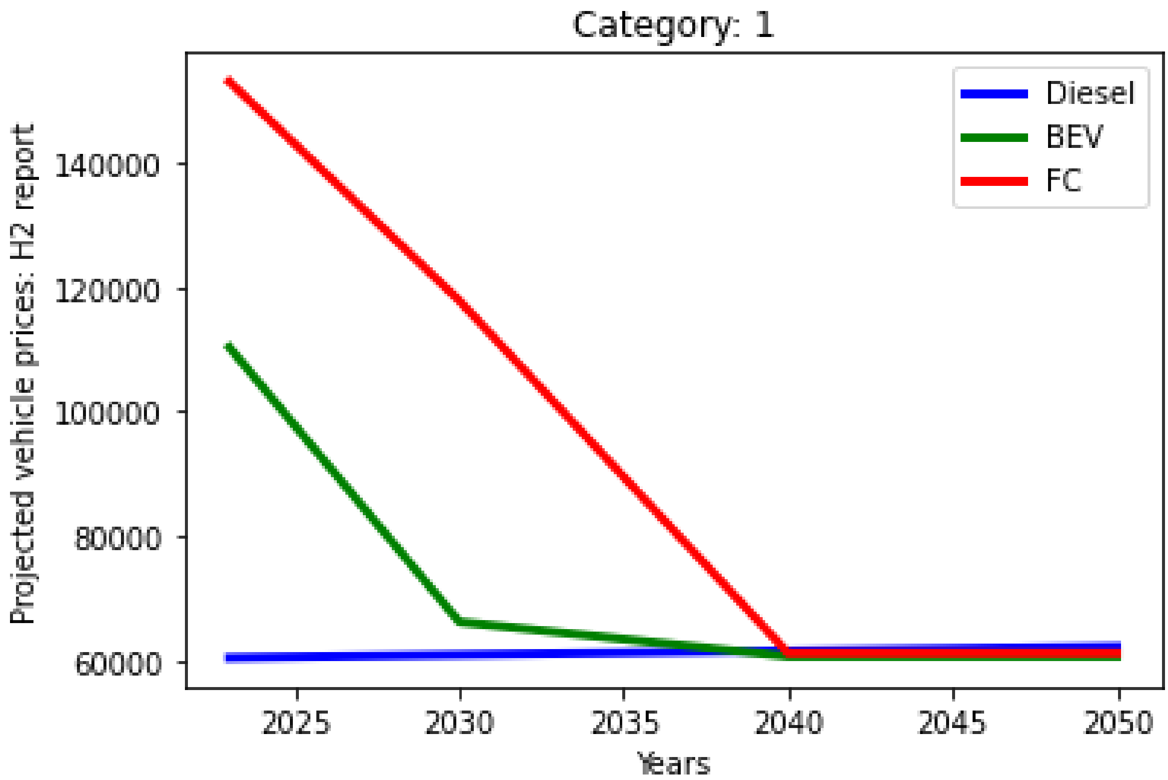


Figure 107: Price projections for a category 1 truck (RIG-S)

Note: Curves for other types of trucks follow the same general pattern.

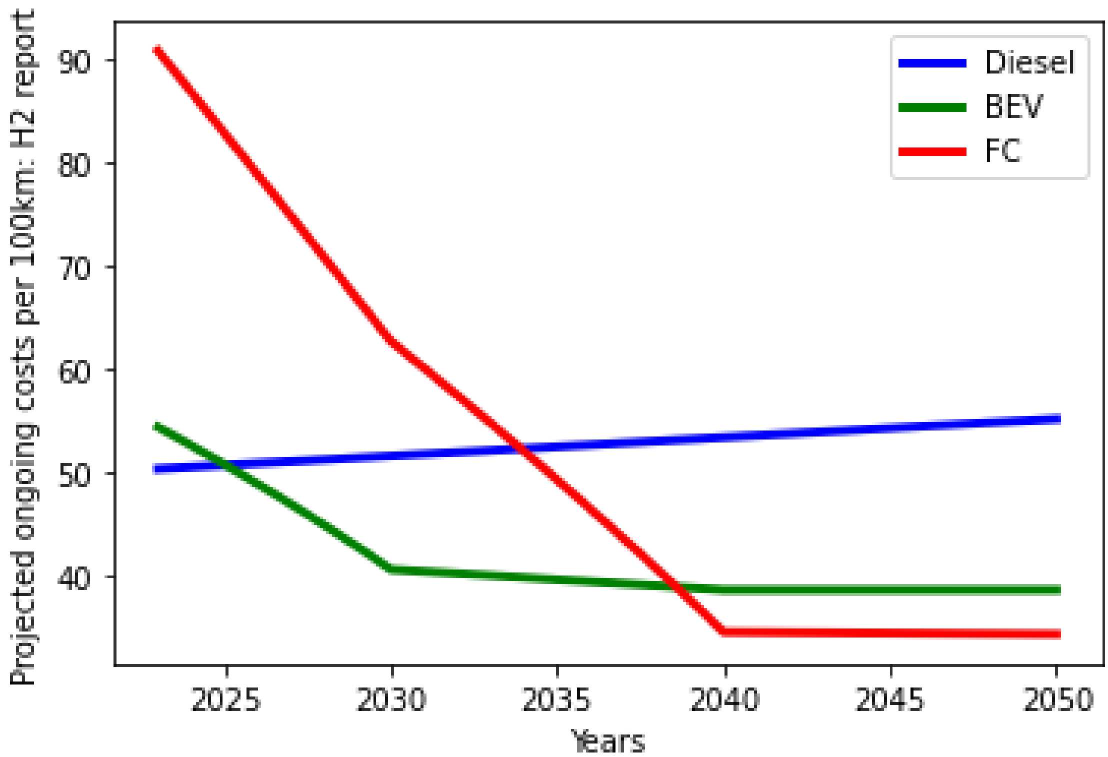


Figure 108: Ongoing costs for a small rigid truck

Note: Includes fuel, maintenance, finance, insurance, fees, and registrations

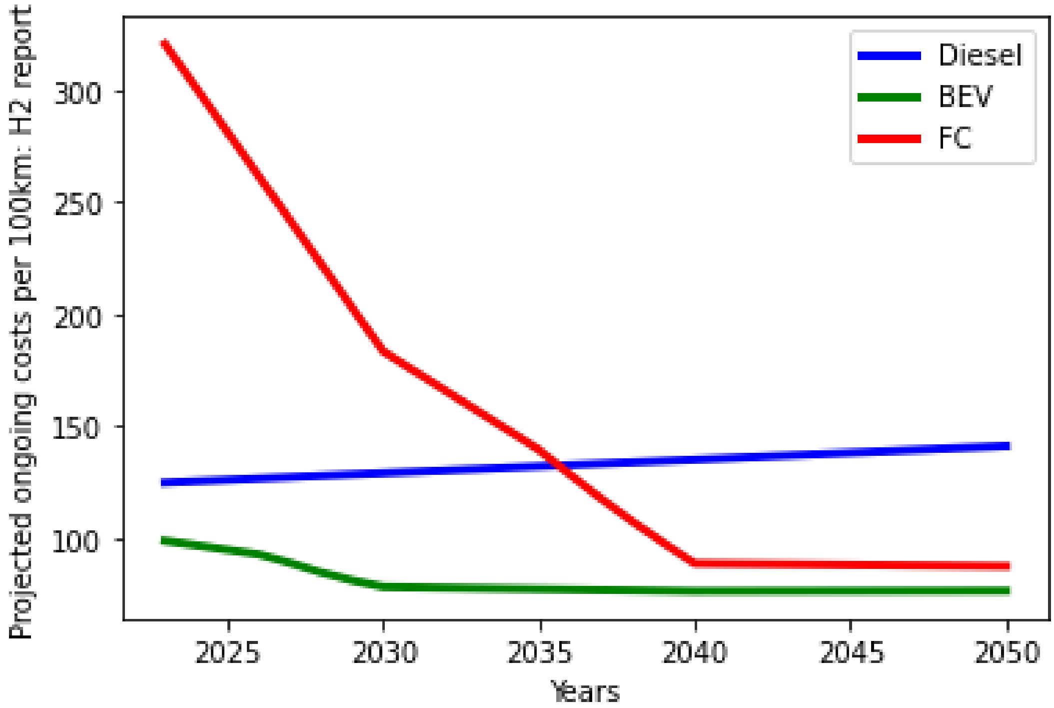


Figure 109: Ongoing costs for large articulated truck

Note: Includes fuel, maintenance, finance, insurance, fees, and registrations

The projections of insurance costs are based on many data points linking insurance costs with purchase price, as shown in **Figure 110.**

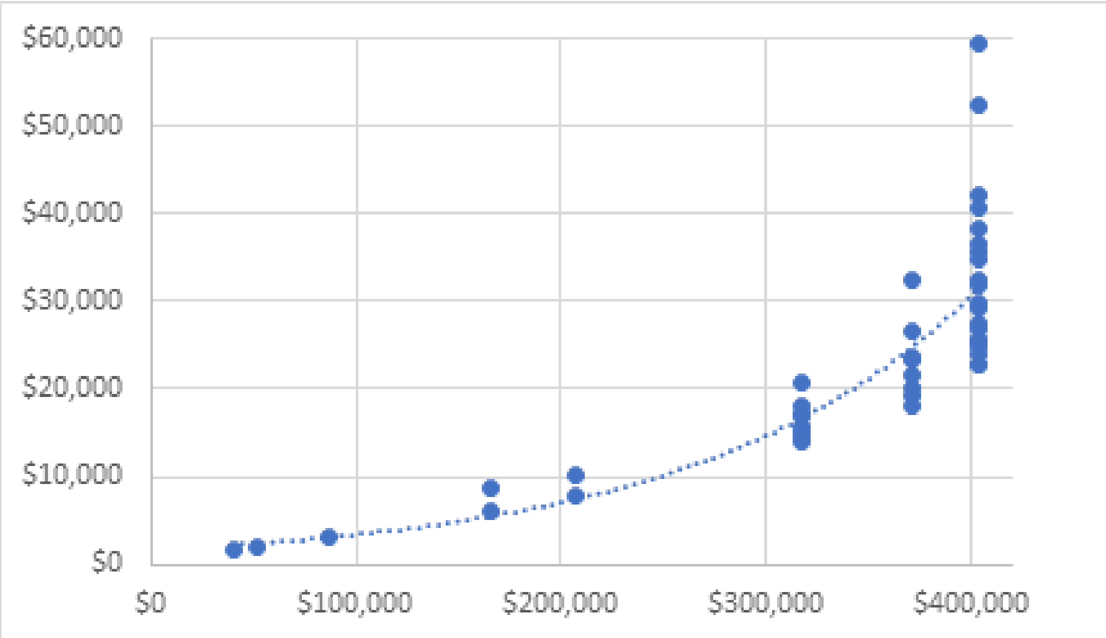


Figure 110: Projected insurance cost as a function of purchase price

Note: Whilst the insurance costs increase with purchase price, it is assumed that a maximum of 15% of the purchase price is paid as insurance costs per annum.

The maintenance cost (per 100 kms) as a function of purchase price is shown in **Figure 111**. The function (of maintenance cost against purchase price) has been established based on estimates of purchase price and maintenance costs for many commercially available vehicles. The non-linear growth of maintenance cost as a function of purchase price can be explained by correlation between purchase price and size, number of tyres, weight, expected VKTs per annum, and cost of spare parts.

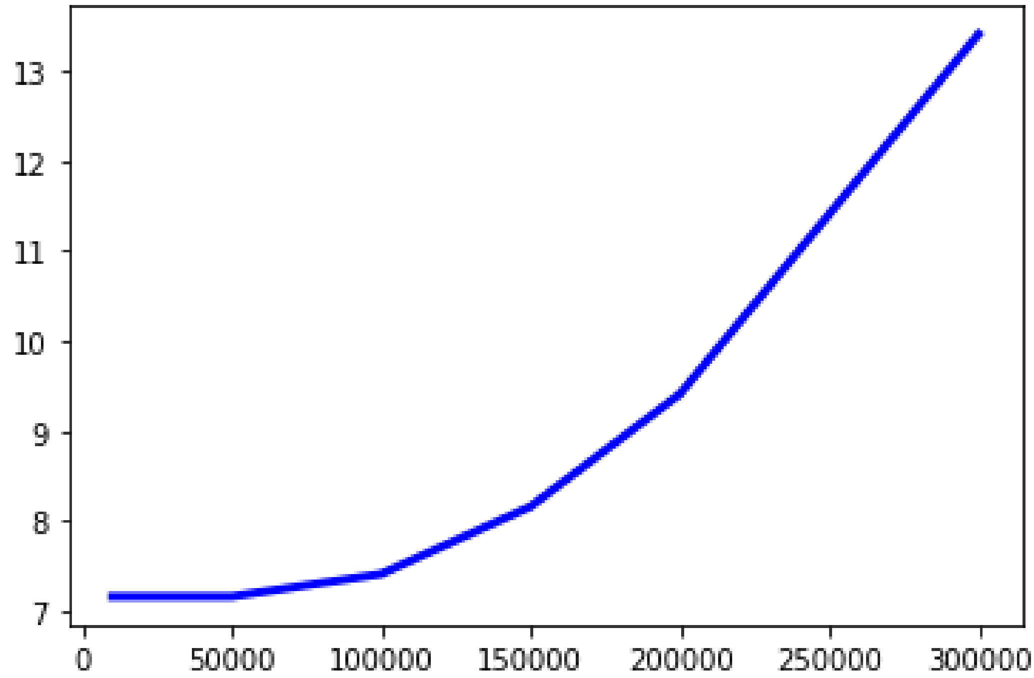


Figure 111: Maintenance cost (per 100 kms) as a function of purchase price

6.3.4 Availability scenarios

It is acknowledged that the issue about availability of appropriate BEV and FCEV trucks on the market is a major limiting factor for the adoption of low emission trucks in Australia and internationally, as is mentioned in several papers and reports (Imre, 2021); (Cantillo, 2022); (Quak, 2014); (Brotherton, 2016); (Grattan Institute, 2022); (World Economic Forum, 2021); (Berglas, 2022).

In fact, the CE results indicate that even at the levels of operating and capital expenditure associated with these trucks, uptake of low emission trucks would be significantly higher if there were models available on the market. To account for this issue, three scenarios are considered in the modelling: baseline, pessimistic, and optimistic scenarios on access to vehicles. To illustrate what the access looks like in these scenarios, the baseline and fast availability scenarios for small rigid trucks (Category 1) and large articulated truck (Category 8) are shown in **Figure 112, Figure 113**, **Figure 114,** and **Figure 115** respectively.

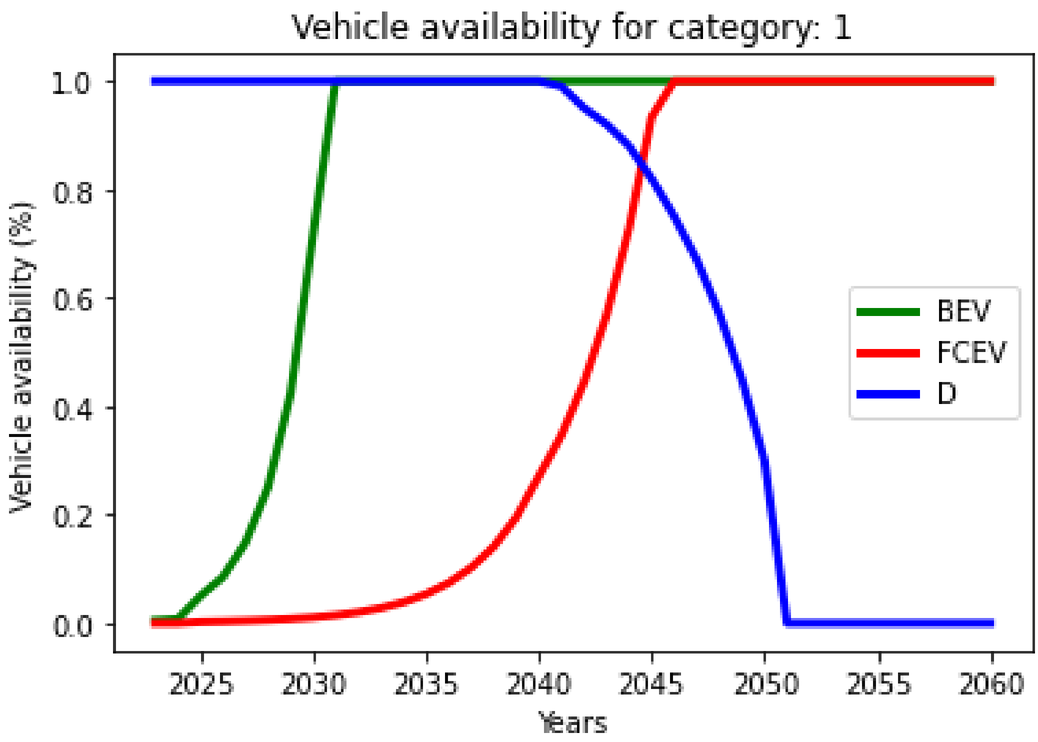


Figure 112: Baseline scenario for vehicle availability for Small Rigid trucks

Note: Y-axis: The probability that a given freight task can be done by a BEV, FCEV, or Diesel truck that is available for purchase on the market.

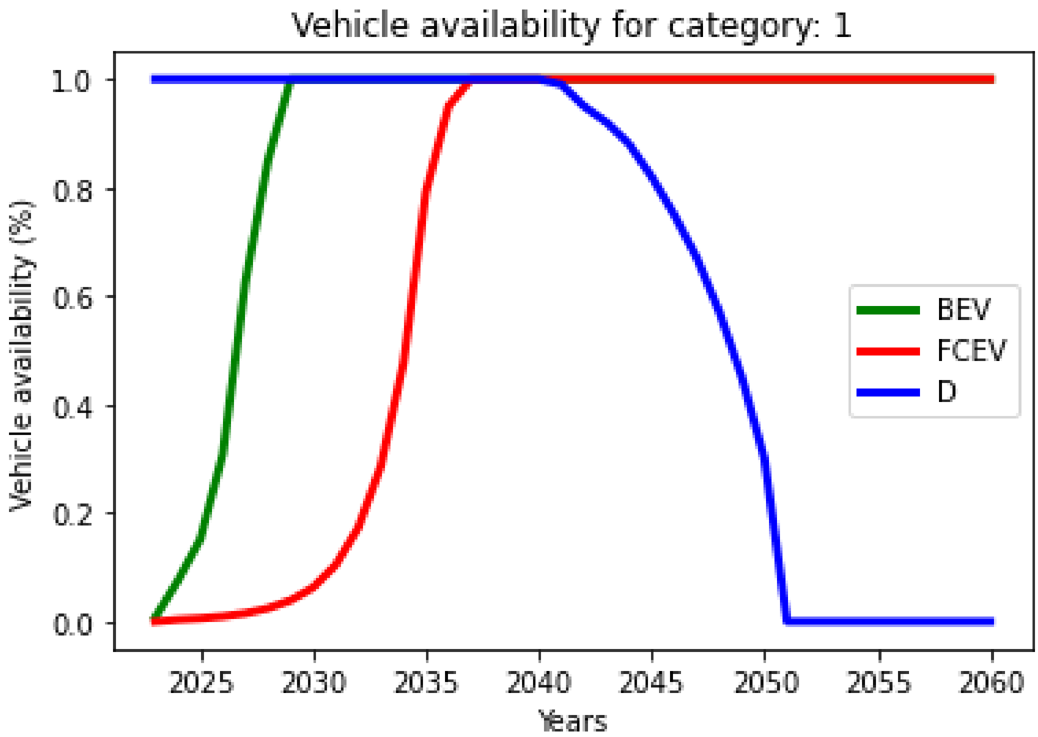


Figure 113: Fast availability scenario for Small Rigid Trucks

Note: Y-axis: The probability that a given freight task can be done by a BEV, FCEV, or Diesel truck that is available for purchase on the market.

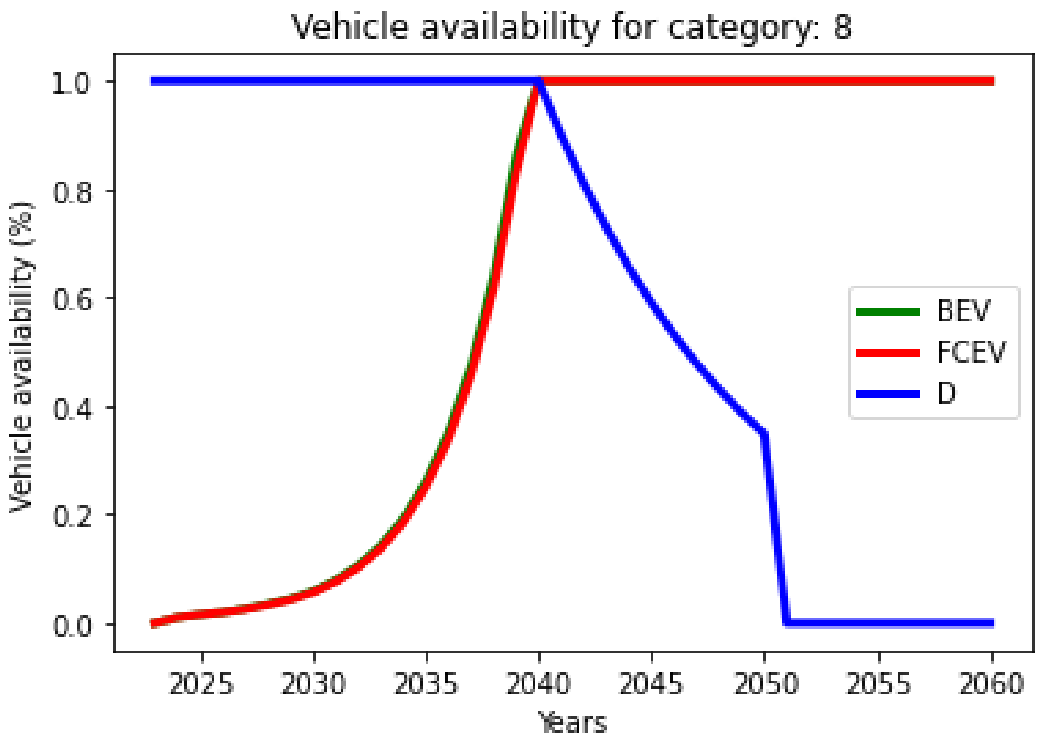


Figure 114: Baseline scenario for category 8 (large articulated trucks)

Note: Y-axis: The probability that a given freight task can be done by a BEV, FCEV, or Diesel truck that is available for purchase on the market. Note that the green curve can be gleaned behind the red curve.

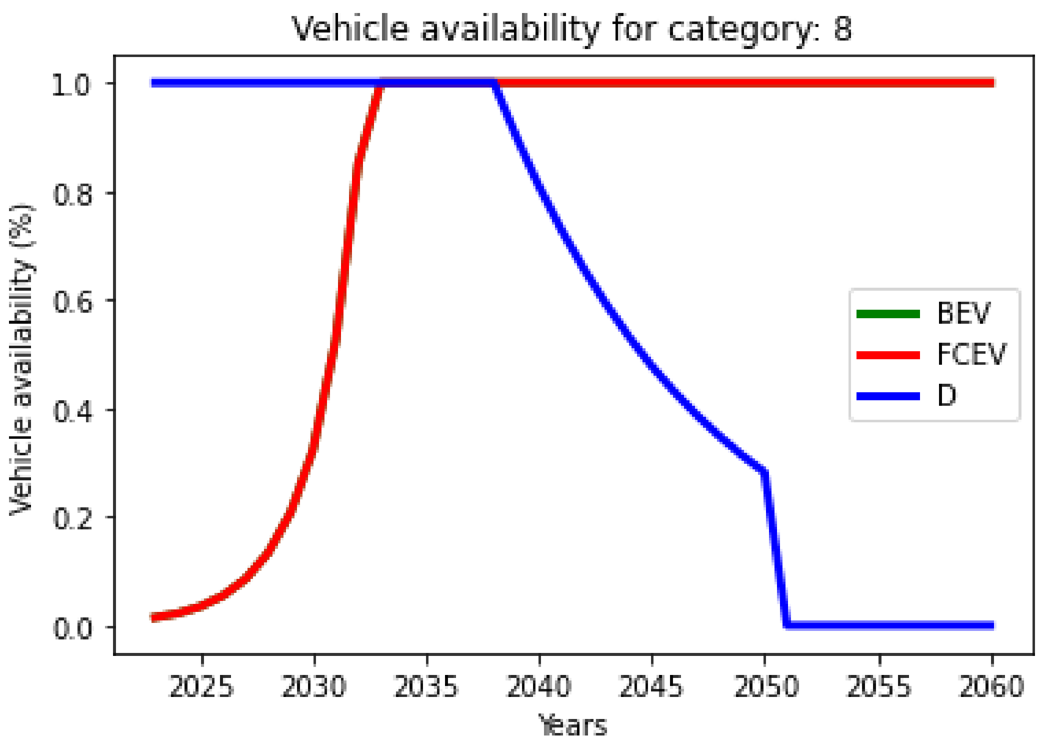


Figure 115: Fast availability scenario for category 8 (large articulated trucks)

Note: The green curve for BEVs can be gleaned behind the red curve.

6.4 Experimental setup

Applying the approach described earlier for modelling the future adoption of LZEVs, a total of 20 scenarios are explored to evaluate the impact of different policy settings.

In these scenarios, up to six policy interventions are modelled which include:

1. OPEX subsidy: This is a $5 rebate on per 100km operating costs – approximately 16.6% rebate.
2. CAPEX subsidy: This is a percentage of the differential in purchase price between a ZEV and an ICE equivalent (40% and 80%)
3. Availability: This reflects policies that aim to increase the stock availability of ZEVs
4. Road network access: This is a policy package of reserved lanes, low emissions zones, and relaxation of nighttime curfews for ZEVs.
5. Discounts: These are discounted free loans (4% and 6%)
6. Phase out year: This is a reference to policies that would include a phase out year 2035.

iMOVE 1: Baseline scenario without any interventions

iMOVE 2: Includes only phase out year 2035.

iMOVE 3: Includes only 4% discounted loans.

iMOVE 4: Includes only 6% discounted loans.

iMOVE 5: Includes only road network access.

iMOVE 6: Includes only truck availability.

iMOVE 7: Includes only 40% CAPEX subsidy.

iMOVE 8: Includes only 80% CAPEX subsidy.

iMOVE 9: Includes only an OPEX subsidy.

iMOVE 10: Includes combinations of OPEX, availability, road network access, 6% discounted loans, and phase out year 2035.

iMOVE 11: Includes combinations of OPEX, 40% CAPEX, availability, road network access, and phase out year 2035.

iMOVE 12: Includes combinations of availability and phase out year 2035.

iMOVE 13: Includes combinations of availability, road network access and phase out year 2035.

iMOVE 14: Includes combinations of 40% CAPEX, availability and phase out year 2035.

iMOVE 15: Includes combinations of 80% CAPEX, availability and phase out year 2035.

iMOVE 16: Includes combinations of OPEX, availability and phase out year 2035.

iMOVE 17: Includes combinations of OPEX, 40% CAPEX, availability and phase out year 2035.

iMOVE 18: Includes combinations of OPEX, 80% CAPEX, availability and phase out year 2035.

iMOVE 19: Includes combinations of 40% CAPEX and availability.

iMOVE 20: Includes combinations of OPEX, 40% CAPEX and availability.

The range of policy settings that were modelled are shown in **Table 30.**

Table 30: Policy settings selected for analysis

OPEX subsidy	$5 rebate on per 100km operating costs - approximately 16.6% rebate
CAPEX subsidy	Percentage of the differential in purchase price between a ZEV and an ICE equivalent (40% and 80%)
Availability	(1) Available (0) Not available A qualitative indicator capturing whether businesses would be able to purchase a ZEV that matches their needs.
Road access	Policy package consisting of road/network access to reserved lanes, low emissions zones and relaxation of night-time curfews for ZEVs
Discounted loans	This is a low or zero interest loan offered by the state for the procurement of new ZEVs (4% or 6%)
Phase out	Year beyond which ICE trucks would no longer be available on the Australian market

Scenario	iMOVE1	iMOVE2	iMOVE3	iMOVE4	iMOVE5	iMOVE6	iMOVE7	iMOVE8	iMOVE9	iMOVE10
OPEX subsidy	0	0	0	0	0	0	0	0	$5	$5
CAPEX subsidy	0	0	0	0	0	0	40%	80%	0	0
Availability	0	0	0	0	0	1	0	0	0	1
Road access	0	0	0	0	1	0	0	0	0	1
Discounted loan	0	0	4%	6%	0	0	0	0	0	6%
Phase-out	0	2035	0	0	0	0	0	0	0	2035

Scenario	iMOVE11	iMOVE12	iMOVE13	iMOVE14	iMOVE15	iMOVE16	iMOVE17	iMOVE18	iMOVE19	iMOVE20
OPEX subsidy	$5	0	0	0	0	5	5	5	0	5
CAPEX subsidy	40%	0	0	40%	80%	0	40%	80%	40%	40%
Availability	1	1	1	1	1	1	1	1	1	1
Road access	1	0	1	0	0	0	0	0	0	0
Discounted loan	0	0	0	0	0	0	0	0	0	0
Phase-out	2035	2035	2035	2035	2035	2035	2035	2035	0	0

Python code was developed in Spyder to embed the assumptions and analysis methodology to predict future uptake rates and determine the percent in stock of zero emissions trucks. This was done for around 160 combinations of settings in total, resulting in the selection of 10 policy scenarios in addition to a base scenario, for further investigation. The base scenario (iMOVE1) reflects the DPE 2022 current policy scenario that uses LZEV uptake rates from the AEMO 'Steady Progress' scenario and the Bloomberg New Energy Futures (BNEF) economic transition scenario (ETS) as reported in the BNEF 2021 Electric Vehicle Outlook. The DPE 2022 current policy scenario also includes the NSW Hydrogen Strategy and the Hydrogen Strategy for truck (but excludes Net Zero Plan Stage 2 and 3 actions). The heavy-duty vehicle emissions factors used in the DPE 2022 current policy scenario are derived from several sources and assumptions including ADR80/02 (Euro IV) to ADR 80/04 (Euro VI) in which the emissions and fuel consumption factors are estimated by reference to the European EMEP Guidebook which is the basis of the COPERT model. Euro VI is assumed to be adopted from 2027.

Each of the 20 policy scenarios reflect a range of policy settings that apply different levels of financial incentives (CAPEX and OPEX subsidies and discounted loans), in addition to policy settings that improve availability of stock, road access to reserved lanes and low emissions zones, and a designation of a phase out year for diesel trucks.

The uptake curves reflecting each of these scenarios are visualised below (**Figure 116**, **Figure 117**), firstly as compared with the DPE baseline, and secondly compared with each other. The scenarios are referred to as iMOVE1-iMOVE20 scenarios where the diagrams show that the iMOVE scenarios provide improvements on the adoption rates reflected in the DPE base scenario. Sensitivity analysis indicates that the largest influence on fleet proportions is the: 1) assumptions/estimates on number of new and retired vehicles each year, 2) suitable vehicles on the market available for purchase by freight operators. In these diagrams, the baseline (iMOVE1) is denoted with the red line. In this diagram, the iMOVE10, iMOVE11 and iMOVE 18 scenarios provided the policy settings that can lead to highest possible adoption rates.

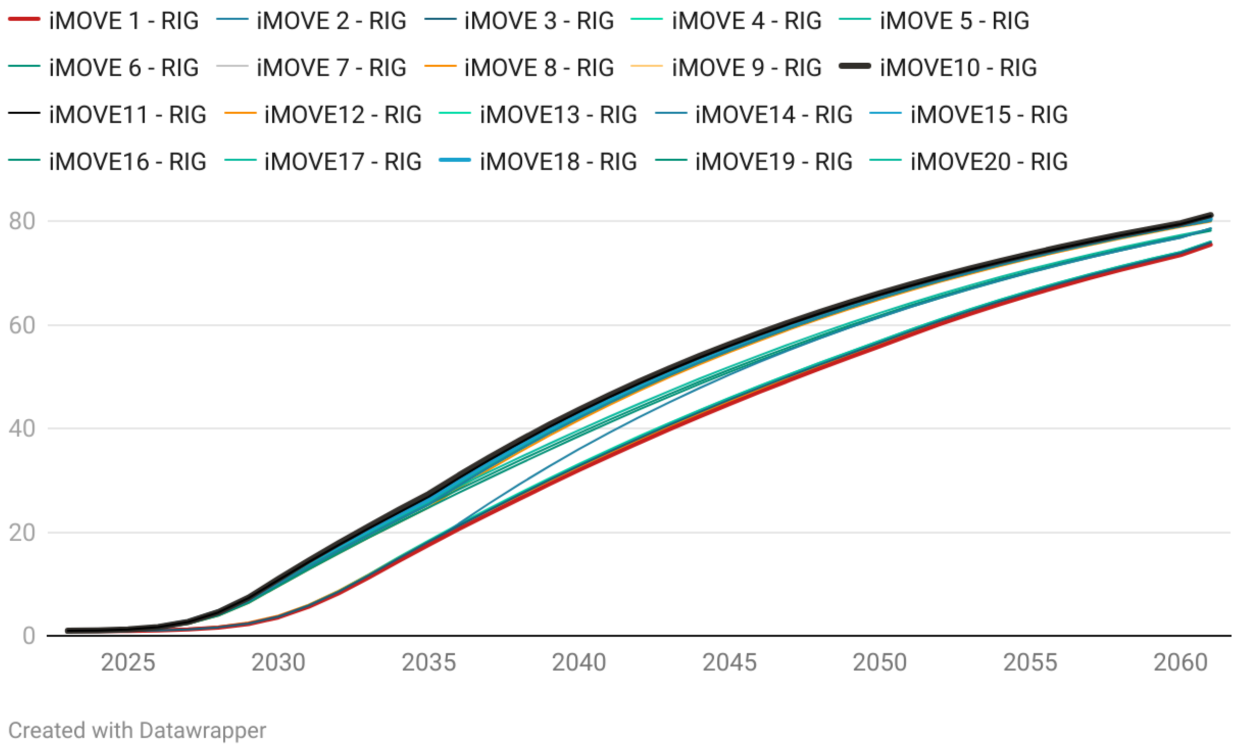


Figure 116: iMOVE scenarios - percent in stock LZET rigid

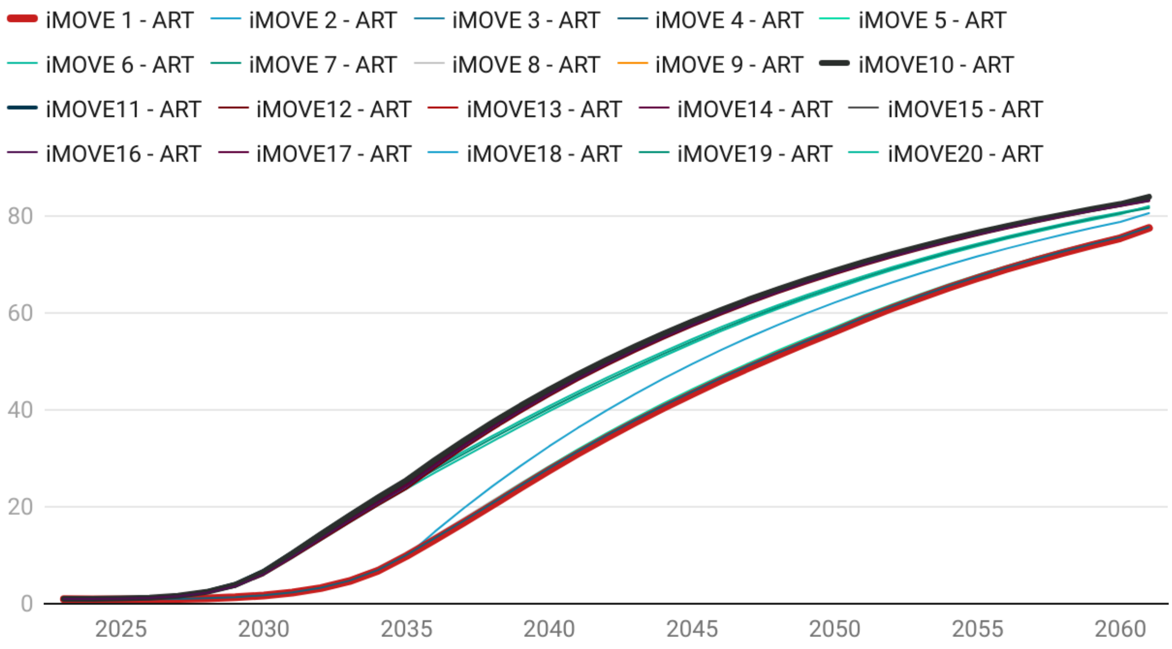


Figure 117: iMOVE scenarios - percent in stock LZET articulated

We note the relatively low uptake rates in scenarios 3, 4, 5, 7, 8, and 9. The reason for this low uptake is limited access to vehicles to purchase, rendering the incentives relatively ineffective. Therefore, out of the single policy options, only the phase out in 2035 and the availability options are relatively effective. The data for these diagrams is available in **Appendix C.**

Emissions Modelling

7. Emissions Under Interventions

The adoption curves described in the previous section were used to estimate the emissions produced under each of the proposed policy interventions represented by the iMOVE scenarios. The impacts of these scenarios on reducing emissions are described next for four types of emissions (CO_2-e, NO_x, $PM_{2.5}$ exhaust and $PM_{2.5}$ non-exhaust emissions). The emissions were estimated using emissions intensity factors for diesel trucks and expected VKT per truck type (rigid and articulated) over the period 2023-2061. As expected, the diagrams show that as the percentage of zero emissions trucks increases between 2023-2061 (as determined by the iMOVE adoption curves), resulting in a substantial reduction in emissions. All diagrams reveal a consistent trend showing that the iMOVE10, iMOVE11 and iMOVE 18 scenarios provide the largest reductions in emissions compared to other scenarios. The diagrams presented in this section will focus mainly on these three key scenarios in addition to the iMOVE 1 baseline scenario.

It should be emphasised here that the analysis undertaken in this section is based on DPE emissions estimation models that only consider total VKT by rigid and articulated trucks. Given that large trucks carry heavier loads, consideration of VKT needs to be complemented with information on payload and tonne-km of travel for each truck category. Such data was not available for this study, and it is recommended that future research should consider development of the payload capacity and freight vehicle utilisation databases and to use this new data for updating the DPE modelling.

7.1 Impacts on CO_2-e reductions

The impacts of the iMOVE scenarios on CO_2-e emissions are presented in **Figure 118** and **Figure 119** for rigid and articulated trucks, respectively. The diagrams show the total CO_2-e emissions produced in each scenario (in million tonnes), compared to the base iMOVE1 scenario, covering the period 2023 to 2061. In these diagrams, GHG outputs of multiple pollutants (e.g., Carbon Dioxide [CO_2], Methane [CH_4], Nitrous Oxide [N_20], Nitrogen Oxide [NO_x] etc) are expressed by a single metric – CO_2-e.

The diagrams clearly show that articulated trucks contribute higher emissions than rigid trucks, mainly due to their higher emissions factors (around 1,400 grams CO_2-e per km for articulated trucks compared to around 500 grams CO_2-e per km for rigid trucks). For example, in the iMOVE1 scenario over the period 2023-2061, the total emissions from articulated trucks were around 122 Mt, compared to 56 Mt for rigid trucks. The iMOVE11 scenario resulted in the lowest cumulative CO_2-e emissions for the two types of trucks, with total emissions of 102 Mt for articulated trucks and 48 Mt for rigid trucks. This indicates that the iMOVE11 scenario reduced emissions from articulated trucks by around 16.4%, and reduced emissions from rigid trucks by around 14.3%, compared to the baseline iMOVE1 scenario.

It is noted that although the iMOVE11 scenario produced the highest reductions in CO_2-e emissions, it does not result in reducing these emissions to zero. Under this scenario, the CO_2-e emissions in 2061 will be 102 Mt for articulated trucks, and 48 Mt for rigid trucks.

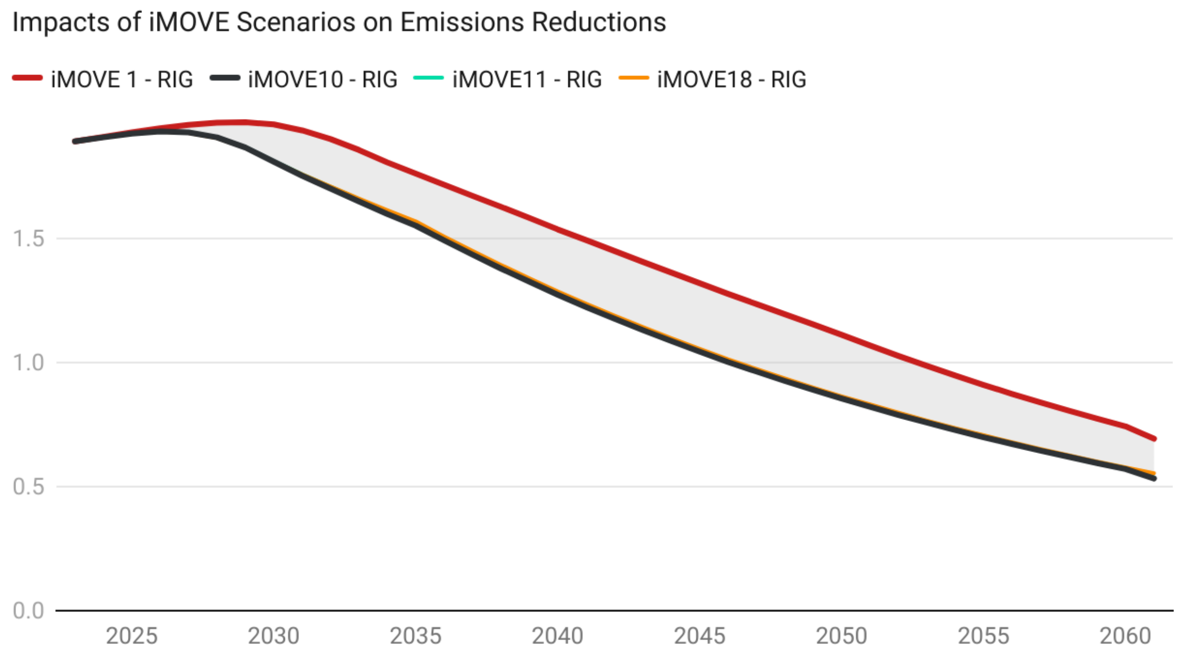


Figure 118: Total CO_2-e emissions (Mt) for rigid trucks

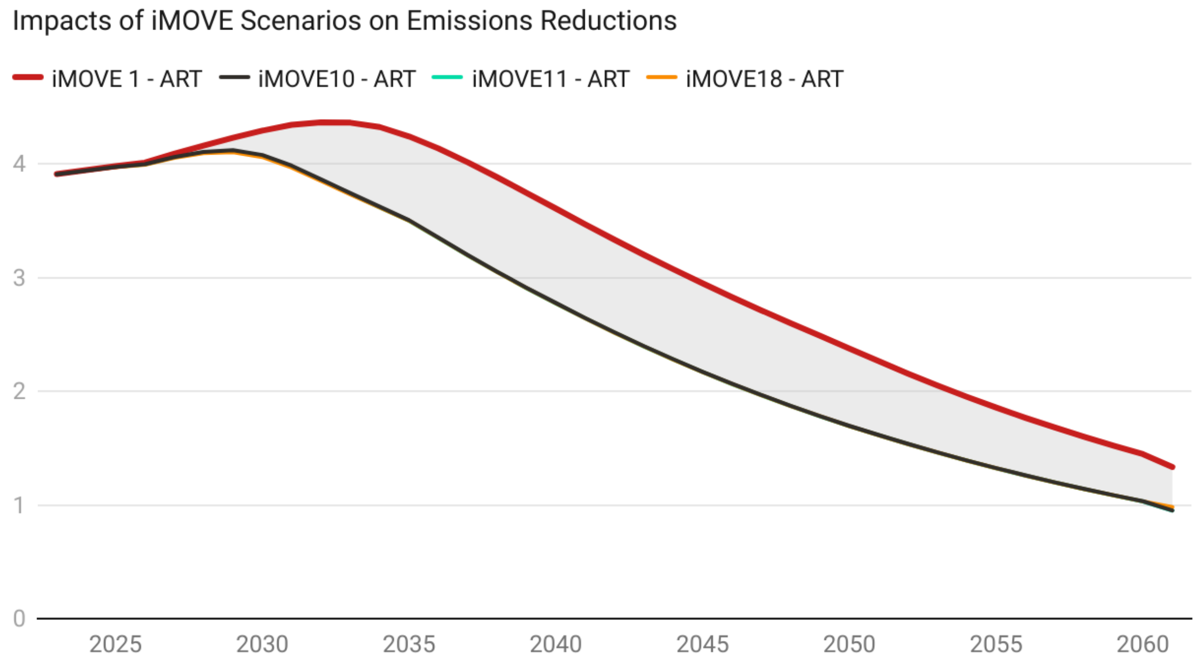


Figure 119: Total CO_2-e emissions (Mt) for articulated trucks

7.2 Impacts on NO_x reductions

The impacts of the iMOVE scenarios on NO_x emissions are presented in **Figure 120** and **Figure 121** for rigid and articulated trucks, respectively. The NO_x emissions not only contribute to the build-up of GHG in the atmosphere, but also air quality at ground levels.

The two diagrams clearly show that NO_x emissions from articulated trucks exceed those from rigid trucks and will continue to be a high source of NO_x emissions up to the late 2040s. The diagrams, however, show that the iMOVE11 scenario will provide a more rapid emissions reductions pathway particularly from the late 2020s, which would lead to realising accelerated benefits in terms of NO_x emissions reductions.

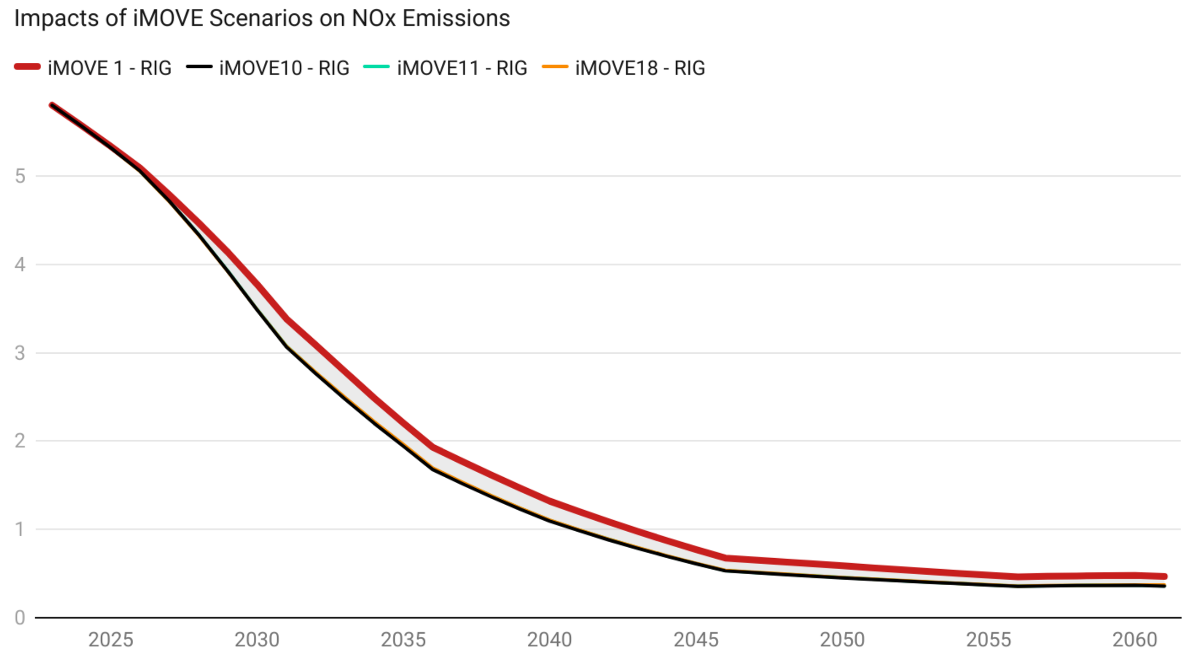


Figure 120: Total NO_x emissions (Kt) for rigid trucks

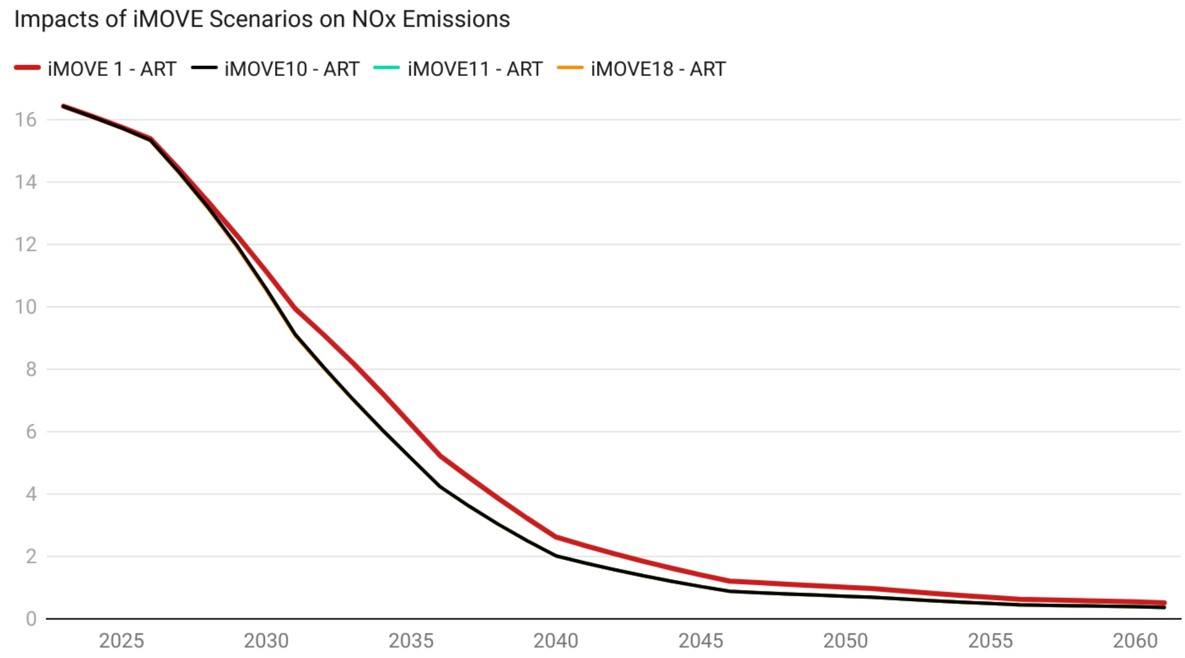


Figure 121: Total NO_x emissions (Kt) for articulated trucks

For example, in the iMOVE1 scenario over the period 2023-2061, the total NO_x emissions from articulated trucks were around 197 Kt, compared to 75 Kt for rigid trucks. The iMOVE11 scenario resulted in the lowest cumulative NO_x emissions for the two types of trucks, with total emissions of 181 Kt for articulated trucks and 68 Kt for rigid trucks. The iMOVE11 scenario reduced NO_x emissions from articulated trucks by around 8.1%, and reduced NO_x emissions from rigid trucks by around 9.3% compared to the baseline iMOVE1 scenario. Similarly, it is also noted that although the iMOVE11 scenario produced the highest reductions in NO_x emissions, it does not result in reducing these emissions to zero. Under this scenario, the NO_x emissions in 2061 will be 181 Kt for articulated trucks, and 68 Kt for rigid trucks.

7.3 Impacts on $PM_{2.5}$ reductions

The impacts of the iMOVE scenarios on $PM_{2.5}$ (exhaust, non-exhaust and total) reductions are presented next for rigid and articulated trucks, respectively.

The diagrams for $PM_{2.5}$ exhaust emissions (**Figure 122** and **Figure 123**) show that emissions from articulated trucks exceed those from rigid trucks and will continue to be a high source of $PM_{2.5}$ exhaust emissions up to the mid-2040s. The diagrams, however, show that the iMOVE11 scenario will provide a more rapid emissions reductions pathway particularly from the early 2030s, which would lead to realising accelerated benefits in terms of $PM_{2.5}$ exhaust emissions reductions.

For example, in the iMOVE1 scenario over the period 2023-2061, the total $PM_{2.5}$ exhaust emissions from articulated trucks were around 3.0 Kt, compared to 1.7 Kt for rigid trucks. The iMOVE11 scenario resulted in the lowest cumulative $PM_{2.5}$ exhaust emissions for the two types of trucks, with total emissions of 2.7 Kt for articulated trucks and 1.5 Kt for rigid trucks. These results show that the iMOVE11 scenario reduced $PM_{2.5}$ exhaust emissions from articulated trucks by around 10%, and reduced $PM_{2.5}$ exhaust emissions from rigid trucks by around 11.8%, compared to the baseline iMOVE1 scenario. Similarly, it is noted that although the iMOVE11 scenario produced the highest reductions in $PM_{2.5}$ exhaust emissions, it does not result in reducing these emissions to zero. Under this scenario, the $PM_{2.5}$ exhaust emissions in 2061 will still be around 2.7 Kt for articulated trucks, and 1.5 Kt for rigid trucks.

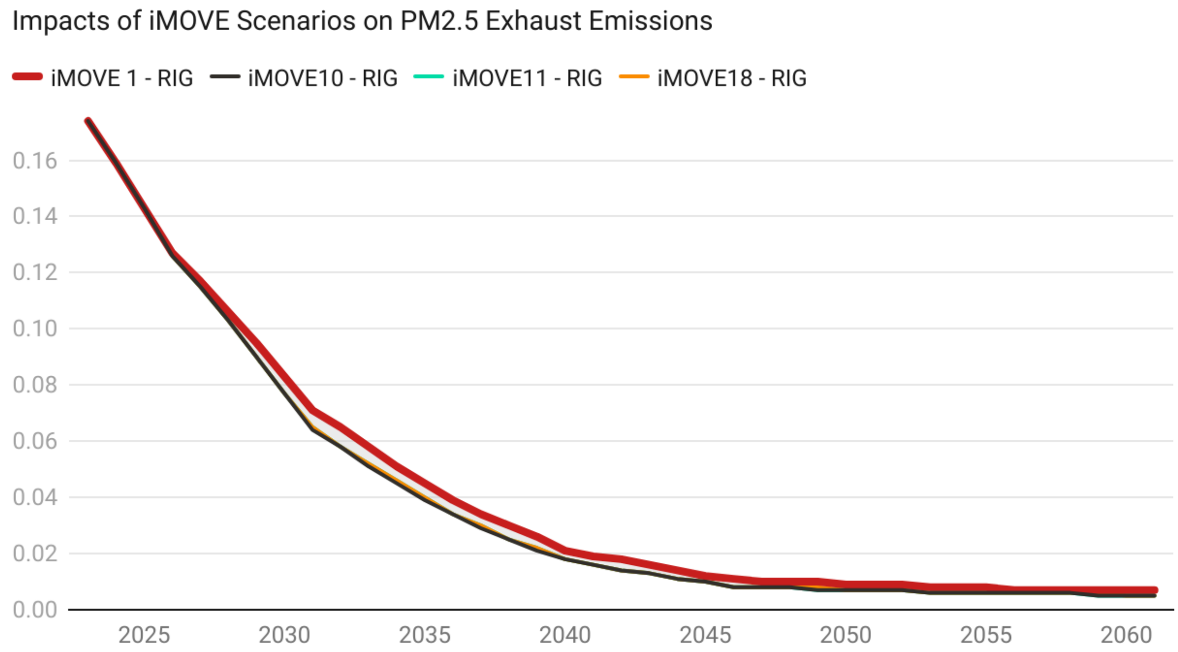


Figure 122: Total $PM_{2.5}$ exhaust emissions (Kt) for rigid trucks

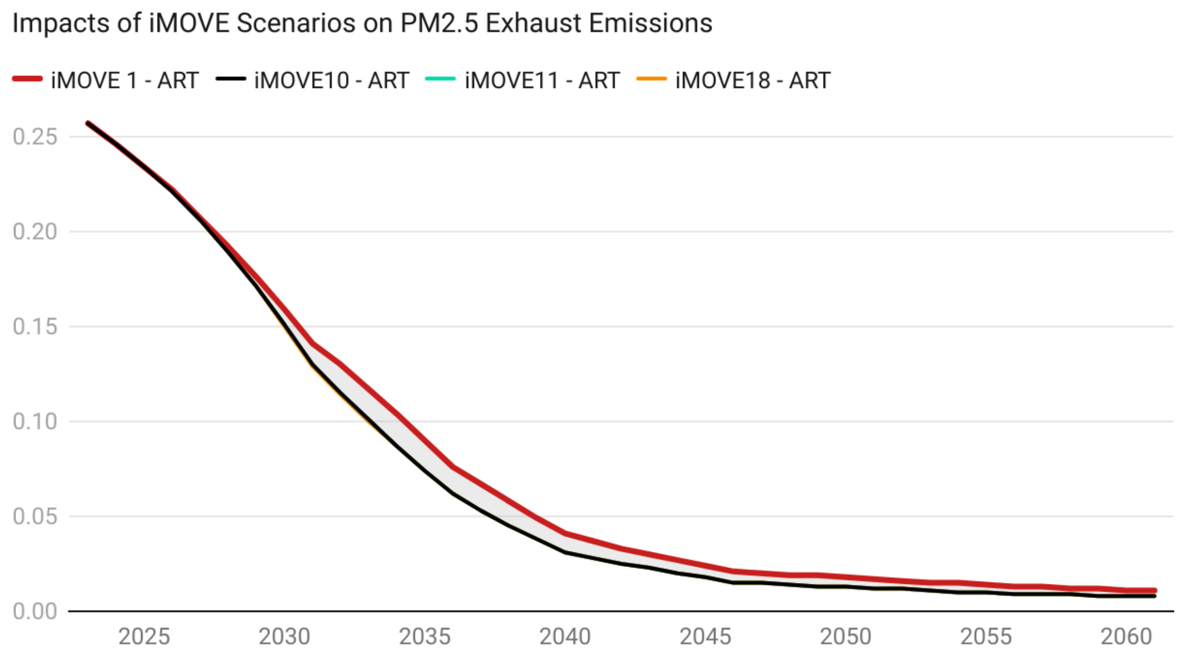


Figure 123: Total $PM_{2.5}$ exhaust emissions (Kt) for articulated trucks

The diagrams for $PM_{2.5}$ non-exhaust emissions (**Figure 124 and Figure 125**) show that emissions from articulated and rigid trucks will continue to rise, due to increased vehicle kilometres of travel and that none of the iMOVE scenarios will have any impact on ameliorating the $PM_{2.5}$ non-exhaust emissions. In the iMOVE1 scenario over the period 2023-2061, the total $PM_{2.5}$ non-exhaust emissions from articulated and rigid trucks were around 10 Kt each. These would remain at the same levels even under the iMOVE11 scenario.

Unlike tailpipe emissions, the $PM_{2.5}$ non-exhaust emissions are produced from the wearing down of brakes, tyres, road surfaces and resuspension of road dust. Exposure to these emissions is associated with a variety of adverse health outcomes, such as increased risks of cardiovascular, respiratory, and developmental conditions, as well as an increased risk of overall mortality.

It is therefore noted that a shift of existing vehicle fleets to zero emissions vehicles won't contribute to reducing this type of non-exhaust emissions. Other established urban transport policies that aim to manage the demand for travel and reduce the number of vehicle trips would be required to ameliorate the expected increases in $PM_{2.5}$ non-exhaust emissions.

The introduction of Euro 7 standards, which will regulate the amount of microplastics that vehicles tyres emit into the environment, will also help in reducing the $PM_{2.5}$ non-exhaust emissions with stricter limits for pollutants like nitrogen oxides and particulate matters. Specifically, the Euro 7 standard will set new restrictions on formaldehyde emissions, a chemical that causes irritation and cancer, as well as ammonia emissions, which cause smog. The Euro 7 will also set criteria for battery life and ultrafine particulate matter (below 10 nanometres) for the first time. The Euro 7 standards and their impacts on truck emissions factors have not been included in this study.

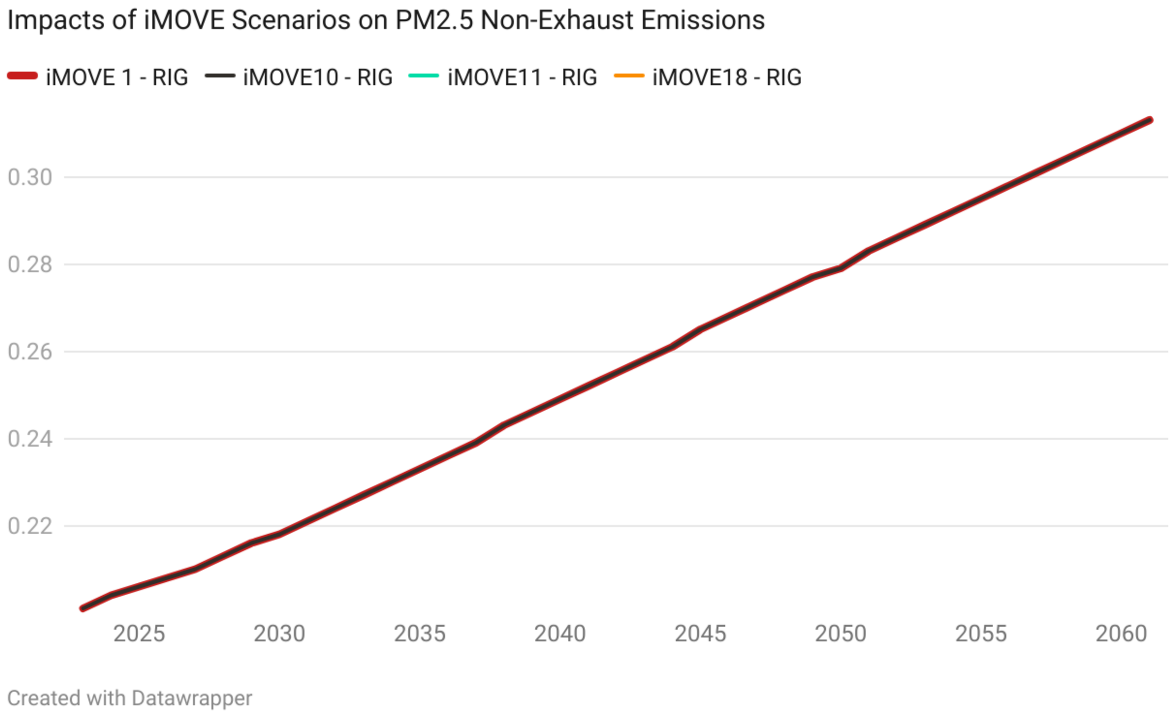


Figure 124: Total $PM_{2.5}$ non-exhaust emissions (Kt) for rigid trucks

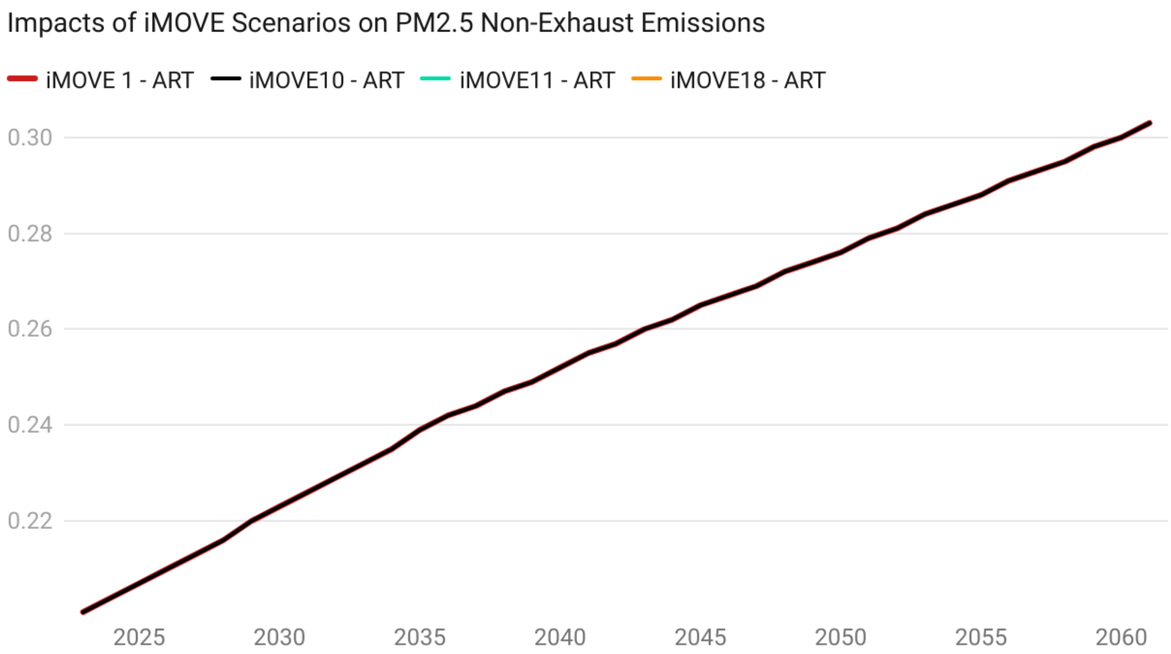


Figure 125: Total $PM_{2.5}$ non-exhaust emissions (Kt) for articulated trucks

Finally, **Figure 126** and **Figure 127** present the $PM_{2.5}$ total emissions, exhaust and non-exhaust combined, for both rigid and articulated trucks, respectively. Although the iMOVE11 scenario results in the lowest $PM_{2.5}$ emissions over the analysis period, it is noted that the differences between the eleven iMOVE scenarios in terms of the total $PM_{2.5}$ emissions do not vary substantially mainly because the non-exhaust emissions are the same for all scenarios.

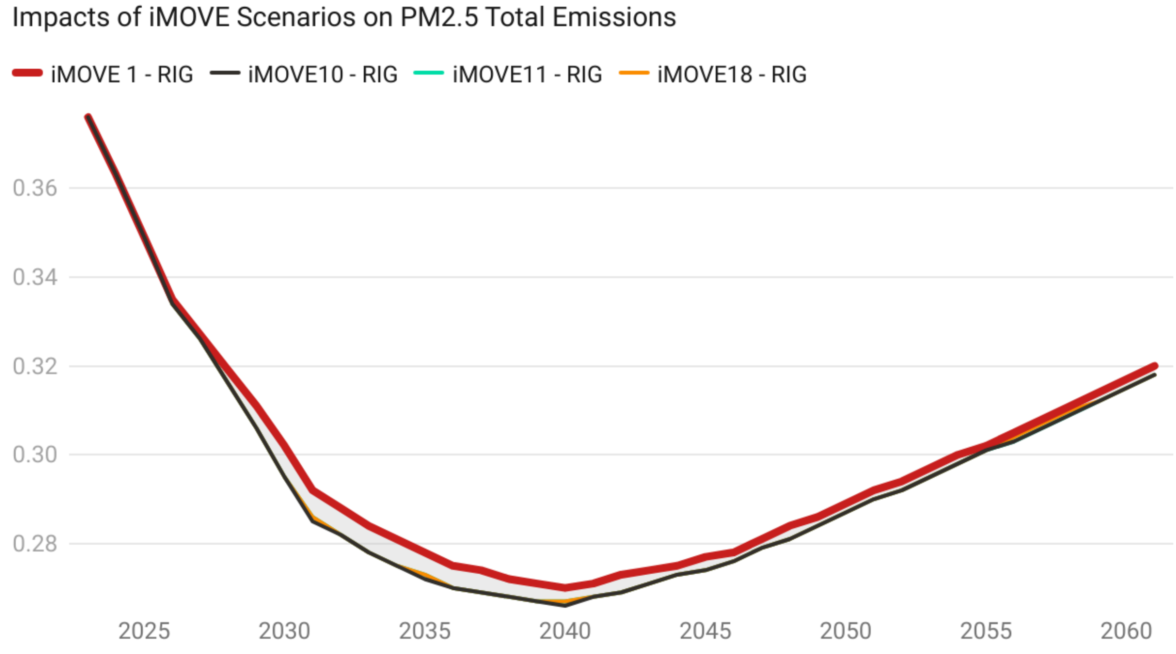


Figure 126: $PM_{2.5}$ total emissions (Kt) for rigid trucks (exhaust and non-exhaust)

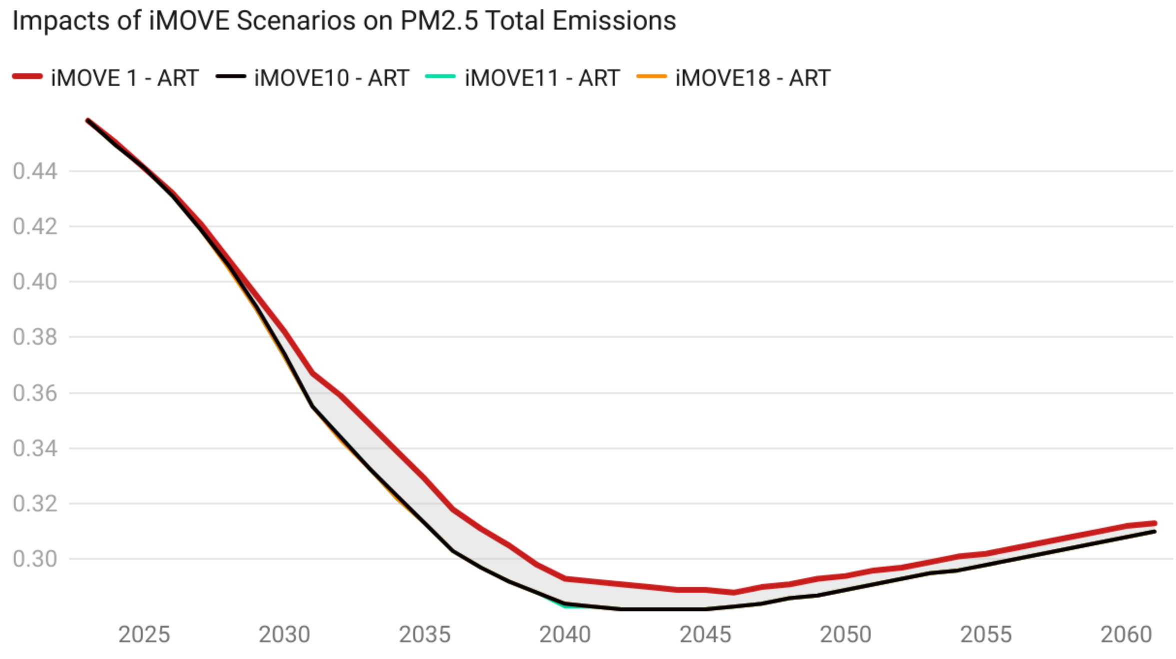


Figure 127: $PM_{2.5}$ total emissions (Kt) for articulated trucks (exhaust and non-exhaust)

7.4 Summary of emissions reductions of iMOVE scenarios

A summary of the impacts of the iMOVE scenarios in reducing emissions are presented next, covering the period 2023-2061.

Figure 128 shows the total emissions produced by each scenario. It includes a "base" scenario reflecting a situation in which no interventions are applied, and the DPE 2022 current policy scenario both of which serve as a base for comparison with the iMOVE scenarios.

As can be noted in the diagram, some of the high impact scenarios, in terms of emissions reductions, include iMOVE 2, iMOVE 6, iMOVE10, iMOVE11 and iMOVE 18.

Scenario iMOVE 2 included only a single policy intervention (phase out 2035) which reduced emissions from 178 Mt in the baseline scenario to around 168 Mt. Similarly, Scenario iMOVE 6 also had one single policy intervention (LZET availability) but that scenario reduced emissions from 178 Mt to around 158 Mt, which is substantially more impactful than iMOVE 2 reflecting the higher importance of stock availability compared to the phase out year policy intervention.

The three most impactful scenarios are iMOVE10, iMOVE11 and iMOVE 18. These scenarios included a package of different policy interventions, which when combined produced the most benefits. These scenarios reduce CO_2-e emissions from around 178 Mt in the base scenario (without any interventions) to roughly 150 Mt.

The diagram also presents the reductions and percentage reductions compared to the base iMOVE1 scenario (or DPE 2022 current policy scenario). The diagram shows that the iMOVE10, iMOVE11 and iMOVE 18 scenarios provide an improvement in reduction of CO_2-e emissions by around 16%, NO_x reductions by around 8.5%, $PM_{2.5}$ exhaust reductions by around 8% and $PM_{2.5}$ total emissions reduction of around 1.6%, compared to the base iMOVE1 (or DPE 2022 current policy) scenario.

Finally, **Figure 129** presents the total emissions produced in the single year 2050 for the two most impactful scenarios (iMOVE 10 and iMOVE 11). The diagram shows that although the iMOVE10 and iMOVE11 scenarios produce the lowest emissions compared to other scenarios for that year, neither achieve zero emissions. The CO_2-e emissions from trucks during that year would still be around 2.6 Mt.

Scenario	iMOVE 1	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10	iMOVE 11	iMOVE 12	iMOVE 13	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19	iMOVE 20
OPEX subsidy	0	0	0	0	0	0	0	0	5	5	5	0	0	0	0	5	5	5	0	5
CAPEX subsidy	0	0	0	0	0	0	0.4	0.8	0	0	0.4	0	0	0.4	0.8	0	0.4	0.8	0.4	0.4
Availability	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Road access	0	0	0	0	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0
Discount	0	0	0.04	0.06	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0
Phase out	0	2035	0	0	0	0	0	0	0	2035	2035	2035	2035	2035	2035	2035	2035	2035	0	0

Results	Baseline	Baseline - control																			
Emissions	**DPE 2022 Current Policy**	**iMOVE 1**	**iMOVE 2**	**iMOVE 3**	**iMOVE 4**	**iMOVE 5**	**iMOVE 6**	**iMOVE 7**	**iMOVE 8**	**iMOVE 9**	**iMOVE 10**	**iMOVE 11**	**iMOVE 12**	**iMOVE 13**	**iMOVE 14**	**iMOVE 15**	**iMOVE 16**	**iMOVE 17**	**iMOVE 18**	**iMOVE 19**	**iMOVE 20**
CO2-e (Mt)	177.95	177.95	168.39	177.10	176.69	176.15	157.98	177.39	176.67	177.03	149.69	149.80	152.52	151.28	151.62	150.47	151.89	151.01	149.88	157.00	156.03
NOx (Kt)	271.98	271.98	266.79	271.38	271.09	270.80	254.69	271.49	270.86	271.38	248.94	248.96	251.62	250.44	250.67	249.44	251.03	250.10	248.88	253.69	252.91
PM2.5 exhaust (Kt)	4.62	4.62	4.54	4.61	4.61	4.60	4.34	4.61	4.60	4.61	4.24	4.24	4.29	4.27	4.27	4.25	4.28	4.26	4.24	4.32	4.31
PM2.5 non-exhaust (Kt	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90
PM2.5 total (Kt)	24.52	24.52	24.44	24.51	24.51	24.50	24.24	24.52	24.51	24.51	24.14	24.15	24.19	24.17	24.17	24.15	24.18	24.16	24.14	24.22	24.21

Reductions on iMOVE 1	**iMOVE 2**	**iMOVE 3**	**iMOVE 4**	**iMOVE 5**	**iMOVE 6**	**iMOVE 7**	**iMOVE 8**	**iMOVE 9**	**iMOVE 10**	**iMOVE 11**	**iMOVE 12**	**iMOVE 13**	**iMOVE 14**	**iMOVE 15**	**iMOVE 16**	**iMOVE 17**	**iMOVE 18**	**iMOVE 19**	**iMOVE 20**
CO2-e reductions (Mt)	9.56	0.85	1.26	1.80	19.97	0.56	1.28	0.92	28.26	28.15	25.43	26.67	26.33	27.48	26.06	26.94	28.07	20.95	21.92
NOx reductions (Kt)	5.19	0.60	0.89	1.18	17.29	0.49	1.11	0.60	23.04	23.01	20.36	21.53	21.30	22.54	20.95	21.88	23.10	18.29	19.07
PM2.5 exhaust reductions (Kt)	0.09	0.01	0.02	0.02	0.28	0.01	0.02	0.01	0.38	0.38	0.33	0.35	0.35	0.37	0.34	0.36	0.38	0.30	0.31
PM2.5 non-exhaust reductions (Kt)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM2.5 total reductions (Kt)	0.09	0.01	0.02	0.02	0.28	0.01	0.02	0.01	0.38	0.38	0.33	0.35	0.35	0.37	0.34	0.36	0.38	0.30	0.31

% Reductions on iMOVE 1	**iMOVE 2**	**iMOVE 3**	**iMOVE 4**	**iMOVE 5**	**iMOVE 6**	**iMOVE 7**	**iMOVE 8**	**iMOVE 9**	**iMOVE 10**	**iMOVE 11**	**iMOVE 12**	**iMOVE 13**	**iMOVE 14**	**iMOVE 15**	**iMOVE 16**	**iMOVE 17**	**iMOVE 18**	**iMOVE 19**	**iMOVE 20**
CO2-e reductions	5.37%	0.48%	0.71%	1.01%	11.22%	0.32%	0.72%	0.52%	15.88%	15.82%	14.29%	14.99%	14.80%	15.44%	14.64%	15.14%	15.77%	11.77%	12.32%
NOx reductions	1.91%	0.22%	0.33%	0.43%	6.36%	0.18%	0.41%	0.22%	8.47%	8.46%	7.48%	7.92%	7.83%	8.29%	7.70%	8.05%	8.49%	6.73%	7.01%
PM2.5 exhaust reductions	1.89%	0.22%	0.33%	0.43%	6.11%	0.17%	0.40%	0.22%	8.20%	8.18%	7.22%	7.64%	7.56%	8.00%	7.44%	7.77%	8.20%	6.47%	6.75%
PM2.5 non-exhaust reductions	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
PM2.5 total reductions	0.36%	0.04%	0.06%	0.08%	1.15%	0.03%	0.07%	0.04%	1.55%	1.54%	1.36%	1.44%	1.43%	1.51%	1.40%	1.46%	1.55%	1.22%	1.27%

Figure 128: Summary of emissions impacts produced for each scenario (2023-2061)

Emissions	iMOVE 1	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10
CO2-e (Mt)	3.489	3.022	3.457	3.441	3.413	2.869	3.473	3.453	3.451	2.550
NOx (Kt)	1.604	1.390	1.588	1.580	1.569	1.325	1.597	1.588	1.586	1.177
PM2.5 exhaust (Kt)	0.027	0.023	0.027	0.027	0.026	0.022	0.027	0.027	0.027	0.020
PM2.5 non-exhaust (Kt)	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556
PM2.5 total (Kt)	0.583	0.579	0.583	0.582	0.582	0.578	0.583	0.583	0.583	0.576

Emissions	iMOVE 11	iMOVE 12	iMOVE 13	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19	iMOVE 20
CO2-e (Mt)	2.554	2.621	2.589	2.600	2.573	2.605	2.584	2.558	2.843	2.811
NOx (Kt)	1.179	1.210	1.195	1.200	1.188	1.202	1.193	1.181	1.312	1.298
PM2.5 exhaust (Kt)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.022	0.022
PM2.5 non-exhaust (Kt)	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556	0.556
PM2.5 total (Kt)	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.576	0.578	0.578

Figure 129: Total emissions produced for each scenario (single year 2050)

7.5 Emissions under rail shift scenario

Although not considered a direct intervention policy, the potential of shifting road freight to rail was also investigated in this study to estimate the likely emissions reductions that would result from such a shift.

Based on available data from the ABS Survey of Motor Vehicle Use (2020), it was assumed that rigid and articulated trucks move around 30% and 70% of tonne-kilometres in NSW, respectively (**Table 31**).

Table 31: Percent of road freight moved by rigid and articulated trucks
Source: ABS Survey of Motor Vehicle Use (2020)

Truck Type	Total Intrastate (million tonne-km)	Percent	Total Australia (million tonne-km)	Percent
Rigid	12,243	29.5%	12,568	25.8%
Articulated	29,222	70.5%	36,166	74.2%

Three scenarios were modelled of a potential overall shift of 20%, 30% and 40% of road to rail between 2023-2061. The CO_2-e emissions reductions from these three scenarios are shown in **Figure 130** compared to the iMOVE 10 scenario. As noted in the diagram, these shifts represent substantial reductions in emissions amounting to around 17.1 Mt, 25.7 Mt and 34.2 Mt for the 20%, 30% and 40% shift scenarios, respectively. **Table 32** presents a summary of how these emissions compare to the iMOVE10 scenario in terms of CO_2-e reductions. The shift to rail CO_2-e emission reductions is substantial and are comparable in magnitude or exceed the impacts of iMOVE scenarios.

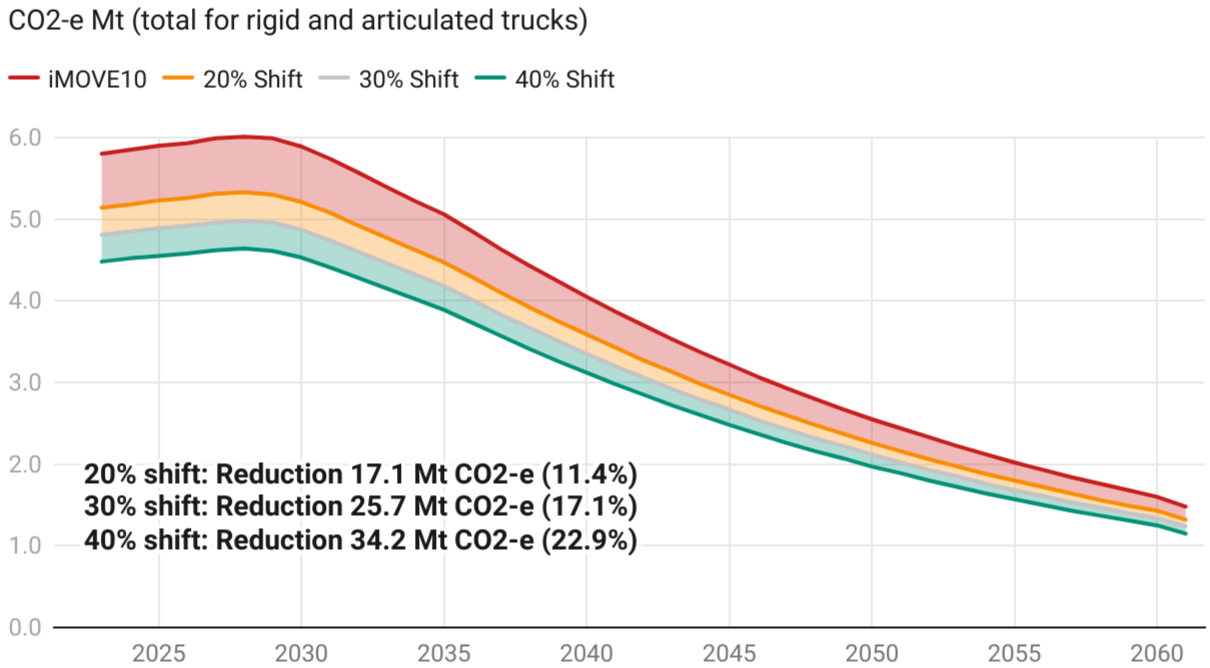


Figure 130: CO_2-e emissions reductions impacts of road to rail shift

Table 32: Comparison of CO_2-e reductions (2023-2061)

iMOVE 1 CO2-e Emissions (2023-2061): 177.95 Mt

	iMOVE 10	20% Shift to Rail	30% Shift to Rail	40% Shift to Rail
CO2-e reductions	28.26 Mt	17.10 Mt	25.70 Mt	34.20 Mt
Combined iMOVE 10 and rail shift reductions		45.36 Mt	53.96 Mt	62.46 Mt
Combined iMOVE 10 and rail shift (% reductions on iMOVE 1)		25%	30%	35%

There is also the potential to combine both sets of scenarios (i.e., shifting road freight to rail in addition to uptake of zero emissions trucks) to provide higher emissions reductions. The total reductions can reach 45.36 Mt, 53.96 Mt and 72.46 Mt when combining the iMOVE10 with the 20%, 30% and 40% rail shift scenarios, respectively.

Finally, and although these represent significant reductions from around 178 Mt in the baseline scenario, they still leave a large gap in emissions that are not met only through these interventions. To address this, these interventions would need to be considered holistically as part of a **comprehensive transport decarbonisation strategy that includes demand management and optimisation of freight distribution networks** and similar freight and transport improvement projects.

7.6 The role of high productivity vehicles

High Productivity Vehicle (HPV) combinations are road freight transport solutions with the potential for immediate decarbonising opportunities of the road freight sector. These vehicles move goods more productively, in terms of tonnes/kilometres meaning fewer vehicles are required for the same task.. Their environmental benefits and current technology-availability makes them a relevant component of a strategy aimed at reducing carbon emissions in road freight.

HPVs are defined as a heavy road freight vehicles that can carry a greater payload than a B-double or general access vehicle permitted on a particular road. They are greater in length, width, and height of mass than B-doubles and are therefore classified as restricted access vehicles.

Modern HPVs, particularly vehicles within the Performance Based Standards (PBS) Scheme, offer safety and sustainability benefits. PBS vehicles are regulated through the national PBS scheme, operating since 2007, which aims to encourage innovation and the development of safer and better equipped HPVs and an alternative to the prescriptive system for regulating heavy vehicles. PBS-approved vehicles are tested against stringent standards that include 16 performance and safety standards, and four infrastructure standards. The PBS scheme focuses on how well the vehicle performs on the road, by assessing the vehicle design against a set of safety standards, rather than assessing a vehicle based on prescriptive limits.

7.6.1 Comparison of high productivity vehicles

HPV combinations involve the use of innovative vehicle designs and technologies to achieve higher payloads without compromising safety or road infrastructure. These vehicles are often equipped with advanced aerodynamics, lightweight materials, significantly reducing their carbon footprint. HPVs include Performance Based Standards (PBS) vehicles, road trains, and other restricted access vehicles including those operating at higher mass limits. In Australia, examples of the use of HPV combinations, which can deliver substantial fuel savings and emissions reductions, are shown in **Figure 131.**

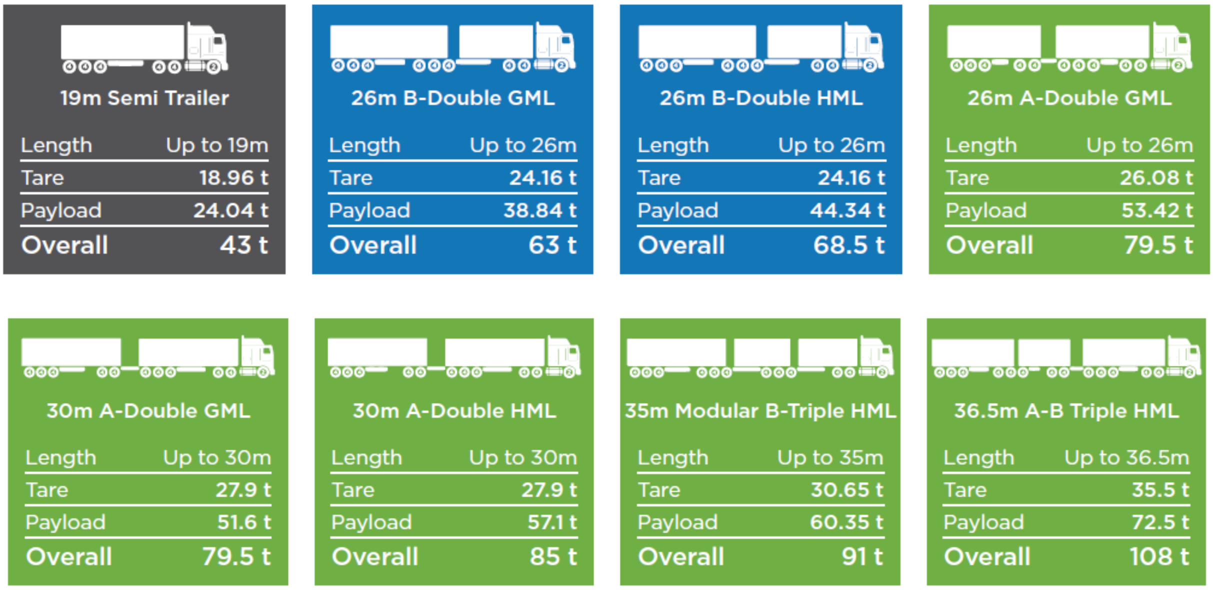


Figure 131: Comparison of high productivity vehicles

By customising dimensions, load capacities, and other features, HPVs can carry more cargo in fewer trips. This directly translates to reduced fuel consumption and emissions per tonne-kilometre of travel. For instance, Australia's PBS program has seen the deployment of longer and heavier trucks that can carry up to 40% more freight per trip, reducing the overall number of trips required.

As of August 2023, there were more than 3,000 PBS vehicles registered in NSW. Most of these vehicles belong to the large articulated category (**Table 33**). Although their emissions profiles are unknown, they are generally considered more efficient than their HPV counterparts.

Table 33: PBS approved registrations for select truck categories (NSW)

PBS Truck Category	Count
3-axle truck 4-axle dog	1,526
A-Double (3-2-3)	293
3-axle truck 5-axle dog	206
3-axle pm quad semi	167
3-axle pm tri semi	139
A-Double (3-3-3)	124
B-Double (3-3)	91
3-axle truck 3-axle dog	80

7.6.2 Benefits of high-performance vehicles

Introducing more productive and efficient vehicles, such as HPVs, provides several benefits that are achieved because of reducing the number of heavy vehicle movements required to complete the freight task. For freight operators, this ensures that goods are transported in the most cost-effective manner, thereby reducing the cost of the road freight movement per unit.

A key advantage for PBS vehicles is that they are designed for the task they need to undertake rather than their conventional counterparts, meaning more freight can be moved in the same number of trips more safely. PBS vehicles have been found to offer 15-30% productivity improvements and benefits, accounting for up to 260 million fewer kilometres travelled annually, compared to conventional vehicles. This also leads to improvements in road safety. Given that the more productive PBS combinations have the capacity to transport more freight per trip, they result in reducing the total number of heavy vehicles on roads which means road users have less exposure to heavy vehicles, reducing the risk of crashes, lowering potential road trauma incidents, and creating safer roads for everyone. Studies have shown that PBS vehicles are involved in 46% fewer major crashes per kilometre travelled than conventional heavy vehicles, and they continue to meet higher safety standards using innovative design and the latest safety technologies. According to Australia’s PBS fleet report (NHVR, 2020), PBS vehicles have a median age of just under four years, compared with over 12 years for the entire heavy vehicle fleet. This younger PBS fleet has considerable advantages, including better safety equipment and fewer maintenance demands compared with older vehicles.

In addition to improving productivity and road safety, HPVs also bring significant environmental benefits for the Australian community.

Environmental benefits

Travelling fewer kilometres and using generally newer vehicles means less fuel is required for a PBS vehicle to complete the same freight task compared to its prescriptive equivalent. For example, the NHVR estimates that, as of March 2019, the PBS fleet will provide annual savings of 200 million litres of fuel and 486,000 tonnes of carbon dioxide emissions (Reference). These savings will continue to increase as the PBS fleet size grows.

Another study by the Industrial Logistics Institute (ILI, 2017) examined several scenarios for deployment of HPVs in Australia. The findings showed that under a moderate growth scenario, HPVs will save 8,860 million kilometres by 2034. This will result in reducing fuel consumption by around 3.2 billion litres, saving at least 8.7 million tonnes of CO_2 in addition to operational savings of at least $17.2 billion in all sectors of the economy. The study also found that just for the year 2016, PBS vehicles were estimated to have reduced fuel consumption by 94 million litres.

A subsequent study by the National Heavy Vehicle Regulator (NHVR, 2019) showed that since the introduction of PBS, and as of March 2019, the HPV fleet has provided annual reductions of 200 million litres of fuel and 486,000 tonnes of carbon dioxide emissions.

A study by the International Transport Forum (ITF, 2019) also showed that HPVs require less energy per unit of transported cargo and thus offer reduced emissions and less impact on the climate.

Similarly, a 2020 study undertaken jointly by the National Heavy Vehicle Regulator (NHVR) and the Australian Road Transport Suppliers Association Institute (ARTSA-I) showed that the improved productivity of PBS combinations was estimated to have reduced the heavy vehicle road transport task by over 2 billion kilometres since they were introduced (NHVR, 2020).

Although not specifically examined in this research, due to the lack of emissions factors for these types of vehicles and payload capacities, incorporating PBS Combination and HPV Combination vehicles into the mix of solutions for road freight decarbonisation is necessary particularly during the transition period towards full fleet electrification. They not only offer immediate emissions reductions but also pave the way for the integration of alternative fuels and electrification, further enhancing their environmental credentials.

These vehicles are particularly relevant to Australia's vast and diverse geography where long-haul transport is essential. By optimising vehicle configurations and introducing innovations like telematics and platooning, they can help the road freight sector in reducing its carbon emissions. Moreover, these strategies have been proven to reduce congestion and wear and tear on road infrastructure, resulting in additional economic and environmental benefits. Having access to data on their operational performance would help in developing a better understanding of their environmental performance and best use cases for their deployment as part of a holistic approach for road freight decarbonisation.

7.6.3 Modelling of potential emissions reductions resulting from replacing existing trucks with HPVs

In this sub-section an illustrative example of potential emissions savings is presented. Four scenarios are presented representing the hypothetical replacement of 10%, 20%, 30% and 40% of existing ART-M trucks (older than 10 years old) with HPV ART-L trucks. In this simplified analysis, it was assumed that two ART-M trucks can be replaced by on ART-L HPV. The analysis covers the period between 2023-2061.

The CO_2-e emissions reductions from these four scenarios are shown in **Figure 132** and **Table 34** and are compared to the iMOVE1 baseline scenario. Over the period 2023-2061 these shifts result in GHG emissions reductions amounting to 4.9 Mt, 8.4 Mt, 12.3 Mt and 15.6 Mt for the 10%, 20%, 30% and 40% scenarios, respectively.

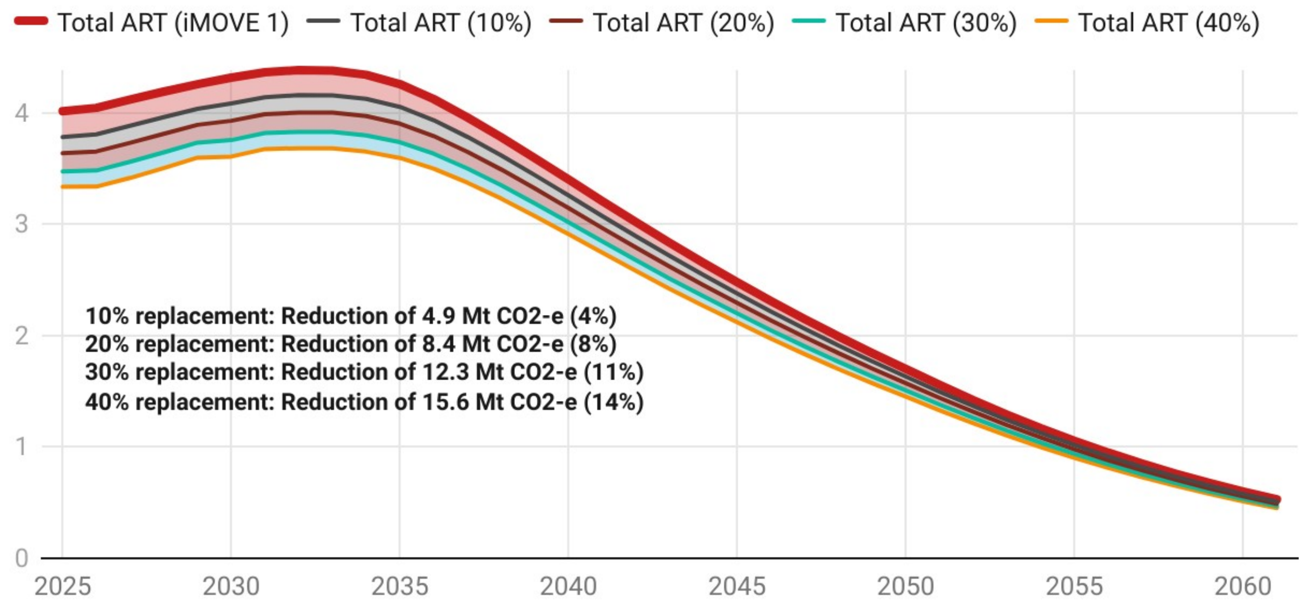


Figure 132: CO_2-e emissions reductions (Mt) for HPV scenarios

Table 34: Comparison of CO_2-e reductions for HPV scenarios

	iMOVE 1	10%	20%	30%	40%
Articulated trucks – cumulative total CO2-e emissions (Mt) (2023-2061)	108.5	103.6	100.1	96.2	92.83
Articulated trucks – cumulative CO2-e reductions (Mt) (2023-2061)		4.9	8.4	12.3	15.6
Percent reduction on iMOVE 1		4%	8%	11%	14%

Assumptions and limitations

As noted before, it is the reduction in VKT, and consequently diesel consumption, that is the primary mechanism for GHG reduction when switching subclasses. While the values in **Table 34** are illustrative of how the emissions savings can be obtained by switching vehicle types, further research is required to establish more exact magnitudes. In calculating the values in **Table 34**, the following assumptions were made and require further testing.

- The simplified modelling assumes that ART-M vehicles that are more than 10 years old are removed from the fleet each year and replaced with ART-L HPV (replacement ratio of 2:1 –i.e., 2 ART-M are replaced by 1 ART-L HPV)

- For each ART-M vehicle number decrease, there is a corresponding 0.5 times increase in ART-L HPV vehicle numbers (50% less vehicles needed to achieve same freight task)
- Only ART-M vehicles older than 10 years are removed from the fleet each year, starting from 2025 (i.e., 18%, 36%, 56%, 73% of ART-M vehicles older than 10 years are removed annually from 2025, corresponding to 8%, 17%, 26% and 34% of the total ART-M fleet removed annually with an associated increase in ART-L HPV of 10%, 20%, 30%, 40%, respectively.
- For new ART-L HPV vehicles added to the fleet, there is an assumed 55% decrease in VKT for new HPV only (reduction in trips is assumed due to HPV higher payload achieving same freight task).
- No additional decrease in VKT is applied for medium articulated trucks (other than associated decrease due to reduction in vehicle numbers)
- The simplified modelling does not account for fleet turnover (i.e., it does not account for new ART-L in 2025 becoming 1-year old vehicles in 2026, 2 years old in 2027 etc with an associated change in VKT by age)
- In the modelling ART-L HPVs are assumed to have the same GHG emissions factor as existing ART-Ls. Moreover, ART-Ls and ART-Ms are assumed to have the same emissions factor. An HPV evaluation study (Austroads, 2014) indicated that although HPVs will generate savings through the annual reduction in kilometres, this may be offset by the higher fuel use (and hence higher emissions) for each HPV replacement vehicle. The magnitude of increase in emissions factors is unknown and should be investigated in future studies but could be substantive. **Appendix B** provide some discussion of intra-type (ART and RIG) variation in emissions factors. For instance, based on Drives data analysis, the average truck classified as ART-L emits roughly 26% more CO_2-e/km compared to the average truck classified as ART-M (**Appendix B**). However, on gross vehicle mass (GVM) / gross combination mass (GCM) basis, the findings in previous sections show that there is a considerable convergence in emissions between the various subclasses.

Economic Assessment

8. Economic Assessment of Policy Interventions

The economic assessment of interventions was based on comparing the GHG emission and air quality impacts associated with specific interventions and the likely cost of implementing interventions. There was no attempt to conduct a holistic assessment of societal impacts or full social cost benefit analysis. Instead, the approach followed cost effectiveness analysis (CEA) principles and compared monetised GHG and air quality impacts with public sector and, where relevant and obtainable, critical freight industry (private) cost factors. The economic assessment included several tasks and assumptions:

- Review of damage cost estimates utilised in the DPE emissions modelling framework, with a view to update values to an agreed base year. This work also included a review of the recently released updates to CBA practice in NSW (NSW Treasury, 2023), and its implications for monetising GHG impacts.
- Mapping of potential policy levers to impacts in the DPE model. For instance, interventions that lower procurement cost of LZEV are expected to operate through stock numbers and composition of vehicle fleet; interventions that target the running cost of either ICE or LZEV vehicles are expected to operate through stock numbers and rate of utilisation (VKT).
- Identification of benefit components. GHG and air quality variables are agreed upon variables for analysis. GHG emissions will be monetised following the updated NSW CBA framework (NSW Treasury, 2023), which draws on pricing of CO_2 in the EU Emissions Trading Scheme (ETS). This value is adjusted annually by 2.25 per cent to account for (an expected) increase in societal Willingness to Pay (WTP) for mitigating of climate impacts. However, there are additional potential benefits in the form of vehicle operating costs, federal flows of funds (if they result in a net increase in NSW resources). Additional benefits still require validation through stakeholder engagement and literature.
- Identification of cost components. Cost components of interventions designed to decarbonise NSW freight in practice encompass public sector (regulatory implementation, infrastructure upgrading), freight industry (capital and infrastructure acquisition, retraining costs etc) and households (for instance, price adjustments in electricity markets, land use for infrastructure rollout etc). An overview of initial potential cost component was shared with the DPE team, who provided feedback and, from a public sector perspective, identified cost components.
- Setting of key parameters for economic assessment over time following review of NSW guidance and regulatory impact statement (RIS) practice.
  - Discount factor (real): 5 per cent (as per NSW Treasury 2023) (NSW Treasury, 2023), with sensitivity at 3 and 7 per cent.
  - Evaluation period: 2022-2061
  - Base year/price: 2022
  - CO_2-e damage cost/price: EU ETS basis; adjusted 2.25 per cent per annum, WTP basis.
  - $PM_{2.5}$ damage cost/price: PAEHolmes approach (PAEHolmes, 2013), following RIS/NSW EPA 2022 (NSW Environmental Protection Agency, 2022).
  - NO_x damage cost/price: Value obtained from (Marsden Jacob Associates, 2018).

This section calculates and compares economic assessments for each of the 10 policy scenarios described in previous sections. The focus in the economic assessment is on difference in economic benefits and costs *relative* to the DPE decarbonisation-baseline or modelling of fleet LZEVs characteristics to 2061. The LZEV baseline is presented in **Figure 133**. Broadly speaking, future decarbonisation trends take off earlier for rigid trucks, due to greater initial availability, but end marginally higher for articulated trucks due to higher turnover rates (retirement) of vehicles.

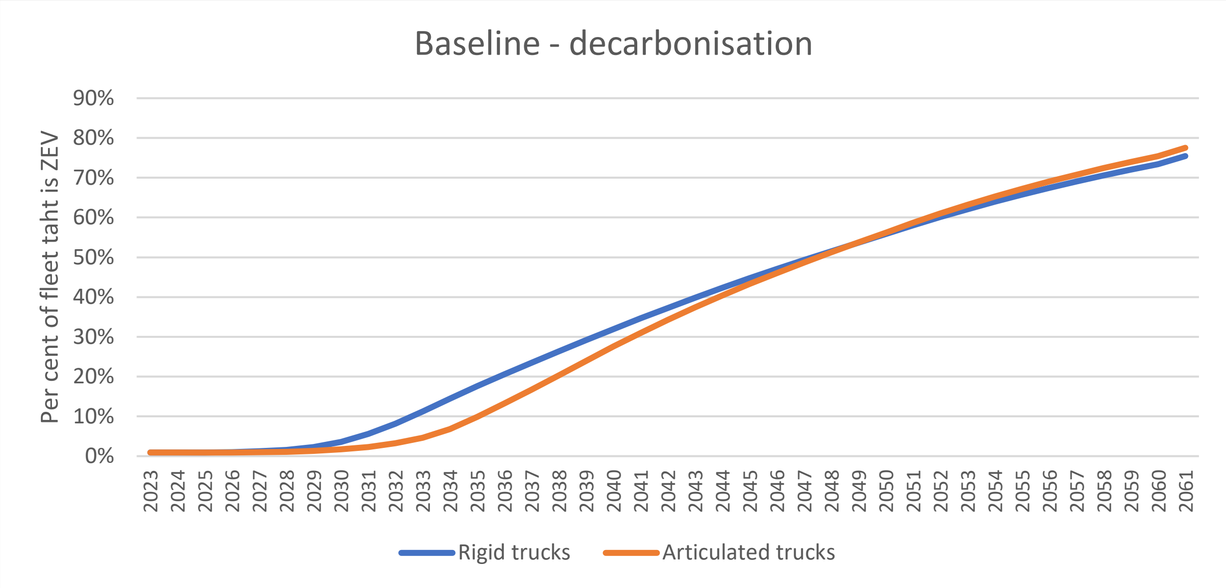


Figure 133: Baseline LZEV fleet characteristics rigid and articulated trucks 2023-2061

Figure 134 (availability) and **Figure 135** (interest free) illustrate the 'area' of economic impact. That is, the economic assessment focuses on identifying the societal benefit, societal costs, and public sector expenditure associated with the area between the two decarbonisation scenarios. This is primarily a marginal analysis – what are the additional costs and benefits from going baseline to any of the modelled policy scenarios. The gap between the respective scenarios in the two diagrams illustrate the magnitude of marginal benefit. In some cases the gap is larger (**Figure 134** – iMOVE6, availability) and in some cases very small (**Figure 135**, iMOVE4, interest free). The magnitude of the gap illustrates the marginal benefit of each policy measure, when implemented on its own.

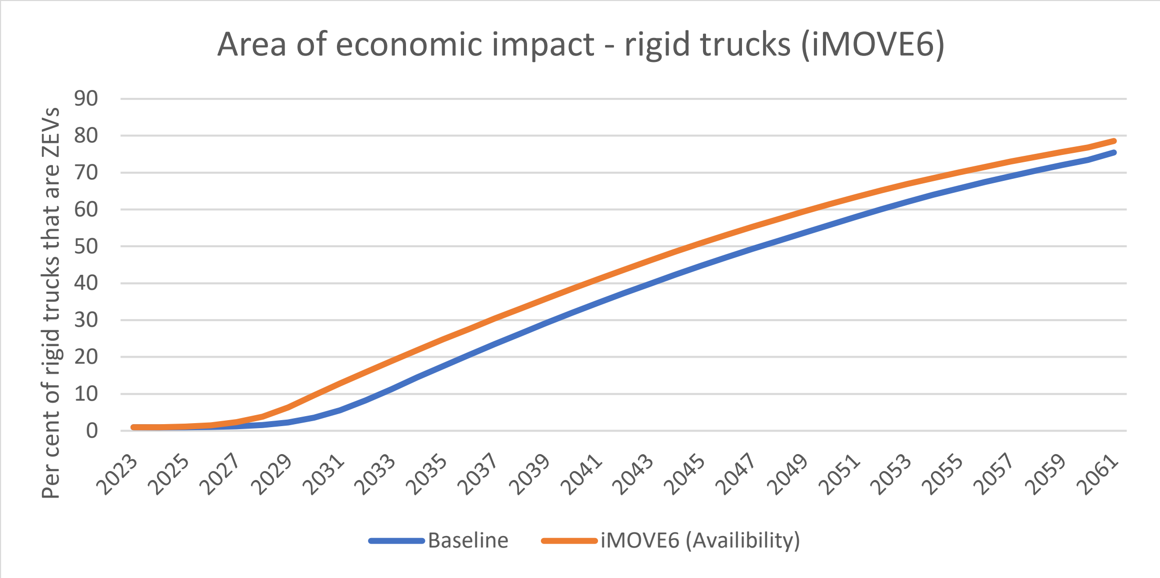


Figure 134: Decarbonisation compared - baseline versus iMOVE6, rigid trucks

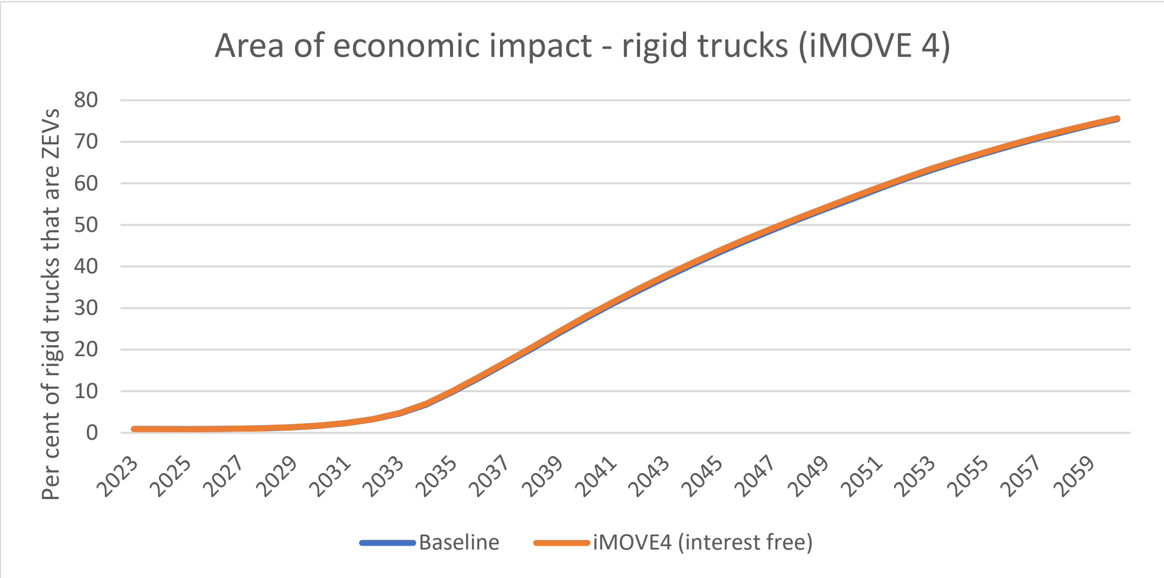


Figure 135: Decarbonisation compared – baseline versus iMOVE4, rigid trucks

8.1 Conceptual assumptions: economic assessment

Comparison against a baseline that already projects decarbonisation taking off towards the end of the 2020s has several implications for how to assess differences in economic benefits and costs across the policy scenarios:

- Expenditures associated with the delivery of the baseline are ignored for the purpose of the analysis. For instance, availability of infrastructure (such as recharging stations) would need to increase under the baseline decarbonisation scenario. Much analysis on decarbonisation of transport focuses on infrastructure requirements for a decarbonised fleet and works with average requirements, for instance per truck charging stations (IEA, 2023); (Moglia, 2022) (Shoman, 2023)), rather than marginal requirements. Some studies can nevertheless be used to arrive at marginal requirements to proxy for additional infrastructure cost under each of the policy scenarios (IEA, 2023).

- Similarly, many societal learning/organisational adaptation and regulatory requirements would take place under the baseline as well. Consequently, these items are ignored for the purpose of this analysis.
- The analysis takes the envelope of VKT and stock numbers (rigids and articulated) as fixed. These inputs are provided by DPE. The envelope VKT is reflective of fleet compositions as well as economy growth/population change assumptions in the DPE modelling. In practice this means that changes to fleet composition following technological change – such as more decentralised freight operations (in case of further urban sprawl) or more compact urban development – is not separately controlled or modifiable. Similarly, technological, or logistical innovations leading to smaller vehicles is not separately controlled or modifiable.
- It is likely that significant electrification of freight (and passenger vehicles) would require upgrades to electricity generation capacity and distribution. (Moglia, 2022) estimate that complete electrification of the passenger vehicle fleet would require electricity consumption around 17% of Australian output. Given that these costs would take place under baseline assumptions as well – and require frontloading of investment – upgrades to generation and distribution are ignored for the purposes of comparing baseline to policy scenarios.
- Finally, the turnover rate of vehicles is based on DPE modelling of future fleet characteristics and numbers. This turnover rate is also taken as fixed (approximately 3% for rigid trucks and 5% for articulated trucks). The implication of this is that the rate of compositional change in the fleet characteristics is bounded by the turnover rate and deviations in adoption rates of LZEVs (for each of the scenarios).

8.2 Economic assessment parameters

The economic assessment is conducted for the period 2023-2061. Net present value (NPV) calculations are based on NSW Treasury 2022 guideline discount rates. A 5% social discount rate (SDR) is used for the central estimates. Estimation at 3% and 7% discount rates were also included. The economic assessment parameters used in the analysis are presented in **Table 35.**

Table 35: Economic assessment parameters

Evaluation period	2023-2061
Prices	2022
SDR for NPV calculation	3%, 5% and 7%

The economic assessment includes public and private benefits. Decarbonisation of transport results in reduced levels of pollution (greenhouse gas and air quality). Reduction in pollution is a reduction in the external effect of transport and treated as a public benefit. Key emissions factors (for the year 2023) are listed in **Table 36.**

Table 36: Social benefit parameters (2022 prices)

BENEFITS	Category	Measurement
Public	CO_2	Rigid trucks: 527g per/VKT Articulated trucks: 1427g per/VKT EU ETS auction price: $120.29 per/ton (scaled 2.25% per annum)
Public	NO_x	Rigid trucks: 1.612g per/VKT Articulated trucks: 5.943g per/VKT NO_x price: $7,296 per/ton.
Public	$PM_{2.5}$	Rigid trucks: 0.048g per/VKT and 0.055g per/VKT exhaust and non-exhaust, respectively. Articulated trucks: 0.093 per/VKT and 0.072 per/VKT exhaust and non-exhaust, respectively. $PM_{2.5}$ price: $344,116 per/ton
Private	OPEX	Based on fuel economy assumptions and adjusted for taxes/transfer payments: Diesel: $0.421 per/VKT Electricity: $0.208 per/VKT H2: $0.883 per/VKT (to diesel price parity in 2030)

LZEV fuel price differ significantly from diesel prices. These differences are treated as a private benefit or cost. Key fuel price assumptions are also listed in **Table 36**. Fuel prices are kept constant throughout the analysis period, apart from hydrogen fuel (H2). Given uncertainty around future price trajectories for diesel and electricity these have been treated as constant. If future electricity prices decline relative to diesel prices, the estimated social (private) benefit is under-estimated. H2 starts the analysis period as more expensive than diesel but is assumed to attain price parity by 2030 (based on (IEA, 2021)). Key prices assumptions are listed in the below table, and all prices are measured in 2022 values. The external cost of CO_2 is based on European Union Emissions Trading Scheme (ETS) values (NSW Treasury 2022).

As noted previously, given the existing escalation of decarbonisation towards the end of the 2020s in the baseline scenario, most of the costs associated with decarbonisation can be treated as baseline cost. Additional costs are, however, associated with two cost categories in particular – road wear and additional infrastructure requirements. Cost factors are summarised in **Table 37**.

Table 37: Social cost parameters

Cost	Category	Measurement
Public	Road wear	Rigid trucks: Road Wear Potential (RWP) uplift 10% and 2%, BEV and FCEV, respectively. Road wear $0.1293 per/VKT (TfNSW, 2022). Articulated trucks: RWP uplift 30% and 6%, BEV and FCEV, respectively. Road wear $0.2097 per/VKT (TfNSW, 2022).
Private	Infrastructure	Depot based infrastructure: 100%. $80,000 per additional BEV. Opportunity charging: one 350kW charger per additional 260 (2023) to 60 (2061) trucks. H2 refuelling: one 1500 kg charger per 50 additional FCEVs.
Private	LZEV additional CAPEX	Cost differential between ICE and BEV/FCEV vehicles. Only applicable in iMOVE2 (Phase out), iMOVE10 and iMOVE11.

Note: TfNSW 2023 Road wear values were deflated back to Dec 2022 to be consistent with remaining prices. Road wear value for rigids based on weighted average of medium and large trucks in TfNSW (2023).

8.2.1 Additional road wear impact

TfNSW guidelines provide road wear factors associated with transportation (TfNSW, 2022). As trucks travel across the NSW road network the grind of tyres against road surface generates a maintenance or replacement costs. In a like-for-like capacity replacement LZEV are typically heavier than diesel trucks – this is particularly the case for BEVs – and can thus be expected to generate addition road wear costs not incorporated in the baseline. To estimate the additional costs the analysis follows (Low, 2023) and calculates the road wear potential (RWP) for 5 rigid and 3 articulated vehicle classes, and a weighted average RWP for rigid and articulated trucks.

RWP= (No. of axles) × (Vehicle Weigh/(No.of axles × 80))^4

The differential in RWP for diesel, battery electric and hydrogen trucks was multiplied by the TfNSW road wear factors and the number of vehicles in each fuel type to generate the additional road wear costs resulting from deviations from the baseline composition of trucks. The RWP uplift factors and TfNSW road wear factors are reported in **Table 37**. In the economic assessment it is assumed that battery technology improves over time and that road surfacing materials improve over time so that from 2037 the RWP declines linearly to zero by 2052.

8.2.2 Additional infrastructure requirements

A key cost consideration is the additional charging infrastructure requirement associated with deviations in fleet decarbonisation across the policy scenarios. Additional refuelling infrastructure covers three types of infrastructure: at depot BEV charging stations, on road BEV charging stations (opportunity chargers), and H2 refuelling stations (**Table 37**).

- The addition of at depot BEV charging requirements is based on a straightforward differential of BEVs under the baseline and alternative policy scenario. The literature broadly assumes a 100% at-depot charging requirement. In costing depot-based infrastructure, the analysis assumes one 50kW charger (capable of charging a 400kW truck overnight/8 hours). Depot based charging is costed at $80,000 (hardware and installation).
- Additional high powered (350kW) BEV charging infrastructure is based on infrastructure requirements reported by (IEA, 2023). IEA reports on two scenarios: stated policy scenario (STEPS) and announced pledges scenario (APS), the latter being more ambitious than the former. DC chargers and trucks for STEPS and APS are reported in **Table 38**.

Table 38: STEPS and APS BEV infrastructure requirements

	STEPS	APS	Change
DC	13,500	25,000	11,500
Trucks	3,500,000	4,200,000	700,000
Trucks per charger	259	168	61

- Based on the above results, the additional DC infrastructure requirement translates into one additional opportunity charger (350kW) per 260 *additional* BEV (over the baseline scenario) in early phases of electrification, declining to one charger per 26 additional BEVs in 2061 (high level of electrification). The intuition behind the declining rate is that opportunity charging initially is in more densely populated or along key connecting road. As electrification proceeds, high-powered charging infrastructure is required in more remote and less frequented connections as well. DC350kW charging is costed at $440,000 (hardware and installation).
- H2 charging stations are based entirely on shared refuelling infrastructure (no depot-based infrastructure is costed). Additional requirements are based on additional fuel volume requirements. A US DOE study (DOE, 2020) found that the median refuelling capacity of 111 H2 refuelling stations in California was 1500 kg H2 per/day. Assuming a 30-35kg fuel capacity per FCEV truck translates into one additional h2 refuelling station per 50 additional FCEV. In the absence of studies providing a marginal analysis this rate is assumed across the analysis period. A 1,500 kg H2 station is costed at $4,662,000 ($3,108 per/kg H2).

8.2.3 Additional truck procurement cost (CAPEX)

An assumption in the modelling is that procurement costs for BEV and FCEV converge upon the procurement cost of ICE by 2039. For most of the scenarios the additional capex expenditure is nevertheless ignored. The reason for this is that the uptake of LZEV options is based on the probability that a truck operator chooses an ICE or LZEV option. The probability of this choice is based on procurement cost, running costs, incentives (policies) and preferences. In making this choice it is assumed that decision-makers make the decision that meets the financial and corporate objectives of the respective truck operators. In other words, in the policy scenarios – as modelled – no decision-makers are artificially made to select a vehicle *that they otherwise would not have chosen*.

The only exemption to this is iMOVE2 (Phase out) and the comprehensive packages iMOVE10 and iMOVE11 that both contain a phase out. In this scenario several ICE vehicles would still have been purchased beyond the phase out year (2035). In other words, these decision-makers would, in the absence of the phase out, have decided that an ICE vehicle was the appropriate choice for their circumstance. In this case the policy (phase out) imposes an additional cost on these decision-makers. Under iMOVE2, iMOVE10 and iMOVE11 this additional cost is the differential between ICE and equivalent LZEV vehicles. Overall, the cost implications are minor, given the assumption around price convergence. By 2035 LZEV vehicles are assumed to almost reach price parity with ICE vehicles.

7.2.4 Public sector financial cost overview

Table 39 summarises details on the financial parameters that are used under different policy scenarios.

- iMOVE3 and iMOVE4 model out the impact of providing a discounted and interest-free loan to each purchase of a new BEV or FCEV. Under such a policy truck operators would take out a loan for the entire cost of a vehicle – the public sector/TfNSW would provide partial (iMOVE3) or full (iMOVE4) payment of the associated interest cost. Financing term is assumed at 5 years.

- iMOVE7 and iMOVE8 model out the impact of providing a 40% and 80% subsidy payment of the price differential between the representative costs of a BEV and FCEV vehicle and its corresponding diesel version.
- iMOVE9 models out the impact of providing a $0.05 per/VKT fuel rebate.

In the economic assessment these financial incentives remain in place until the purchase price of LZEVs reach price parity with diesel vehicles.

Table 39: Financial parameters

Financial	Category	Measurement
Public	OPEX subsidy	$0.05 per km - applicable until price ICE=BEV, ICE=FC
Public	Financing subsidy	Low-interest or interest-free loan (5-year term), applicable until price ICE=BEV, ICE=FC
Public	CAPEX subsidy	Percentage of price differential, applicable until price ICE=BEV, ICE=FC

8.3 Economic assessment outputs

Economic assessment is concerned with real resource use in the economy. That is, how should scarce resources be allocated today to maximise societal welfare or wellbeing over time? This is the basis for cost-benefit analysis. In cost-benefit analysis the focus is on societal outcomes. From a public policy perspective, it is also relevant to understand what generates the greatest societal welfare or wellbeing benefit for each dollar the public sector spends. These two questions are related but can generate very different answers.

The economic analysis is therefore presented both on a societal basis and a public sector (or partial) basis.

Societal outcomes (welfare and wellbeing)

When examining societal outcomes, transfer payments (taxes, subsidies) and interest payments are typically ignored. These constitute financial resource that are moved between actors in the economy, which, at a societal level, balance out. The allocation of resources today requires a method for translating future values into present values. The conventional approach here is to apply discount factors. Since interest rates also compensate for the time-value of money, these are ignored under social economic assessment. The societal analysis provides estimates of the NPV of benefits, costs, and net benefits, as well as the benefit-cost ratio. The input factors to this analysis are the parameters described in previous tables.

Public sector outcomes (resource cost-benefit)

When examining policy scenarios from a public sector perspective the value of subsidies and interest payments constitute real constraints on what the public sector can do. The economic analysis therefore also provides estimates of the NPV of *public* benefits (externality reductions) and cost (additional road wear – plus the (relevant) financial parameters. This analysis also provides the ratio of societal net benefits relative to each dollar of public cost – a measure of the net social benefit generated for each dollar of public sector expenditure.

Table 40 summarises and contrasts the cost and benefits elements included under societal and public sector outcomes.

Table 40: Comparing societal and public sector cost and benefit components

	Social analysis	Public sector analysis
Benefits	• Reduced GHG ($C0_2$-e) emission (public) • Reduced NO_x emission (public) • Reduced $PM_{2.5}$ emission (public) • Reduced resource/fuel expenditure (private)	• Reduced GHG ($C0_2$-e) emission (public) • Reduced NO_x emission (public) • Reduced $PM_{2.5}$ emission (public)
Costs	• Additional road tear (public) • New infrastructure cost (private)* • Vehicle (additional) purchase cost (private)	• Additional road tear (public) • Interest rate subsidy (public) • OPEX running cost subsidy (public) • CAPEX subsidy (public)

Note: * Following extensive discussion in the project steering committee it was agreed that LZEV infrastructure costs alleviation was not considered an in-scope policy lever. Consequently, additional infrastructure costs are modelled out as private sector costs.

Elements included in the public sector analysis (such as subsidies), but not included in the societal analysis constitute financial or transfer payments. These represent a redistribution of funds, rather than societal gains. They do represent a change in the distribution of costs and benefits, but do not result in a change in the overall net benefit. For instance, a $1,000 subsidy for an LZEV increases the cost to the public sector by $1,000, and the benefit to the private sector by $1,000. Societal net benefit is, however, unchanged.

From a decision-making point of view, both societal and public sector outcomes should be considered. The societal analysis evaluates whether society is better off in real terms. Both the magnitude of any NPV and the ratio of benefits to costs should be examined. The public sector analysis is in practice a partial cost-benefit analysis (or financial appraisal). It only evaluates outcomes from the perspective of the policy organisation or unit. In **Table 40**, many of the public sector costs are not included in the societal analysis. The are nevertheless highly relevant in terms of political feasibility and budget decision-making. They are also relevant in any assessment of public sector cost effectiveness.

8.4 Aggregate NSW results for all trucks

The economic analysis assessed 21 policy scenarios in comparison to baseline assumptions around decarbonisation of freight. **Table 41, Table 42, Table 43** and **Table 44** summarise the societal and public sector net costs and benefits.

Benefits are a function of externality reductions (GHG and air quality) and reduced fuel expenditure (adjusted for taxes and transfer payments). Variations across the policy scenarios reflect i) degree of decarbonisation (switch away from diesel transportation) and ii) relative uptake of BEV versus FCEV transportation. For instance, the difference in net benefits between iMOVE 4 (zero interest loan) and iMOVE8 (80% subsidy of price differential) reflect that under iMOVE4 the penetration of BEV vehicles is nearly 10 (rigid trucks) and 6 (articulated trucks) percentage points higher than under iMOVE8. Since private benefits are entirely determined by differentials in fuel prices, and H2 is only projected to reach price parity with diesel, the private benefit under iMOVE8 is substantially less.

Private net benefits constitute a substantial share of societal benefits. Comparing the total benefits calculations in **Table 41** and **Table 42, Table 43** and **Table 44** gives a measure of differences in magnitude between these two sources of benefits. The exemption here are the two price differential subsidy scenarios. These both attain a comparatively high rate of H2 uptake and therefore – even compared to the baseline – a lower rate of electrification. Consequently, under these two scenarios (iMOVE7 and iMOVE8) the difference between net social and net public benefit is negligible.

Societal costs are a function of additional road wear and additional infrastructure requirements. Like variations in benefits, these too vary by i) degree of decarbonisation (switch away from diesel transportation) and ii) relative uptake of BEV versus FCEV transportation. Faster rates of decarbonisation results in additional infrastructure requirements. Greater uptake of BEVs, rather than FCEVs, results in greater wear and tear and maintenance/replacement of road surfaces.

iMOVE2 (phase out 2035) and iMOVE6 (availability) are the two policy initiatives with the single greatest impact on decarbonisation and consequently net societal benefits (**Table 41**) – $203m and $1.03bn, respectively. Common to both is that they are primarily regulatory in nature. This is reflected in **Table 42** with the greatest net societal benefit per dollar of public expenditure.[8] iMOVE6 also creates a near $44 net social benefit for each dollar of public expenditure.

[8] iMOVE5 is not discussed in detail due to uncertainty around its actual real resource implications (e.g., land, construction, congestion).

Table 41: Societal economic assessment of iMOVE2-iMOVE11, central estimate (5% SDR)

Scenario	iMOVE2	iMOVE3	iMOVE4	iMOVE 5*	iMOVE 6	iMOVE7	iMOVE8	iMOVE9	iMOVE 10	iMOVE 11
Societal analysis	**Phase out 2035**	**Low interest**	**Interest free**	**Road Access**	**Availability**	**40% CAPEX**	**80% CAPEX**	**$5 OPEX**	**Comprehensive + interest free**	**Comprehensive + 40% CAPEX**
NPV Total Benefits (million, $)	$1,108	$249	$370	$240	$2,731	$48	$101	$125	$4,090	$3,720
NPV Total Costs (million, $)	$905	$336	$500	$186	$1,697	$56	$126	$97	$2,779	$2,589
NPV Net Benefits (million, $)	$203	*-$87*	*-$130*	$54	$1,034	*-$8*	*-$26*	$28	$1,311	$1,131
Societal B/C	1.22	0.74	0.74	1.29	1.61	0.86	0.80	1.28	1.47	1.44

Note: * Results should be treated with caution. Provision of reserved access lanes, zero-emission zones will likely have real resource implications that are not captured in this analysis.

Table 42: Public economic assessment of iMOVE2-iMOVE11, central estimate (5% SDR)

Scenario	iMOVE2	iMOVE3	iMOVE4	iMOVE5*	iMOVE6	iMOVE7	iMOVE8	iMOVE9	iMOVE 10	iMOVE 11
Public sector analysis	**Phase out 2035**	**Low interest**	**Interest free**	**Road Access**	**Availability**	**40% CAPEX**	**80% CAPEX**	**$5 OPEX**	**Comprehensive + interest free**	**Comprehensive + 40% CAPEX**
NPV Public/Transport Benefits (million, $)	$603	$59	$87	$121	$1,507	$43	$97	$62	$2,080	$2,074
NPV Public/Transport Cost (million, $)	$7	$2,226	$3,378	$1	$24	$381	$852	$75	$5,750	$1,184
NPV Net Public/Transport Benefits	$595	*-$2,168*	*-$3,291*	$120	$1,484	*-$338*	*-$754*	*-$13*	*-$3,670*	$889
Net societal benefit per/public $	$27.95	*-$0.04*	*-$0.04*	$38.66	$43.68	*-$0.02*	*-$0.03*	$0.37	$0.23	$0.95

Note: * Results should be treated with caution. Provision of road access to reserved lanes, zero-emission zones will likely have real resource and financial implications that are not captured in this analysis.

Table 43: Societal economic assessment of iMOVE12-iMOVE20, central estimate (5% SDR)

Scenario	IMOVE 12	iMOVE 13 *	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19	iMOVE 20
Societal analysis									
NPV Total Benefits (million, $)	$3,360	$3,653	$3,419	$3,459	$3,469	$3,524	$3,559	$2,811	$2,957
NPV Total Costs (million, $)	$2,285	$2,421	$2,395	$2,534	$2,356	$2,463	$2,599	$1,818	$1,985
NPV Net Benefits (million, $)	$1,074	$1,233	$1,024	$925	$1,114	$1,061	$959	$993	$973
Societal B/C	1.47	1.51	1.43	1.37	1.47	1.43	1.37	1.55	1.49

Note: * Results should be treated with caution. Provision of reserved access lanes, zero-emission zones will likely have real resource implications that are not captured in this analysis.

Table 44: Public economic assessment of iMOVE12-iMOVE20, central estimate (5% SDR)

Scenario	IMOVE 12	iMOVE 13*	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19 *	iMOVE 20
Public sector analysis									
NPV Public/Transport Benefits (million, $)	$1,831	$2,039	$1,935	$2,030	$1,911	$1,983	$2,076	$1,588	$1,658
NPV Public/Transport Cost (million, $)	$28	$29	$932	$2,113	$213	$1,143	$2,351	$902	$1,110
NPV Net Public/Transport Benefits	$1,834	$2,010	$1,003	*-$83*	$1,697	$840	*-$275*	$685	$548
Net societal benefit per/public $	$38.89	$42.26	$1.10	$0.44	$5.23	$0.93	$0.41	$1.10	$0.88

Note: * Results should be treated with caution. Provision of reserved access lanes, zero-emission zones will likely have real resource implications that are not captured in this analysis.

iMOVE2 (phase-out of ICE trucks by 2035) and iMOVE6 (improved availability of LZEV trucks) also have the highest societal benefit to cost ratio, with, compared to remaining scenarios, high return on investment of public expenditure. Both policies are also included in the two comprehensive policy packages iMOVE10 (comprehensive package, zero-interest loan) and iMOVE11 (comprehensive package, 40% price differential subsidy). This is a key reason for the overall relative benefit of these two composite policy initiative scenarios.

iMOVE3 (low interest loans) and iMOVE4 (interest free loans) provide a financial subsidy (payment of interest) that lowers annual financial payments for freight operators. Given the limited availability of LZEV options on the Australian market these measures are currently less effective in shaping LZEV-uptake choices than regulatory measures. This is reflected in relatively modest societal benefits with a comparatively high public finance implication. In modelling the uptake of LZEVs, interest rate subsidies are somewhat more effective in incentivising BEV uptake. Due to the heavier nature of these vehicles, the resulting public cost in the form of road wear is also high.

iMOVE5 (provision of improved road access for LZEVs) is another regulatory policy intervention. iMOVE5's societal benefit is small, compared to either phase out or regulatory changes to enable the availability of LZEV trucks. Moreover, unlike relating to the iMOVE2 and iMOVE6, there is considerable uncertainty around the cost implications of this initiative. Depending on design of the policy additional cost aspects of providing reserved lanes, low emissions zones and relaxation of night-time curfew, cost may extend to acquisition of land and/or built structures and construction of new roads. If design is based on utilisation of existing road infrastructure additional congestion costs might arise. Therefore, although the balance of costs to benefits is positive in **Table 41** and the benefit per public dollar is comparatively high (**Table 42**), this policy option requires further design and costing for a firmer economic assessment.

iMOVE7 (40% CAPEX) and iMOVE8 (80% CAPEX) are, like the interest rate subsidy, less effective than regulatory measures in incentivising LZEV uptake, primarily because they are poorly targeted in a context of high baseline adoption of LZEV trucks. Consequently, the societal benefit attained is the lowest of each of the modelled policy initiatives. Given the somewhat higher uptake of FCEVs under these CAPEX subsidies, the balance of societal benefits to cost is marginally better than the interest rate incentives. The public finance impact of these CAPEX subsidies is also less than the interest rate incentive. The cost of CAPEX subsidies also varies considerably depending on rates of fleet turnover which uncertain (therefore adding uncertainty to estimates of benefits of costs). In years with more trucks purchased, the cost of this policy increases.

Of the pure financial incentives, iMOVE9 (fuel subsidy) is the only one to generate a positive B/C (>1). The net social value $125m is not as large as that of subsidised loans (**Table 41**), but neither are the financial costs to the public sector (**Table 42)**. The lower societal benefit is reflective of a relatively modest change in uptake. Interest rate subsidies are high relative to subsidising price differentials. For instance, public sector payment of a 6% loan with a 5-year term comes to approximately $220,000 for a loan taken out in 2023 on an average FCEV and approximately $156,000 for an average BEV. For comparison, a 40% subsidy on the price differential comes to $175,000 (FCEV) and $95,000 (BEV), respectively. While the price gap is assumed to close relatively quickly (and so these payments decline quickly too), discounting of values means that costs and benefits nearer in time (to 2023) have comparatively greater impacts on the analysis than costs and benefits later in time.

The two comprehensive policy packages are the only scenarios that generate a comparable net social value to policies which include access interventions (6, 11-20), and all scenarios that include access interventions have comparable B/C ratios. However, iMOVE10 (zero-interest loan) also comes with high public sector financial cost and consequently a low net societal benefit per dollar of public expenditure. A key consideration for the interpretation of the comprehensive packages is that higher impact initiatives, such as iMOVE6 (availability), now come with added public finance implications. When iMOVE6 is modelled out as an individual package, the uptake of LZEVs is high, but at limited public finance cost. However, when coupled with any of the financial incentives, higher uptake of LZEVs also means that the public finance impact increases. In practice, each of the trucks that would emerge at no additional public finance cost under iMOVE6, now also obtain a financial incentive.

Varying the discount rate to 3 or 7 per cent makes little difference to the above insights. The magnitude of benefits and costs do change, but the structure of net benefits and insights for public expenditure remains fundamentally unaltered. These results are included in **Appendix B** of the report.

With the insight that regulatory measures will be the most cost effective, a set of policy scenarios were developed (iMOVE 12-20) which included phase out of ICE trucks by 2035 as well as efforts to improve availability of LZEV trucks. Based on an analysis of these scenarios, we find that adding the provision of improved road access for LZEVs further improves on the societal cost to benefit ratio, as well as the societal benefit per public cost. However, as noted under iMOVE5, the cost implications (and so the BC ratio) have a high degree of uncertainty.

We also note that, given the symbolic importance of financial incentives, the inclusion of such policies was added to the mix, and it is notable that iMOVE16 which includes a small OPEX subsidy (5 cents per km) also maintains a high societal benefit to cost ratio, as well as a relatively high social benefit per public dollar spent. iMOVE19 is also worth noting, which includes a 40% discount on the difference in price between an ICE truck and an LZEV truck (i.e., a CAPEX discount), although this scenario does not compare favourably compared with iMOVE16. The benefit of using a CAPEX subsidy (rather than an OPEX subsidy) is that it can be more easily targeted to chosen segments of the fleet. For example, it could be targeted at older, and larger (and therefore more polluting) vehicles.

Finally, the previous analysis was based on NSW Treasury guidance on carbon price setting. **Table 45** provides sensitivity analysis of the estimates based on 25%, 50% and 100% mark-ups in the carbon price. Only the resulting BC ratios are shown. Overall, while the impact on the societal BC ratio, while positive, is relatively limited because of an even substantially higher carbon price.

Table 45: Sensitivity analysis carbon price, societal BC ratio (5% SDR)

Scenario	IMOVE2	iMOVE3	iMOVE 4	iMOVE 5*	iMOVE 6	iMOVE7	iMOVE8	iMOVE9	iMOVE 10	iMOVE 11
Societal analysis	**Phase out 2035**	**Low interest**	**Interest free**	**Road Access**	**Availability**	**40% CAPEX**	**80% CAPEX**	**$5 OPEX**	**Comprehensive + interest free**	**Comprehensive + 40% CAPEX**
Societal B/C, $$CO_2$ (central estimate)	1.22	0.74	0.74	1.29	1.61	0.86	0.80	1.28	1.47	1.44
Societal B/C, $ CO_2+25%	1.38	0.78	0.78	1.45	1.81	1.03	0.97	1.43	1.64	1.62
Societal B/C, $ CO_2 +50%	1.54	0.82	0.82	1.60	2.02	1.20	1.15	1.58	1.82	1.80
Societal B/C, $ CO_2+100%	1.86	0.90	0.90	1.90	2.42	1.55	1.50	1.88	2.16	2.17

8.5 Disaggregating emissions and economic costs by truck class

The results in Chapter 7 and the economic assessment in previous section examined GHG and air quality impacts (physical and economic) in response to a series of potential policy interventions over time (iMOVE scenarios 2-20). In this section the analysis disaggregates the GHG impacts of the current ICE freight fleet by truck type (rigid and articulated trucks) and size to identify the relative GHG impact associated with sub-classes. While the analysis in previous sections suggests that regulatory policy intervention – from the vantage point of 2023 – has the greatest effect in incentivising LZET uptake, it is also the case that the availability of BEV and FCEV technologies remains limited both in Australia and internationally. The disaggregation of GHG impact by freight vehicle subclass therefore enables reflecting on policy intervention options, from a GHG reducing perspective, relative to vehicle technological availability.

8.5.1 Emissions and damage cost per truck per year

The GHG impact for each truck subclass is a function of how polluting each subclass typically is and how many kilometres trucks in each subclass typically travel. **Table 46** therefore provides an overview of the GHG emissions impact of the individual freight subclasses by two measures: (1) CO_2-e impact per VKT – comparing across the individual classes provides insight on the relative impact of each kilometre travelled by the different categories of trucks; and (2) typical usage or travel patterns for each subclass using the average VKT travelled within each class as a proxy for typical usage pattern.

Table 46: CO_2 emissions and damage cost per truck, rigid and articulated, per year
Note: Reference year 2023

Truck category (1)	Number of trucks, DPE fleet mode (2)	CO2e g/per km (3)	Average VKT, per truck (4)	CO2e (tons) per average truck (5)	Total CO2e (tons) (6)	Social cost per average truck (7)
RIG-S	71,330	366	23,561	8.6	613,438	$1,058
RIG-SM	19,160	392	21,113	8.3	159,028	$1,021
RIG-M	29,220	602	20,957	12.6	368,172	$1,550
RIG-ML	17,167	641	21,899	14.0	240,338	$1,722
RIG-L	23,816	938	23,591	22.1	526,334	$2,718
ART-S	4,697	1,438	73,561	105.8	496,943	$13,013
ART-M	28,243	1,311	60,899	79.9	2,256,616	$9,828
ART-L	10,868	1,652	66,670	110.2	1,197,654	$13,555

Source: Authors calculation from DPE fleet model inputs and Drives data.
Note: The modelled carbon price in 2023 was $123.

The entries in **Table 46** are based on the DPE's fleet model and analysis of the Drives data (2021-2022). The DPE model provides aggregate emissions factors for rigid and articulated trucks. To derive appropriate proxies for the GHG emission by subclass, the GHG emissions factors in the Drives data was calibrated to match the average GHG emissions factor in the DPE fleet model.[9]

Average VKT was calculated from the DPE fleet model data by dividing total VKT for each subclass by number of vehicles in the respective subclasses. Total VKTs in the DPE fleet model are based on BITRE estimates – the DPE fleet model does produce VKT estimates for each subclass, and these are used to identify the share of BITRE VKT attributed to each subclass.

In **Table 46** emissions factors by subclass broadly fall into four groups: (1) small and small-medium rigids; (2) medium and medium-large rigids; (3) large rigids; and (4) articulated trucks. The typical distance travelled for rigid trucks is broadly similar – this is also the case for medium and large articulated trucks, with small articulated trucks typically travelling further.

The combined effect of CO_2 emissions and travel distance is shown in column (5). The annual carbon emission ranges from 8.3 tons (small-medium rigid) to 110.2 tons (large articulated). These values are monetised in column (7) with annual social cost of CO2e ranging from $1,021 to $13,555.

It is worth noting that this analysis is based on available data which includes VKT travelled by each vehicle type and subclass. Because a larger truck can carry more goods (larger payloads) comparing classes only by VKT size skews the analysis in favour of smaller vehicles. Importantly therefore, the purpose of presenting this data is not to optimise the choice of different size trucks for the movement of goods, but to provide further detail on the emission reduction potential of different classes in relation to technological availability. Focusing entirely on vehicle subclass and emissions reduction (in other words setting aside payload) would suggest prioritising decarbonisation of larger trucks. On the other hand, there are better technological options available already for the smaller trucks, and fewer options available for larger trucks. In other words, decarbonising smaller trucks is, in the short to medium term, more achievable.

Moving away from a focus only on vehicle subclass there are of course other considerations and options. Freight currently undertaken by larger trucks can be shifted to other modes of transport (e.g., rail and ship).

Moreover, adding payload to the analysis would at the very least alter the relative social cost of good transported by each vehicle class, reducing the apparent CO_2 and social cost of transportation for larger trucks. While data to robustly interrogate the implication of weight / tonne-km is not available the issue can be illustrated by comparing the GHG emissions based on gross vehicle mass (GVM) / gross combination mass (GCM) for small rigids and large articulated trucks. A common 2 axle rigid truck has a GVM/GCM of 15 tons. A common road train (type 1) has a GVM/GVM or 79 tons. The average GHG emission per GVM/GCM is thus 0.57 tons CO_2-e for small rigids and 1.39 tons CO_2-e for large articulated trucks. On a truck category basis, a large articulated truck generates nearly 13 times more GHG than a small rigid truck. On a GVM/GCM basis a large articulated truck generates approximately 2.5 times as much GHG. A further factor to consider where data was not available is the utilisation factor

[9] The calibration assumes that the *relative* emissions factors in the Drives is an appropriate proxy relative GHG impact across the freight subclasses. For consistency with earlier analysis the GHG emissions factors are constrained to match the DPE's average emission factors. It should be noted that the GHG emissions factors in the Drives data (2021-2022) are larger than those of the DPE fleet model. This potentially is a source of downwards bias in the estimated GHG reductions and social value generated by decarbonisation. **Appendix B** provides a comparison of results constrained to the DPE fleet model and alternative estimates derived from the Drives data. Given the cross-section nature (2 years) of the Drives data difference should be treated with caution.

of each truck type. If articulated trucks are more likely to fully utilise their load capacity in both directions, and smaller rigids utilise their load capacity fully only in one direction and return with a reduced or zero load, then the factors converge even more.

The comparison of small rigid and large articulated trucks does suggest that some GHG emissions savings can be achievable by shifting load between truck subclasses.[10] However, redistributing weight across vehicle subclasses – such as from larger to smaller trucks (where in the short to medium term LZEV alternatives more readily exists) – will also have other consequences, such as adding number of trips and vehicles to NSW roads.

It is recommended that future research extends and deepens this analysis by considering the weight transported by each truck subclass and factoring this data into the relative contribution of each truck subclass on emissions such that VKT, payload and tonne-km transported by each vehicle type and subclass are considered. There also remains considerable uncertainty (from a modelling perspective) around GHG emissions factors for the current fleet. Reported readings of GHG emissions are typically done in controlled environments that may not fully reflect the actual on-road outputs of GHG.[11]

8.6 Emissions in baseline and iMOVE 10 scenarios

Following on from the previous analysis, this section compares the relative GHG emissions composition across the subclasses for two of the iMOVE scenarios – iMOVE1 (baseline) and iMOVE10 (a comprehensive package of decarbonisation incentives). The analysis then focuses on the *change* in GHG emissions – relative to the baseline – and its subclass composition. iMOVE10 is chosen as the comparison as this policy package had the greatest effect. All other iMOVE scenarios lie somewhere between these two scenarios. The results of this analysis are provided in **Table 47.**

The results in **Table 47** show that in the baseline scenario (iMOVE 1), rigid trucks are responsible for 52.27 Mt (31% of total emissions) and articulated trucks account for around 116.28 Mt (69% of total emissions). The relative contributions in the iMOVE 10 scenario are slightly different with rigid trucks contributing around 46.14 Mt (33% of total emissions) and articulated trucks accounting for around 95.76 Mt (67% of total emissions).

Overall, the iMOVE 10 scenario produces total reductions in emissions of 26.64 Mt over the period 2021-2061, or a 15.8% reduction relative to the baseline. In line with the average statistics presented in **Table 47**, the average reduction arising from rigid trucks (11.7%) is somewhat smaller than the reduction arising from articulated trucks (17.6%).

As noted earlier, this analysis is based only on VKT by each subclass and does not take into consideration payload and tonne-km travelled (such data is not available to the research team) or utilisation rates.

[10] It is not suggested that different truck subclasses necessarily constitute viable substitutes for each other / different freight tasks. Any such shift would likely need to be accompanied by additional structural shifts in modes (rail, ship) and logistical distribution networks.

[11] For comparison, **Appendix B** contains emissions factors from two sources.

Table 47: Relative contribution of truck subclasses to overall emissions

Vehicle Type	Emissions Mt CO2-e	iMOVE 1	iMOVE 10
		168.54	141.90
Rigid trucks		52.27	46.14
RIG-S	Emissions Mt CO2-e	24.87	21.94
RIG-SM	Emissions Mt CO2-e	5.60	5.05
RIG-M	Emissions Mt CO2-e	8.36	7.45
RIG-ML	Emissions Mt CO2-e	5.09	4.47
RIG-L	Emissions Mt CO2-e	8.35	7.23
Articulated trucks		116.28	95.76
ART-S	Emissions Mt CO2-e	12.06	10.41
ART-M	Emissions Mt CO2-e	71.33	59.39
ART-L	Emissions Mt CO2-e	32.89	25.96
Reductions on iMOVE 1			26.64
Rigid trucks			6.12
RIG-S	Emissions Mt CO2-e		2.93
RIG-SM	Emissions Mt CO2-e		0.55
RIG-M	Emissions Mt CO2-e		0.91
RIG-ML	Emissions Mt CO2-e		0.62
RIG-L	Emissions Mt CO2-e		1.12
Articulated trucks			20.52
ART-S	Emissions Mt CO2-e		1.65
ART-M	Emissions Mt CO2-e		11.94
ART-L	Emissions Mt CO2-e		6.93
% Reductions on iMOVE 1			15.8%
Rigid trucks			11.7%
RIG-S	Emissions Mt CO2-e		11.8%
RIG-SM	Emissions Mt CO2-e		9.8%
RIG-M	Emissions Mt CO2-e		10.8%
RIG-ML	Emissions Mt CO2-e		12.1%
RIG-L	Emissions Mt CO2-e		13.4%
Articulated trucks			17.6%
ART-S	Emissions Mt CO2-e		13.7%
ART-M	Emissions Mt CO2-e		16.7%
ART-L	Emissions Mt CO2-e		21.1%

Note: The analysis in this table relies on an updated version of the DPE model which considered the new uptake curves generated in this research. This has resulted in small differences in estimates of total emissions produced in the baseline and iMOVE 10 scenarios compared to results reported in previous sections of the report.

8.7 Insights for policy

The economic assessment yields several insights to decarbonise freight:

1. Regulatory initiatives appear – from the vantage point of 2023 – more effective measures to speed up decarbonisation of freight. Phasing out diesel, or combustion engines, in the mid-2030s speeds up decarbonisation faster than any of the financial incentives.
2. Phasing out vehicles requires appropriate substitutes for different freight tasks and for different usage patterns and sizes.
3. There is an urgent need to bring suitable makes and models to Australia, and to test them in Australian conditions and use-cases. Availability of trucks has the single greatest impact on projected decarbonisation rates. Increasing availability of LZEV trucks requires, at least in the short-medium term, regulatory changes to permissible truck widths and axle mass. These regulatory initiatives are federal level policy levers, but critical to ensuring that international improvements in LZEV technology and vehicles – currently existing and futures ones – can be adopted in Australia. This will help to build confidence among operators that even this segment of the freight sector could transition to LZETs.
4. Financial incentives, from the vantage point of 2023, are comparatively less effective measures to achieve decarbonisation.
   - In part this is because financial incentives alone cannot address availability or suitability of current LZEV alternatives to diesel trucks. It is thus highly likely that the responsiveness of LZEV uptake to financial incentives would be (much) greater when and if there are viable substitutes.
   - Uptake is responsive to financial incentives (subsidising price differentials and/or removal of stamp-duties, registration costs), as they are likely to reduce behavioural barriers associated with large upfront cost decisions. Moreover, capital cost subsidies may also serve to bridge financing gaps experienced by some truck operators – particularly in early years while price differentials remain significant.
   - Financial incentives also act as signals to producers and may serve to bring forward technological availability points in the Australian market. That is, manufacturers too take financial incentives as a signal that markets are worthwhile supplying with state-of-the-art technology. Thus, financial incentives work on buyers as well as suppliers. This also makes financial incentives more important early on when technology otherwise is limited, and price differentials are high, than later.
   - Financial incentives are, however, poorly targeted in the above economic analysis and therefore costly. It cannot a priori be determined which LZEV purchase would have taken place without the presence of a financial incentive. Similarly, the introduction of loan or purchase subsidies would need to be available to every potential purchaser. Given the significant expected decarbonisation under the baseline the public sector would end up subsidising many trucks that would have been purchased as LZEVs anyway. In practice the financial cost identified before measure the public finance impact of both the baseline and the different scenarios.
5. A key determinant of decarbonisation in the modelling and economic assessment is the rate with which existing vehicles are retired. Financial incentives could be better targeted by subsidising the removal of older trucks and more polluting trucks. Financial rates could be differentiated by age and emissions to ensure that low polluting trucks are not discouraged to the same extent as high polluting trucks. Financial incentives targeting the service lifespan of trucks could potentially additionally increase the retirement rate of vehicles all together enabling decarbonisation to proceed faster.
6. Whilst there already are smaller LZETs available for purchase on the market, and in operation in Australia, there are fewer options available for larger segments, especially for

long-haul uses. The disaggregated analysis highlights that there is a considerable divergence between short- to medium-term LZEV technological feasibility and the main sources of GHG emissions in the freight sector. Decarbonisation of larger truck segments therefore, in addition to LZEV technological innovation, also require mode shift (to rail or ship) to enable bringing decarbonisation forward in time.

The absence of payload analysis and truck utilisation likely exacerbate the relative GHG emissions of different vehicle subclasses. Nevertheless, emissions reductions may also be attainable by switching freight from some higher emitting subclasses to lower emitting classes. A caveat here is that this source of potential emissions reduction may not effectively address the technology-availability constraint, nor the economics of transporting large loads across longer distances and may result in additional road congestion.

Stakeholder Consultations

9. Stakeholder Consultations

This section of report presents findings from the stakeholder consultation survey which was completed as part of this research. At the broadest level, the stakeholder consultation included questions related to the demography of participants and the nature of their work, knowledge of zero emission trucks, availability of zero emission trucks, their preferred fleet configurations and general questions about opportunities and challenges associated with freight decarbonisation.

9.1 Methodology and sampling approach

For the stakeholder consultation, the research team developed a survey instrument, which was pilot tested and refined through an extensive feedback process and communication with TfNSW and the research team. The survey was then transformed into an online form using the Qualtrics platform for distribution among stakeholders.

The survey participation time was estimated approximately 20 minutes to complete. Once the sampling and online questionnaire was finalised, the survey link was then distributed among potential stakeholders. Although unique links were sent to participants to avoid duplication of responses, the data collection and analysis was carried out completely anonymous.

Accompanied with the survey, participants were provided with an extensive Information Sheet that explained the background and objectives of the study, the participant selection process, the risks, and benefits and how the results support informed decision making. Furthermore, before starting the survey, participants were required to review the information statement and provide their consent to contribute to the survey.

For this survey, non-probability sampling approach was adopted by engaging online panels. This method was selected to arrive to the required sample size, coverage, and simplified implementation. The research team engaged a third-party data collection company to support the data collection by engaging their online panels of experts. The Online Research Unit (ORU) is a professional survey services company assisted the research team to collect responses be leveraging on their extensive online panel of experts.

Data collection commenced on 18th July 2023 with a focus on participants from NSW. Due to low response, it was expanded to Victoria and Queensland on 21st July and Australia wide on 27th July. Data collection was completed on 2nd August 2023.

9.1.1 Research ethics clearance

The research team followed Swinburne's research ethics approach to engage with participants contributing to the consultation. To carry out human related research, it is a requirement to receive ethics clearance. Therefore, an ethics application was developed and submitted to Swinburne University of Technology Human Research Ethics Committee (SUHREC) in June 2023. The application was then carefully reviewed to assess any potential risks involved in the research process and the arrangements planned to minimise the risks. The assessment involves several factors, including the vulnerability of and risks to participant, the participation selection criteria, implications of participation, procedures related to data collection and management, but also how research findings are disseminated. Initial ethics clearance was received on 22nd June 2023 (Ref: 20236803-13480). Throughout the data collection process, several sub-applications were submitted to expand the data collection region.

9.1.2 Selection criteria

Given the nature of this consultation and the need to capture authentic information from decision makers, a rigorous protocol was considered that included several inclusion and exclusion criteria. The selection process included the following filters:

- Participants consent to complete the survey.
- Participants meet age requirement of 18 years and older.
- Direct involvement in freight transport in Australia
- Own or operate heavy vehicles with Gross Mass Limit (GML) of more than 4.5 tons.
- Directly involved in vehicle purchasing decisions

For data analysis, the research team only focused on participants completing all survey questions. Furthermore, as an additional quality control step, responses with low quality input were excluded. **Figure 136** summarises the extensive screening process followed, resulting in 58 useful responses.

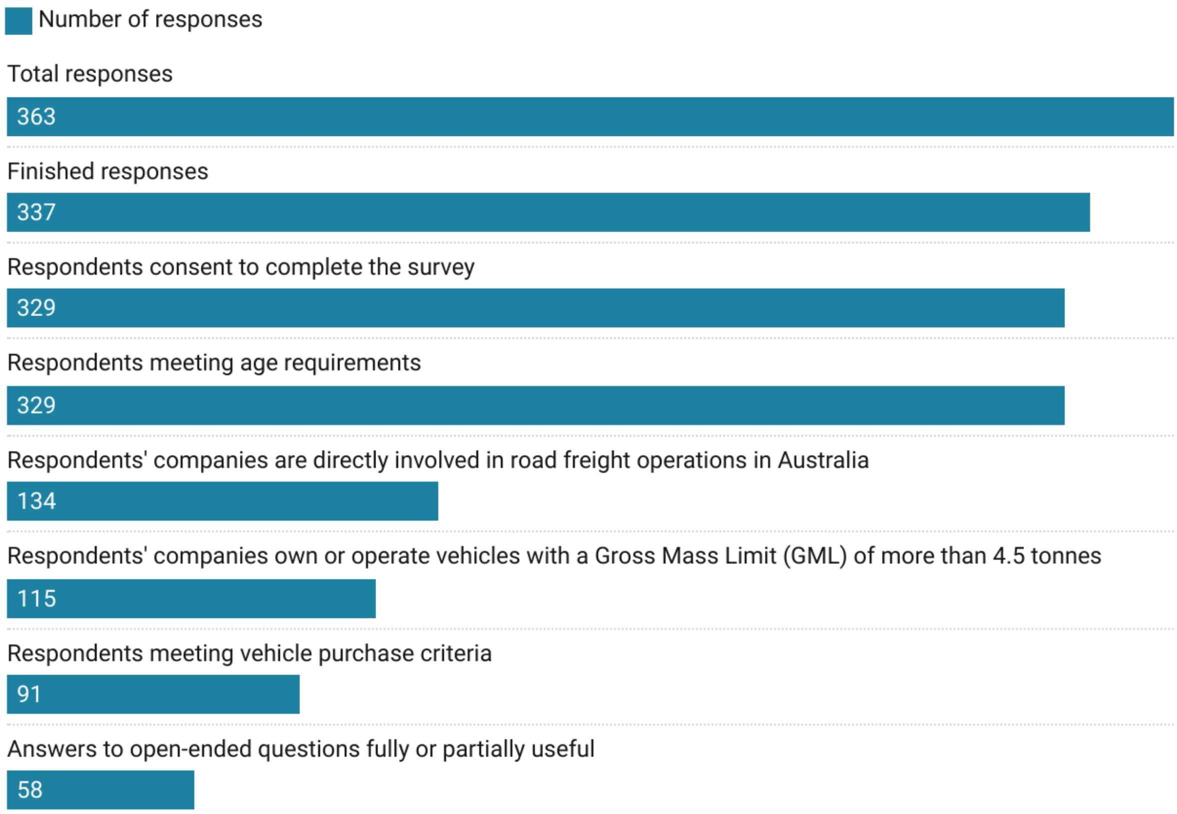


Figure 136: Data collection screening process

9.2 Descriptive and demographic statistics

The first part of data collection involved questions regarding the demography of participants. From an age point of view, participants represent a wide range of groups, with majority of them in the 35 to 64 range (**Figure 137**). In terms of gender, 39 male and 19 female participants completed the survey (**Figure 138**).

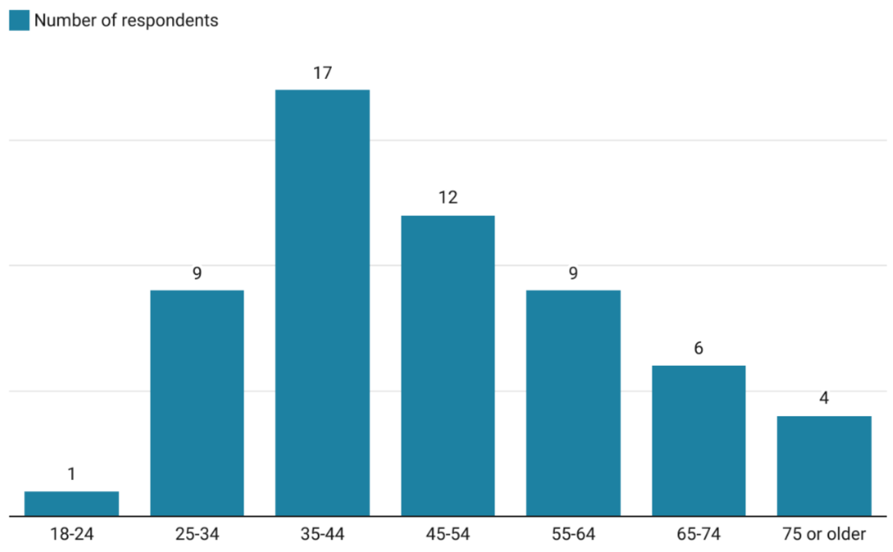


Figure 137: Age distribution of participants

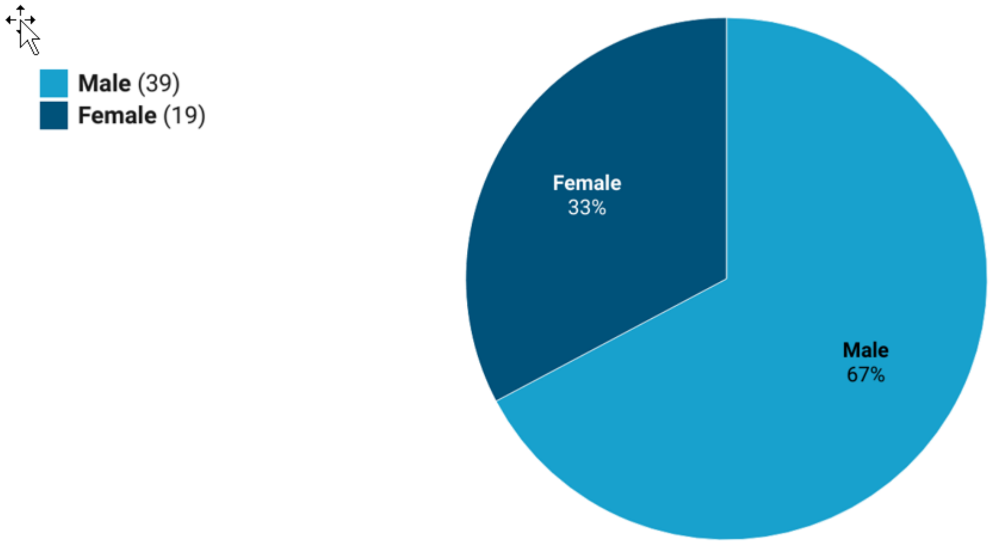


Figure 138: Gender distribution of participants

In terms of work experience, participants demonstrated a diverse range. Overall, the sample represented highly experienced participants. **Figure 139** summarises the work experience of participants based on their gender. Similarly, 50% of sample represented mid-level managers, 31% other levels and 19% represented roles associated with executive management (**Figure 140**).

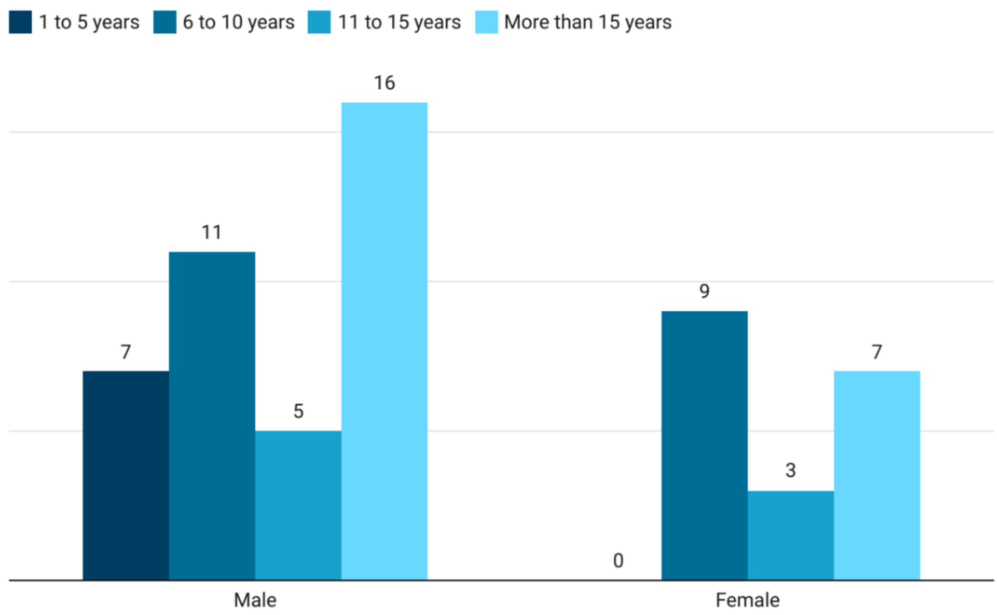


Figure 139: Work experience of participants based on their gender

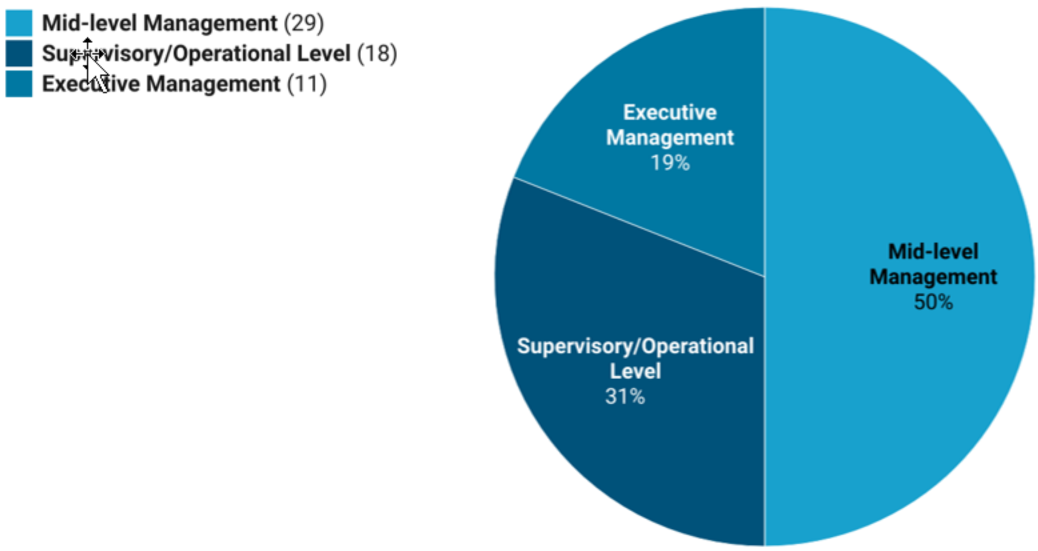


Figure 140: Decision making level of participants

As shown in **Figure 141**, out of 58 responses, 25 were from New South Wales, followed by 14 from Victoria and 7 from Queensland. Only one freight operator participated form Tasmania. Despite the staggered recruitment, this state break-down is roughly representative of the population state distributions (ABS, 2021).

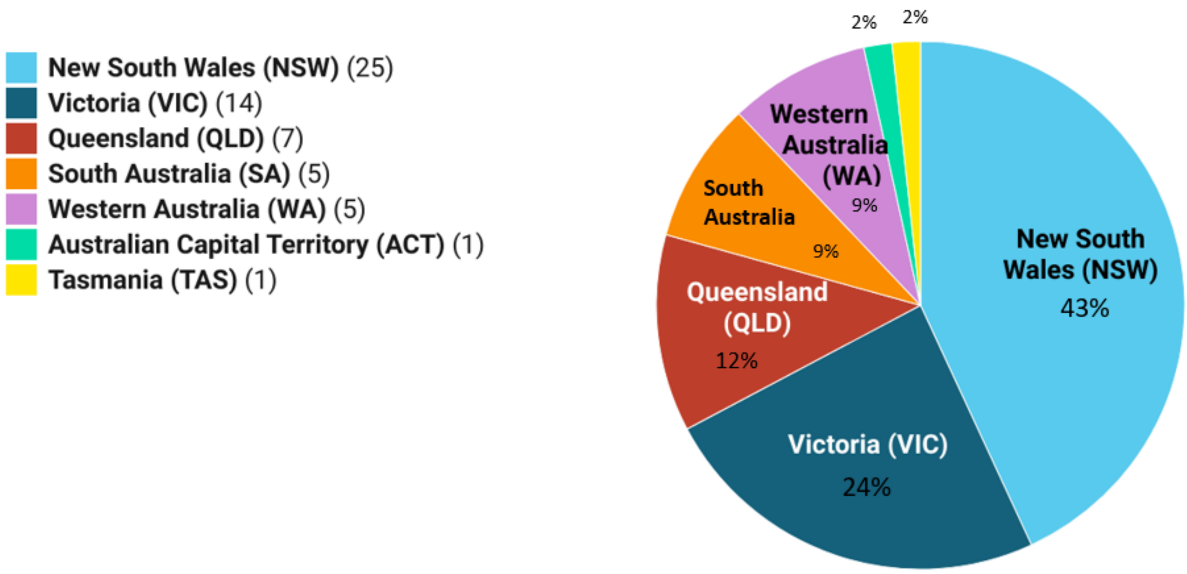


Figure 141: Geographical distribution of participants by states and territories

The research team was also interested to understand the size of participating organisations, as such factor could significantly influence their decision to invest and operate zero emission trucks. We have followed the Australian Bureau of Statistics (ABS) classification to measure firm size based on the number of employees. ABS defines a small business as a business employing less than 20 people, medium sized business employing between 20 and 199, and large businesses employing 200 or more employees. As shown in **Figure 142**, small firms represent 40%, medium firms 45% and large firms 16% of participating organisations in this survey.

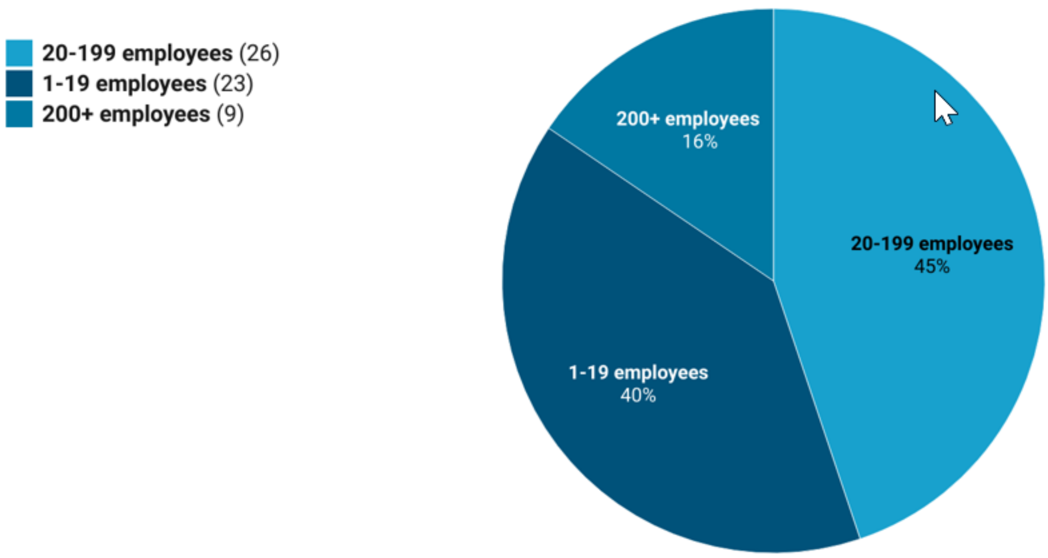


Figure 142: Firms size distribution based on the number of employees

We have also examined the size of participating organisation from the perspective of their fleet size. Specifically, participants were asked to indicate the number of vehicles they own or operate with a Gross Mass Limit (GML) of more than 4.5 tons. According to **Figure 143**, 55% of participating organisations operate between 1-5 vehicles, followed by 31% and 10% with fleet sizes of 6-20 and 21-50 vehicles, respectively. There were two participating organisations operating a fleet of more than 50 vehicles.

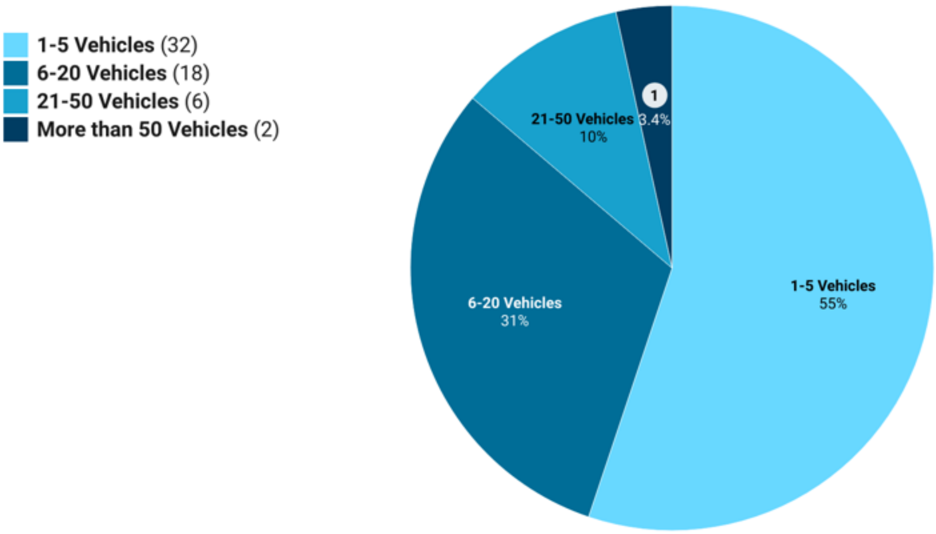


Figure 143: Firms size distribution based on fleet size

Participating organisations were asked to reflect on their operation types. Seven (7) standard categories were provided by TfNSW, allowing them to select more than one option. **Table 48** summaries participants' operations type by their state.

Table 48: Operations type by state

State	Concrete agitator/mixer	Line-haul (i.e. multi-shift/long inter- and intrastate journeys)	Pick-up compactor (e.g. waste truck)	Plant and equipment truck (e.g. pump truck or crane)	Regional haul (i.e. single shift/distribution centre deliveries)	Site truck (e.g., mechanic or service truck)	Urban delivery
Australian Capital Territory (ACT)	0	0	0	0	0	1	0
New South Wales (NSW)	0	6	4	10	8	9	11
Queensland (QLD)	2	3	2	3	2	2	1
South Australia (SA)	0	1	2	1	2	1	2
Tasmania (TAS)	0	0	0	0	0	0	1
Victoria (VIC)	1	3	1	0	4	1	6
Western Australia (WA)	1	2	1	2	2	1	2

9.3 Knowledge of zero emission vehicles

One of the objectives of this consultation was to assess the road freight industry's knowledge of zero emission heavy vehicle. Informed operators, predominantly, can make better decisions when it comes to purchase and operations of zero emission vehicles. For example, knowledge about range and payload enable operators to assess whether a zero-emission vehicle could address their current and future operational needs, while acquisition, maintenance and energy cost are important factors for pricing and costing decisions. Therefore, participating organisations were asked to self-report their knowledge of zero emission trucks based on three levels of basic, intermediate, and advanced. We first analysed the responses based on participant' age (**Figure 144**).

Overall, self-reported knowledge of zero emission vehicle tend to skew towards the younger cohort (25-34 and 35-44) with most respondents (21 out of 26) reported their knowledge as either intermediate or advanced. While those 55 or older, mostly reported their knowledge as only basic.

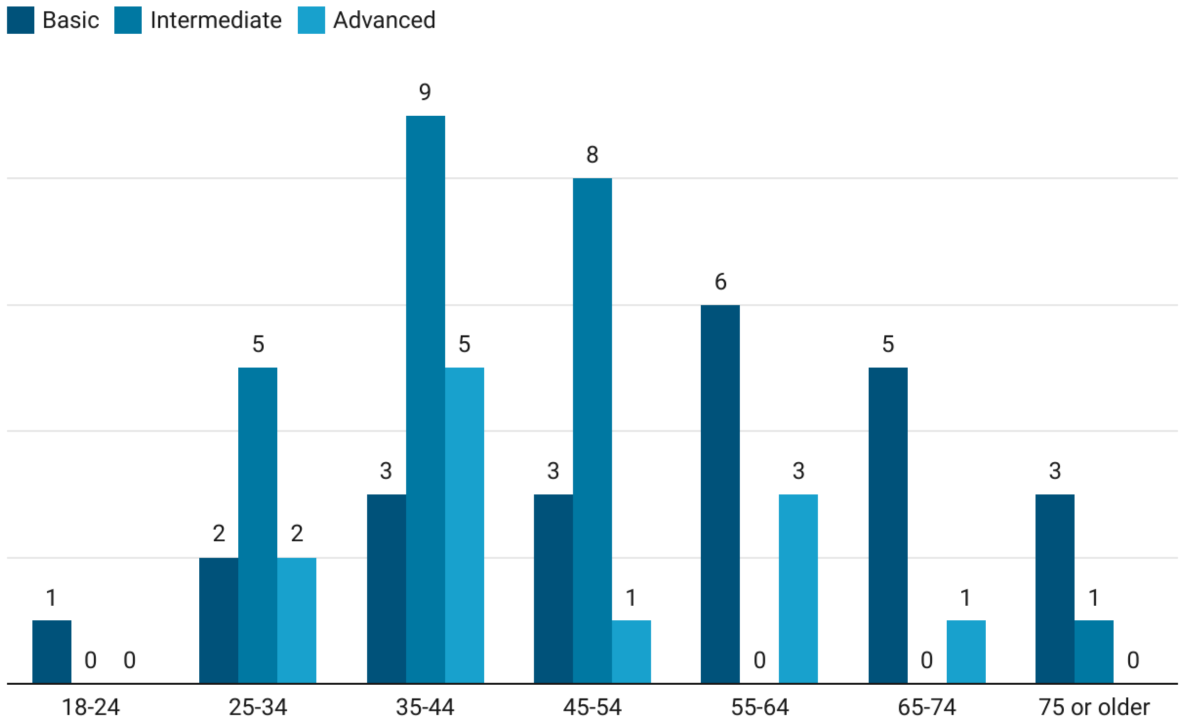


Figure 144: Knowledge of zero emission trucks – categorised by age

Next, knowledge was analysed based on participants' years of work experience (**Figure 145**). As shown, participants with more years are associated with knowledge level of basic.

Knowledge of zero emission trucks of participants was also analysed based on their state and territories, as shown in **Figure 146.** Given the sample size and larger number of participants from New South Wales, no statistically meaningful findings can be determined.

Next, we analysed participants' knowledge of zero emission trucks based on their fleet size and nature of their operations. As shown in **Figure 147**, those with smaller fleet size (i.e., 1 to 5 vehicles) have self-reported their knowledge as basic level, 18 out of 32. In the category 21 to 50 vehicles, 3 indicated their knowledge as intermediate, 2 as advanced and only one as basic.

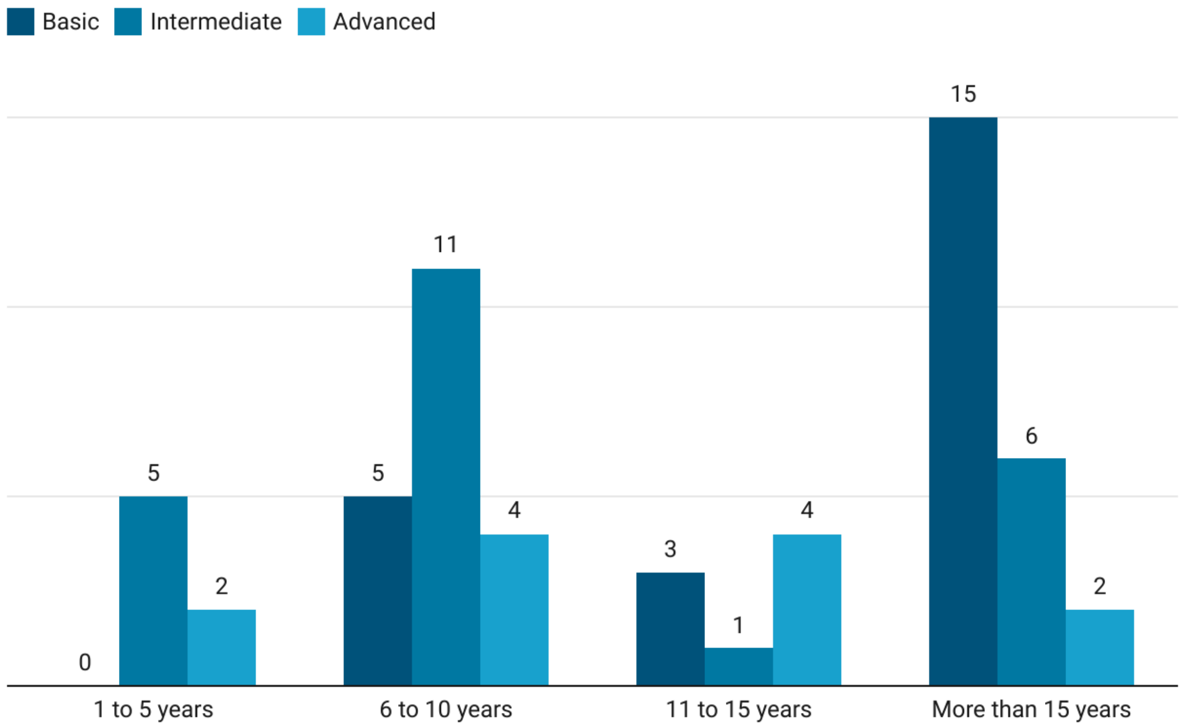


Figure 145: Knowledge of zero emission trucks – categorised by work experience

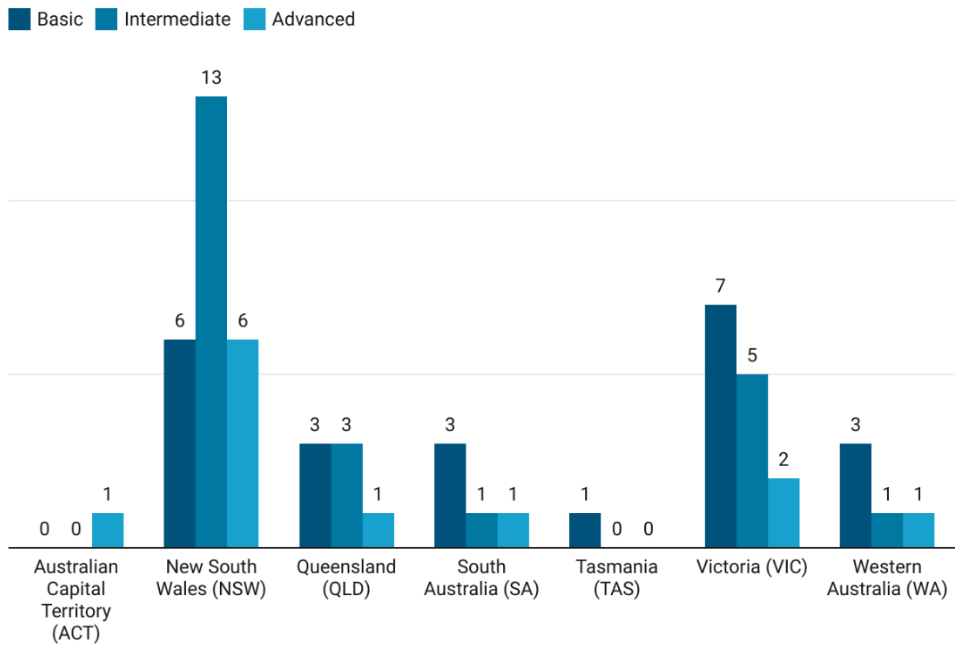


Figure 146: Knowledge of zero emission trucks – categorised by states and territories

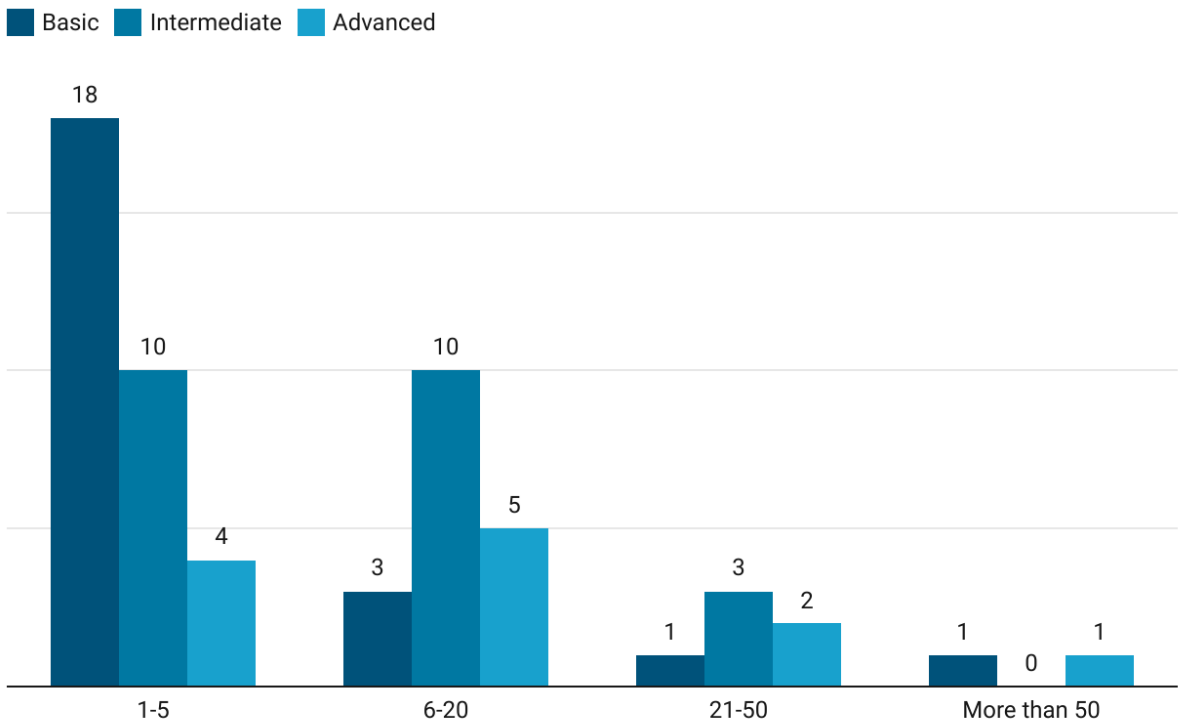


Figure 147: Knowledge of zero emission trucks – categorised by fleet size

In terms of operations type, 7 categories of freight operations were considered earlier. Given the sample size, these 7 categories were aggregated into urban and non-urban groups. Specifically, the urban group included urban delivery, pick-up compactor (e.g., waste truck), site truck (e.g., mechanic or service truck), concrete agitator/mixer and plant and equipment truck (e.g., pump truck or crane), while the non-urban group included regional haul (i.e., single shift/distribution centre deliveries) and line-haul (i.e., multi-shift/long inter- and intrastate journeys). This categorisation allows us to better understand operators' need based on vehicle range, frequency of use (e.g., VKT) and payload requirements. **Figure 148** shows the knowledge of zero emission trucks self-reported by participants based on their operations type noting that participants were allowed to select more than one operations type.

An accompanying factor to the knowledge of zero emission trucks, is the source of information. Therefore, in this consultation, the research team aimed to explore the main sources through which participants seeks information about zero emission trucks. **Figure 149** demonstrates the main sources of information, according to their frequency. For this question, participants were allowed to select more than one option. The responses showed that general internet searches and truck manufacturer website are the top used sources of information. Interestingly nine participants indicated they do not seek any information at all about zero emission trucks.

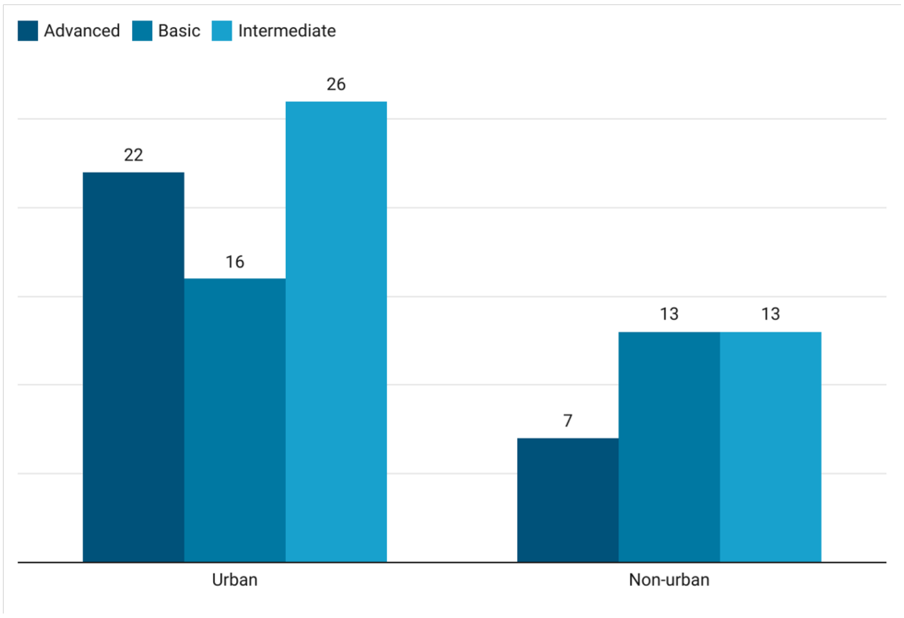


Figure 148: Knowledge of zero emission trucks – categorised by operations type

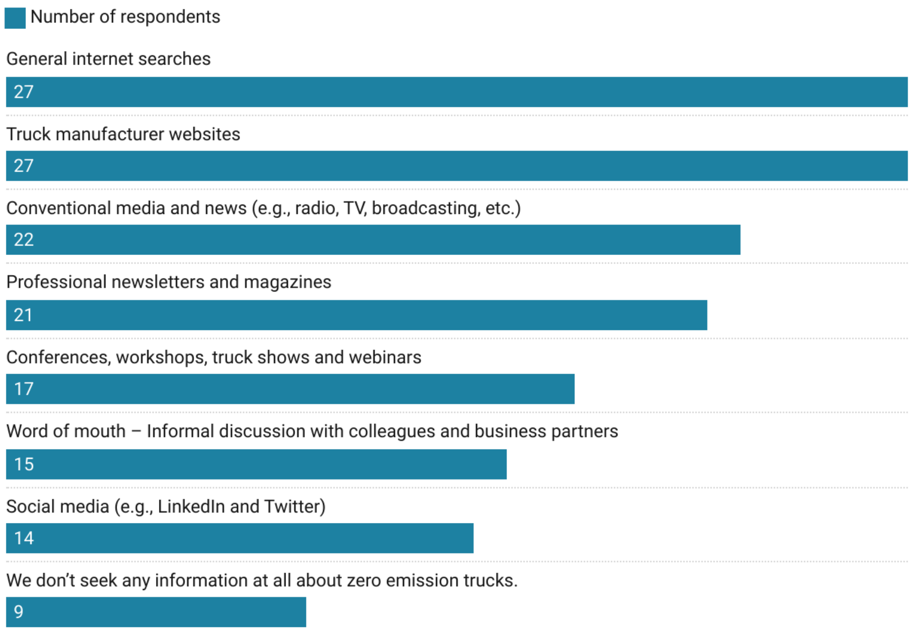


Figure 149: Main sources of information used by participants for zero emission trucks.

To further examine participants' views of zero emission trucks, they were asked about the consistency and reliability of information, including driving range, charging/refuelling time, reliability, power, cost, availability. At the broadest level, operators confirm lack of reliable and available information about zero emission trucks. Some state the information is over-stated by manufacturers and is very generic. Example quotes include:

"I think that the consistency and reliability of information at this stage is very minimal because of the limited number of vehicles using this technology at this time and the period that they have been available to be assessed has been too short."

Some others highlight lack of clarity on the wider implications of battery electric and hydrogen fuel cell trucks. For example, one participant highlights lack of information about the environmental impacts of such vehicles:

“Very little information available about how it will all work and what’s the best Hydrogen or electric also how clean is the electricity being used and what environmental impact does the manufacture and life of these units have”.

Furthermore, it was highlighted that besides manufacturers, there are other sources that provide unreliable and generic information about zero emission trucks.

9.4 Zero emission truck purchase decision making

The literature on transport service provision and its relationship to fleet performance is well established. Several factors have been identified by researchers that influence the decision of freight operators when deciding on the choice of their vehicle purchase. Currently, freight operators adopting green practices also face the choice between battery electric and hydrogen fuel cell technologies. Traditionally, for ICE vehicles, such factors include acquisition price, maintenance costs, safety, power (horsepower) and payload. With the introduction of battery electric and hydrogen fuel cell technologies, operators take into consideration other factors such as availability of charging and refuelling stations within their operational network, recharging and/or refuelling time, fuel/energy cost, driving range of the vehicle, ease of service and maintenance, recharging and refuelling station’s reliability and experience and preference of the driver. In the past, ICE (i.e., diesel powered) vehicles were the only option for heavy duty freight task, while operators now face various technological choices. To assess the importance of such factors, participants in this consultation were provided with 12 items (**Figure 150**).

Next, they were asked to only select 5 items and rank them based on importance of 1 being most important and 5 being least important. Accordingly, the ranking given to each factor was accumulated as a pointing system to identify the most important factors when they want to purchase a zero-emission truck. For example, an item ranked 1 received a score of 5, while for an item ranked 5, a score of was given. As shown in **Figure 150**, ‘purchase price’ and ‘availability of charging and refuelling stations within their operational network’ were ranked highest both with 98 points, followed by ‘recharging and refuelling time’ with 92 points, ‘fuel cost’ (KW of electricity or kg of hydrogen) with 89 points and ‘recharging and refuelling station’s reliability’ with 82 points. On the other hand, the least important factors were ‘experience and preference of driver’ with 32 points, payload with 53 points and safety with 57 points.

To further examine the influencing factors in purchase decision making, in an open-ended form, participants were asked to provide their rational for choosing and raking their top 5 items. It appears that operators expect that zero emission trucks must be able to operate in the same condition as their current diesel counterparts.

At the broadest level, the answer to this open-ended question was largely aligned with the way participants ranked the items. For example, one participant states:

“For us to transition from diesel to electric we need a solution that provides quite long range and fast recharging available in regional areas.”

< 40 | 40−60 | 60−80 | ≥ 80

1	Purchase price	98
2	Availability of charging and refuelling stations within your operational network	98
3	Recharging/refuelling time	92
4	Fuel cost (KW of electricity or KG of hydrogen)	89
5	Recharging/refuelling station reliability (i.e., the chargers are working when needed)	82
6	Driving range	79
7	Maintenance cost	68
8	Ease of service and maintenance	62
9	Power (i.e., horsepower)	60
10	Safety	57
11	Payload (i.e., Gross Mass Limit)	53
12	Experience and preference of driver	32

Figure 150: Factors influencing the purchasing decision of zero emission trucks

As shown in **Figure 150** above, price was the most important factor influencing the decision of an operator to purchase a zero-emission truck. Given the fact that currently such vehicles are significantly more expensive than their diesel counterparts, if participants selected purchase price as their most important factor, they were asked about their preferred subsidy mechanism provided by the government. At the broadest level two mainstream options were identified from the literature:

- **Option 1**: A subsidy targeting the difference in purchasing price between battery electric or hydrogen fuel cell trucks vs a diesel counterpart.
- **Option 2**: An interest free loan on the entire purchasing price of a battery electric or hydrogen fuel cell truck

We analysed participants' responses to this question based on their location and fleet size. As shown in **Figure 151**, 10 operators with fleet size between 1 to 5 vehicles prefer Option 1, while 8 prefer Option 2. In the category of 6 to 20 vehicles, a similar trend is observed. For larger categories, given the small sample size, no concrete conclusions can be made. Overall, out 31 participants selecting purchase price as their most important factor, 18 preferred Option 1 and 13 opted for Option 2.

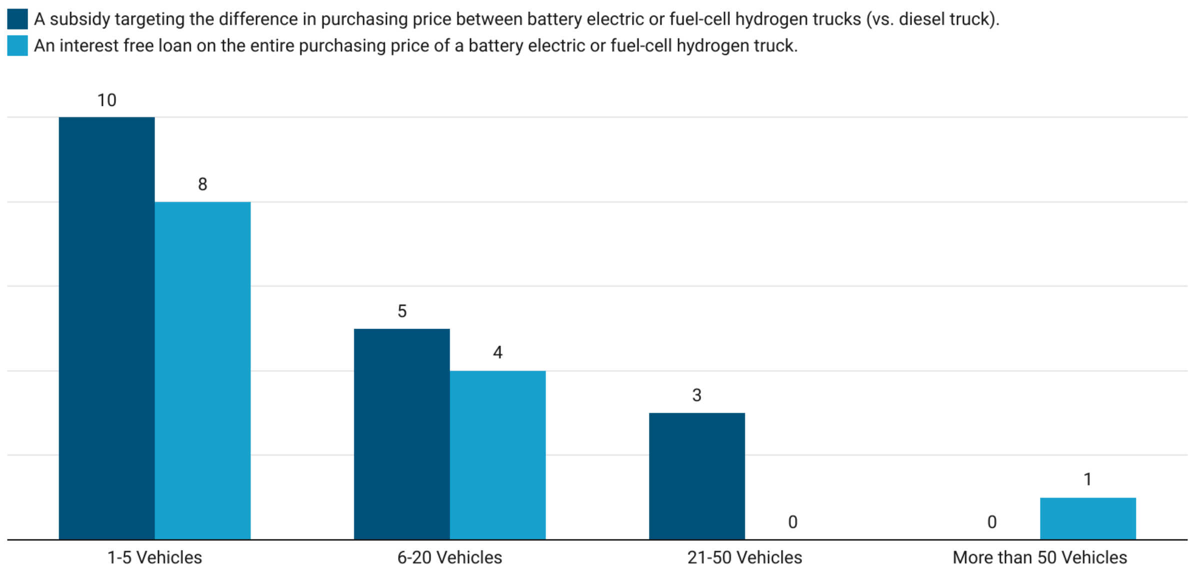


Figure 151: Preferred subsidy mechanism based on fleet size

Analysing the responses by participating states and territories, out of 13 participants from New South Wales, 10 opted form Option 1. On the other hand, out of 8 Victorian responses, 5 opted for Option 2 and 3 for Option 1. **Figure 152** summarises the preferred subsidy mechanism by participating states and territories.

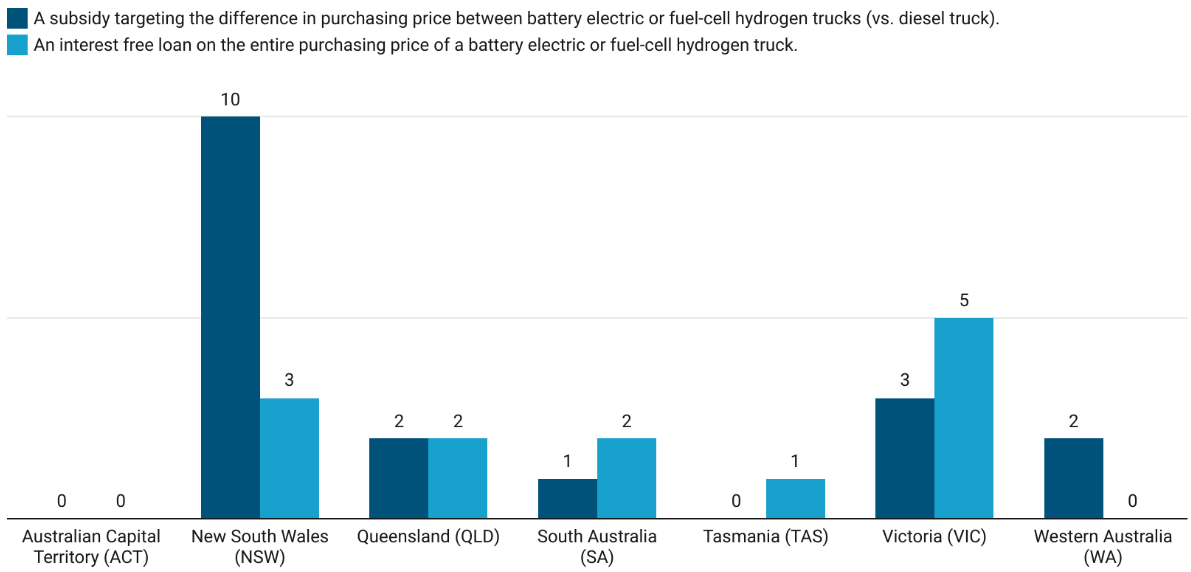


Figure 152: Preferred subsidy mechanism by states and territories

9.5 Operators' expectations of zero emission trucks – a comparative evaluation

A series of questions were proposed to participants to understand their view on the pros and cons of zero emission trucks versus each other and against current ICE counterparts. In the first question, they were asked to indicate top two pros and cons of fuel-cell hydrogen trucks vs diesel for the Australian conditions. In summary, the top two pros of hydrogen fuel cell trucks were being (1) eco-friendly (around 50% of participants) and (2) cost advantage. In the category of eco-friendly, responses included items related to lower noise, smell, and emission, but also general sustainability benefits. For cost efficiency, participants included factors related to fuel cost, lower maintenance, and energy efficiency. Some other advantages such as ease of use was also indicated. In terms of cons, majority of participants indicated higher costs is a major disadvantage, followed by refuelling availability, vehicle reliability, vehicle availability, reduction in payload and technology unfamiliarity. Overall, participants provided mixed and conflicting responses, indicating that their knowledge of hydrogen fuel cell trucks is perhaps limited.

Next, participants were asked to indicate the top two pros and cons of battery electric trucks versus diesel counterparts for the Australian conditions. Like hydrogen fuel cell, the top pros were related to (1) being eco-friendly and (2) cost competitiveness, followed by factors such as easy to use, reliability and no reliance of fuel. Within the eco-friendly category, responses were related to being quitter, cleaner and wider benefits for the environment. Shifting the focus to cons, top responses were related to higher acquisition and operations costs, range anxiety, lower power, and payload, charging time and safety considerations (e.g., fire). All inclusive, it appears there are conflicting responses provided by participants, indicating their lack of knowledge about battery electric trucks. For example, for some participants, cost competitiveness was mentioned as their top pros, while for others, cost was indicated as their top cons.

In the next questions, participants were asked to provide a comparison of zero emission technologies, specifically by indicating the top two pros and cons of fuel-cell hydrogen trucks over battery electric trucks for the Australian conditions. In terms of pros, participants indicated that hydrogen fuel cell trucks are stronger (e.g., higher payload), have longer range and quicker refuelling time, while maintenance cost is lower. Other factors such as cost efficiency, durability and technology familiarity were also considered as pros of hydrogen fuel cell against battery electric trucks. In terms of cons, lower safety, restricted refuelling station network, technology readiness compared to battery electric, stock availability and reliability were factors indicated by participants. Like previous comparative questions, it appears participants' knowledge of zero emission trucks is limited.

9.6 Preferred zero emission truck fleet

After assessing participants' view on the advantages and disadvantages of battery electric and hydrogen fuel cell trucks, they were asked to indicate their preferred purchase options, if the technical features (e.g., cost, range, power, recharging/refuelling, and reliability) were equal. Participants could select battery electric and hydrogen fuel cell trucks, but also an option for mixed fleet of both. As shown in **Figure 153**, more than half of participants prefer a mixed fleet, 33% opted for hydrogen fuel cell and 14% selected a fleet of battery electric trucks.

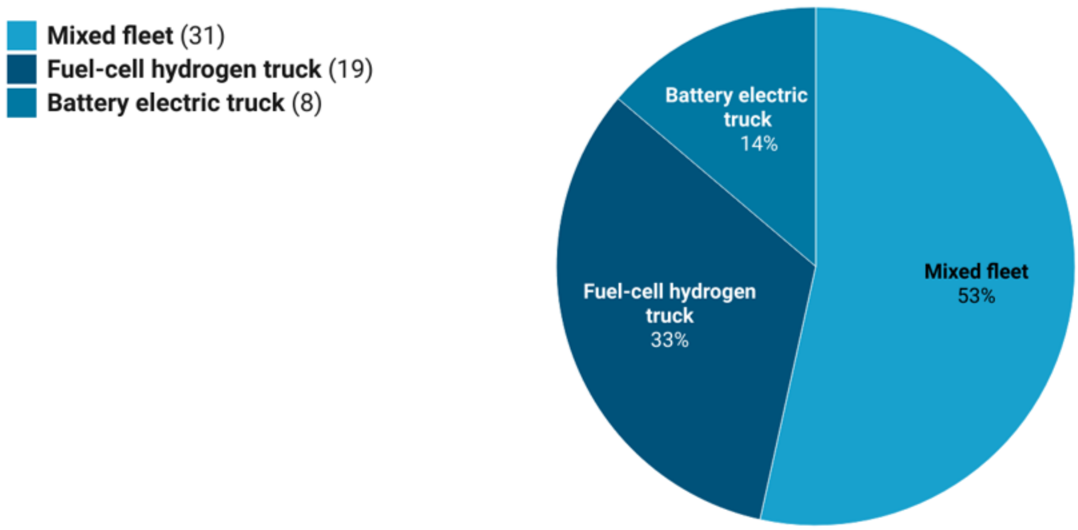


Figure 153: Preferred zero emission truck fleet

We further analysed the responses based on participants' fleet size and operations type. As shown in **Figure 154**, within all categories of fleet size, a mixed fleet option has the highest responses. Furthermore, this trend is also evident when accounting for operations type. As shown in **Figure 155**, mixed fleet is the preferred option within both urban and non-urban categories.

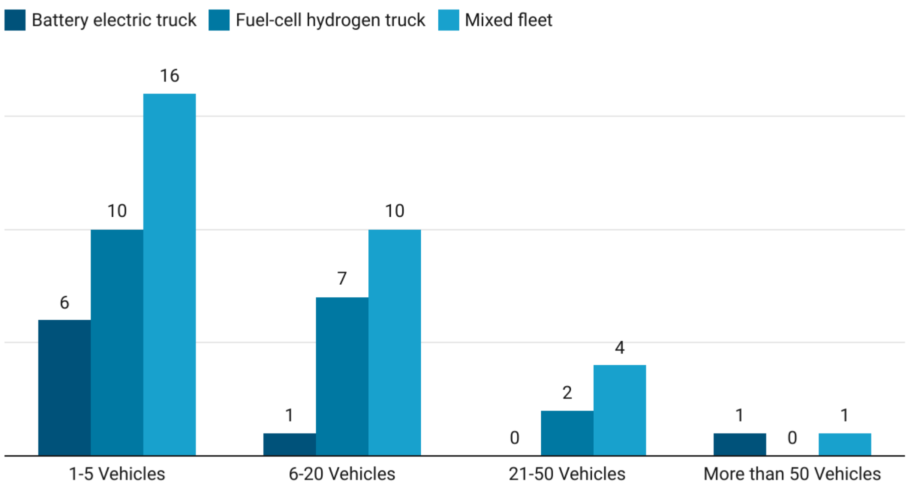


Figure 154: Preferred zero emission truck fleet – based on fleet size

To further demystify the rationale behind participants' choice of fleet, they were asked to provide? further explanation. For the 8 operators (6 with 1-5, 1 with 6-20 and 1 with more than 50 vehicles) selecting battery electric fleet, the justifications were related to their existing knowledge of battery electric technology, vehicle availability, environmental benefits, and lack of trust in hydrogen technology. For the 19 participants (10 with 1-5, 7 with 6-20 and 2 with 21-50 vehicles) selecting hydrogen fuel cell fleet, responses were justified by their concerns around lithium and battery reliance and recycling, lighter vehicles compared to battery higher power and lack of trust in battery technology for long range operations. Finally, 31 participants (16 with 1-5, 10 with 6-20, 4 with 21-50 and 1 with more than 50 vehicles) selected a mixed fleet option. Their justification for this choice were linked to offset risk if one option fails, fleet flexibility and to experience both options.

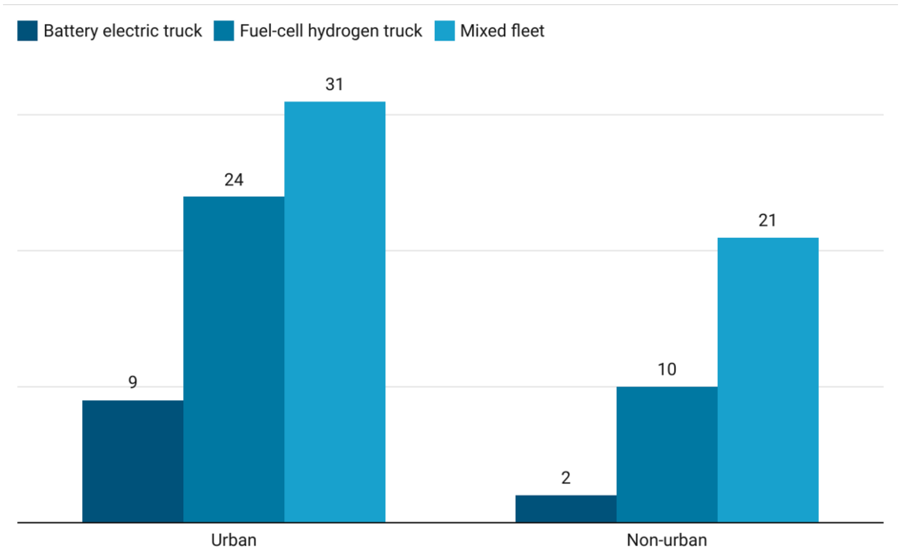


Figure 155: Preferred zero emission truck fleet – based on operations type

9.7 Zero emission truck availability

There is currently limited availability of zero emission trucks (both battery electric and fuel-cell hydrogen trucks) on the Australian market. In this context, participants were asked to reflect if their company wanted to purchase LZET, would they be able to find one on the Australian market suitable for their operation. As shown in **Figure 156**, 40% of participants indicated they would be able to find a BET option that suits their operational needs.

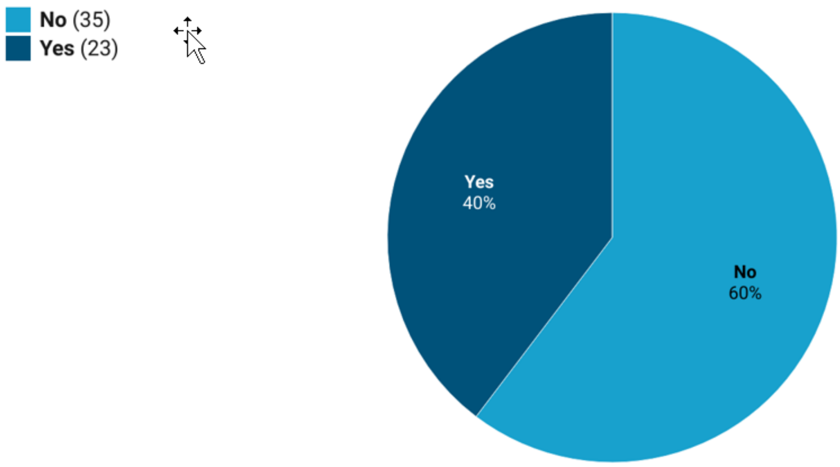


Figure 156: Availability of suitable battery electric trucks

Analysing the responses based on operations type, more participants within the urban category agree on the availability of a suitable battery electric truck compared to the non-urban category (**Figure 157**).

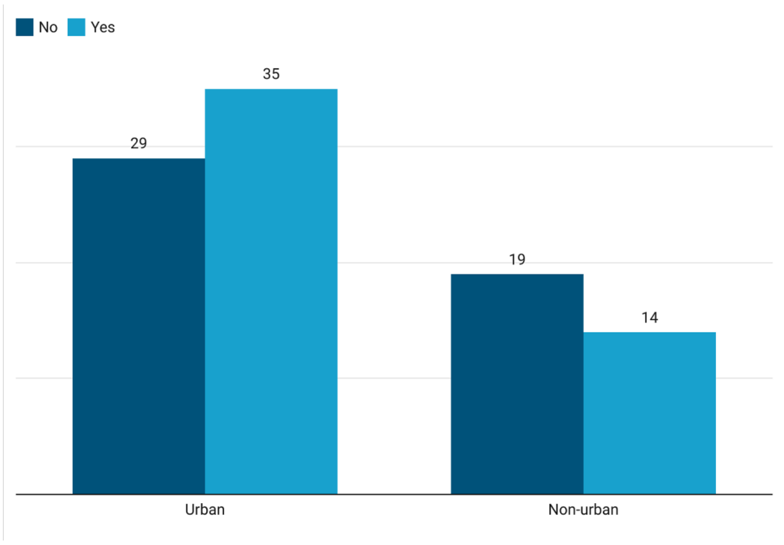


Figure 157: Availability of suitable battery electric trucks – based on operations type

Participants were also asked to reflect on the availability of hydrogen fuel cell trucks suitable for their operational needs. As shown in **Figure 158,** 34% indicate they would be able to find a hydrogen fuel cell option.

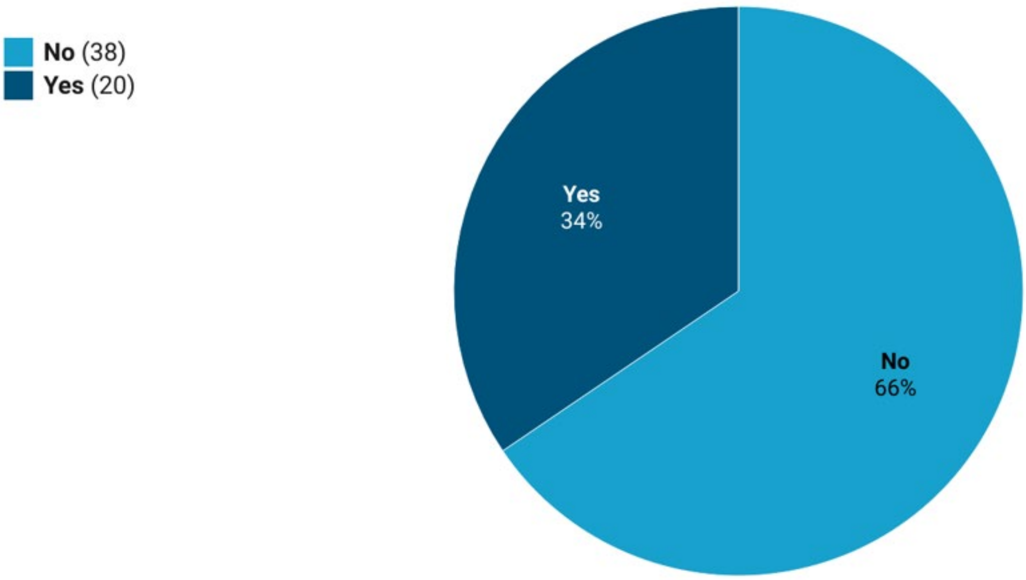


Figure 158: Availability of suitable hydrogen fuel cell trucks

We further analysed the responses based on operation type in **Figure 159**. As shown, compared to battery electric option, less participants are confident they would be able to find a suitable hydrogen fuel cell truck. While this outcome is not surprising, to the best of our knowledge, at the time this stakeholder consultation was performed no commercially available hydrogen fuel cell truck was available on the Australian market for freight operations. This further emphasises a disconnect in the levels of perceived availability of zero emission trucks vs. the zero options available currently.

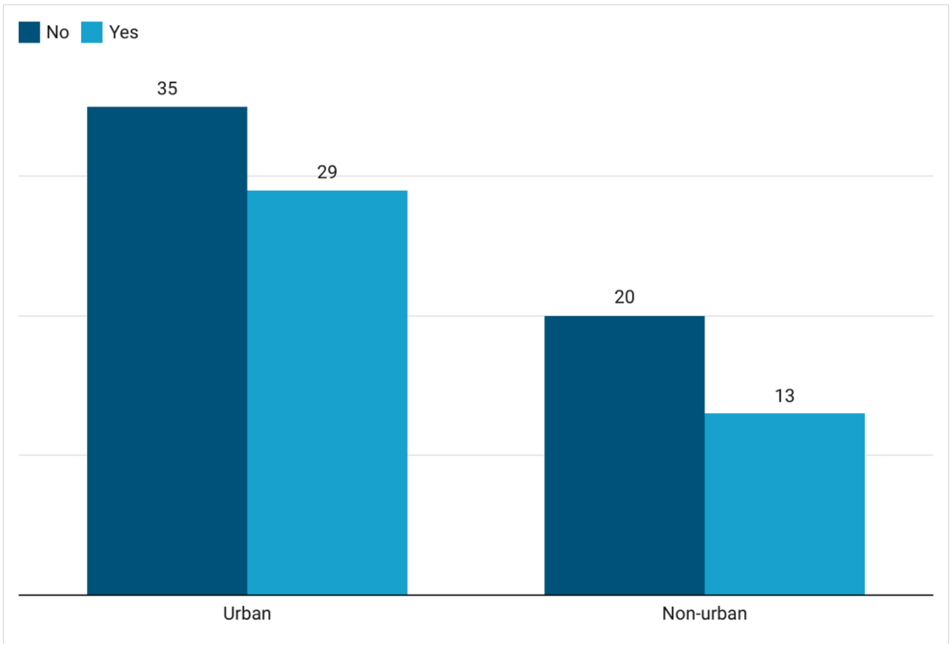


Figure 159: Availability of hydrogen fuel cell trucks – based on operations type

9.8 Wider opportunities and challenges

Towards the end of survey, participants were asked to reflect the wider opportunities and challenges for their organisation, but also nationally, because of road freight decarbonisation. In terms of opportunities at the organisation level, around one third of responses were centred around the sustainability benefits of zero emission trucks, including reduction in noise and pollution. Similarly, one third of responses were related to opportunities to save cost as the result of reduced down time, lower operational cost, potential subsidies, and tax incentives. Participants, with a sizeable number, stated operating zero emission trucks could create value from the viewpoint of marketing, new customer acquisition and business growth, reputation, and brand image. A handful of responses also indicated that the introduction of zero emission trucks is an opportunity for fleet modernisation.

In terms of challenges, around half of responses were around higher acquisition costs, including lack of funding. Truck availability was another challenge indicated by operators, followed by recharging/refuelling stations availability, technology uncertainty in long term, workforce readiness and potential maintenance complications. We note that cost is seen both as an opportunity and challenge, indicating varying knowledge of zero emission trucks among participants. Finally, participants were asked to reflect on the biggest challenges and barriers to large scale uptake of low and zero-emission trucks in Australia. Cost considerations, lack of sufficient recharging and refuelling infrastructure, vehicle availability, practicality for Australian conditions and technology reliability were among indicating factors.

9.9 Summary

The stakeholder consultation conducted in this research provided important insights on the perceptions, expectations, and knowledge of the future operators of zero emission trucks. The key concluding remarks are summarised here:

Low and varying level of zero emission truck knowledge

At the broadest level, participants of this consultation demonstrated low and varying degree of zero emission truck knowledge. The low level of knowledge was demonstrated in several areas, including performance, vehicle availability and technology. Perhaps the most evident factor was related to the acquisition cost of zero emission trucks, compared to their current diesel counterparts. A large group of participants indicated that operating zero emission trucks would be more expensive, while a considerable number indicated they expect lower costs (e.g., as the result of lower downtime and maintenance costs). In terms of availability, when asked about the availability of zero emission trucks suitable for their work on Australian market, a large number indicated they would be able to find one (%40 for battery electric and %36 for hydrogen fuel cell options). To the best our knowledge, at the time this research was conducted, very limited model for zero emission trucks were commercially available in Australia. While in the light duty vehicle space limited battery electric range exists, in the case of hydrogen fuel cell it was difficult to identify available models.

Preferred fleet configuration

As indicated by participants, the most preferred configuration of zero emission truck fleet is the mix of both hydrogen fuel cell and battery electric options, with more than half of responses confirming this approach. Interestingly, hydrogen fuel cell-only fleet was the next preferred fleet configuration with %33 and battery electric with %14 of responses, respectively. While the size of the sample size is small, the preference for a mixed feel configuration was driven by factors such as risk reduction and fleet flexibility. Furthermore, such preferences could also be impacted by participants' knowledge of zero emission trucks, information availability and sources of information. Importantly, driving range has been mentioned several times by participants across various parts of the survey, as a main concern for the purchase of zero emission trucks. Such factor could have influenced participant's preference for hydrogen fuel cell vehicles over battery electric options. Not surprisingly, this insight was in line with the data captured during the choice experiment.

Independent testing and information sharing

Given the concerns and uncertainty about zero emission trucks technical features (e.g., range and reliability), accompanied by the existing of knowledge of different vehicle technologies, unbiased vehicle testing, and knowledge sharing could support operators with informed decision making. Unlike light vehicles and personal mobility, freight market is diverse in geography and operations, meaning that there is no one-for-all policy lever supporting all stakeholders in their decarbonisation journey. Furthermore, reliable information about performance, reliability, and cost of zero emission trucks could also support governments in identifying and designing the most impactful and targeted policy levers (e.g., supporting manufacturers for lowered cost and capability building vs one-time purchase of zero emission trucks for operators).

Limitations

This consultation comes with limitations, which opens new door for future work. Given the importance of engaging the right decision makers in this study (i.e., managers involved heavy vehicle purchasing decisions), our sample size was limited (58 operators). We suggest, future consultations to engage industry associations and representative bodies to further disseminate the survey instrument to increase the number of participants. This allows for better understanding of attitudes, experiences and needs of participants related to zero emission trucks in different freight operations categories.

Summary

10. Summary and Recommendations for Future Research

10.1 Summary of findings

The key findings of this research include:

1. LZET technology acceptance is high amongst most freight operators, providing the basis for incentivising decarbonisation of freight.
   - Choice modelling and econometrics analysis showed a high acceptance of LZETs – when suitable alternatives are available.
   - There is however, one cluster of respondents currently not willing to shift away from the current status quo. This group is generally older, more often operating in regional areas, less likely to transport perishable goods, less likely to view leasing options positively, and is sceptical about the likelihood of electrification of freight in NSW by 2030. They are also on average more influenced by the price of trucks when making purchasing decisions.
   - Even without policies in place, there is a relatively high rate of likely adoption of LZETs in the baseline scenario.
2. Financial incentives matter, but regulatory changes have the greatest short to medium term effect:
   - Modelling results showed improved adoption rates for all proposed policy intervention scenarios compared to the baseline scenario.
   - In terms of policy measures, the greatest impacts were associated with two regulatory options: truck availability and phase-out year 2035.
   - Comprehensive LZET packages that include both regulatory as well as financial incentives had the largest combined impacts.
3. Modelled policies generate significant decarbonisation and air quality improvements, but more is required to drive emissions towards net zero.
   - On its own, fleet electrification is not sufficient to drive down emissions to target levels.
   - Shift to rail provides significant emissions reductions.
   - Road freight decarbonisation would also need to consider demand management and optimisation of freight distribution and must also be part of a holistic road transport decarbonisation approach.
   - In the interim, there are opportunities to incorporate PBS Combination and HPV Combination vehicles into the mix of solutions for road freight decarbonisation particularly during the transition period.
4. Financial incentives should be carefully designed to enhance the economic impact of public expenditure.
   - Financial incentives are less effective in reducing emissions and they therefore tend to generate lower net social benefits.
   - Financial incentives could be better targeted by subsidising the removal of older trucks and more polluting trucks. This would require some further analysis in future research

to establish target truck segments and undertake an economic analysis to estimate benefits of such subsidies.

5. The stakeholder consultation survey provided insights into the perceptions, expectations, and levels of knowledge about LZETs. Analysis of survey responses showed:
   - Low and varying level of zero emission truck knowledge among fleet operators
   - A preference for a mixed LZET fleet that includes both BET and FCET options, with more than half of respondents confirming this preference.
   - High level of uncertainty about LZET technical features (e.g., range and reliability). Independent pilot studies, field testing and knowledge sharing of the capabilities and limitations of LZETs could support operators with informed decision making.

The research findings also provide some insights on the suitability of the proposed interventions as related to the type of technology (e.g., battery electric and hydrogen trucks)

1. The current LZET landscape in Australia suggests that financial incentives will not drive substantial decarbonisation in the road freight sector. This is largely because LZET technology solutions are still not widely available and hence financial incentives applied now would not have a substantial impact. However, when the technology solutions become available (either through regulatory changes that allow current technology on Australian roads or through innovation) financial incentives <u>will</u> have (much) more of an impact. Financial incentives will then be useful for getting early adoption and a boost when vehicles arrive on the market, which for BETs is now or as soon as possible, and for FCETs is likely sometime in the 2030s.
2. The study's findings show that FCETs are not an option for large-scale adoption in the short term, though they may become more promising in the medium to long term. The technology will take many more years to mature and become competitive on financial terms, and there will not be suitable FCETs on the market for most segments soon.
3. BETs, on the other hand, look more promising in terms of financial performance as well as availability of stock, vehicle sizes and models, in the short to medium term, especially for smaller truck segments. It is yet unclear when larger BETs will be available and competitive in the larger truck segment, hence, the regulatory changes will make a difference to speed up the process. For the larger truck segment, rail mode shift and wider adoption of HPVs are viable solutions in the short term.
4. Around 67% of respondents were in favour of hybrids. Out of three classes (i.e., categories) of respondents identified in the Choice Experiment, there were two groups (i.e., Classes 1 and 3) that showed a strong willingness to pay for hybrid diesel-electric trucks. These represented generally younger, and urban operators, especially those with an expectation of high levels of electrification of the freight sector by 2030, i.e., those that are also positive about BETs or FCETs.
5. The Phase-out of ICE vehicles will be an effective lever for the shift to any kind of LZET.
6. Survey respondents' preferences were found to vary:
   - About 43% were very positive about BETs, and would most prefer this option, but they were also positive about FCETs.
   - About 24% were very positive about FCETs, and would most prefer this option, but they were not particularly positive about BETs.
   - About 34% were very positive about diesel trucks, and would most prefer this option, and prefer to avoid using LZETs.
   - These results indicate that the broadest support was found for FCETs (67%), followed by BETs (43%), and Diesel trucks (34%).

7. The data available currently which was used in this study did not consider truck payload and capacity utilisation. While large articulated trucks were found to produce high levels of emissions, they are most efficient when considering the freight task in terms of tonne-km of cargo transported, but they are also the hardest to target for electrification now due to technology limitation. Future research should improve the emissions modelling to include payload considerations and truck capacity utilisation. Future research should also examine potential policy levers that could be introduced to encourage improved fleet utilisation via improved logistics planning. This would require advanced data capturing/sharing. The Intelligent Access Program (IAP) could facilitate such models.
8. Trucks operating on renewable fuels were not considered in this study and could be considered in future research.

The research findings also provide several considerations for policy making that include directions for:

1. Removal of regulatory barriers that limit LZET options for the Australian market, including width and weight restrictions which have been found to be particularly relevant. These will affect the different truck segments differently. BETs are typically heavier than diesel or FCEV alternatives so that on a like-for-like basis in terms of usage, the axel weight of smaller BETs may increase. Similarly, across the different weight classes. At the upper end of the weight categories (12.5 tons and above), heavier LZET alternatives may require special dispensation and, due to variations in road quality/standards, not be suitable across all the NSW road network without considerable investment in road upgrades. Shifting heavier freight to rail or coastal shipping may be more attractive options. Moreover, shifting to rail is technologically achievable within a short to medium term timeframe.
2. Standardisation of key technological solutions to ensure that new LZET technology can be used more widely. Charging connectors and payment standardisation are two examples. This will ensure that users can make use of enabling infrastructure when it becomes available thus avoiding the impact of limited infrastructure that is additionally exacerbated by lack of compatibility.
3. Targeted financial incentives. Financial incentives were found internationally to be highly effective in enabling LZET technology uptake. The lower responsiveness to financial incentives in this research is likely a function of limited availability of suitable LZET alternatives. Financial incentives are currently not effective in addressing regulatory barriers, limited infrastructure availability and infrastructure compatibility considerations. However, once these are addressed – or once LZET options that conform to the current Australian regulatory framework become available – financial incentives will become more effective decarbonisation tools. In the economic assessment, financial incentives are poorly targeted and hence very costly.
4. Shift of road freight to rail and optimisation of logistics practices. The breakdown of CO2e emissions by subclass provided some indications of where public policy may want to concentrate. Smaller rigid trucks are not as polluting as larger trucks but are larger in numbers and from a technological perspective are likely to be attainable sooner than heavier articulated trucks. Decarbonisation of large articulated trucks – while highly polluting – may technologically not be attainable in the next 10 years. Decarbonisation in this truck segment may thus consider transferring freight to rail or coastal shipping, but also logistical practices that shift freight from larger articulated trucks to several smaller (LZEV) trucks.

10.2 Recommendations for future research

10.2.1 Updating and refining the modelling of uptake

As the Choice Experiment and Modelling results were used to predict LZET adoption rates and fleet proportions, there are many assumptions being used, including about sales of vehicles per truck class, the number of kilometres travelled by each truck each year, depending on the type and age of the truck, as well as the survival function of different truck types, i.e., after how many years that a truck is being retired and scrapped. Currently, this is largely modelled based on aggregate assumptions, and an alternative approach would be to describe each truck individually in a computational sense (this is referred to as an Agent-Based Model) – thereby enabling more detailed policy analysis. There is therefore an opportunity to develop this capability which would allow easier integration between different models used by the various planning departments. Specifically, we suggest that this activity would explore the following issues:

- Review and update of survival functions for each of the eight truck types.
- Review and update of the VKT by age functions for each of the eight truck types.
- Review and update of the new truck purchase rates for each of the eight truck types.
- Review and update of the emissions factors for each of the eight truck types.
- Further development of an individual-truck based Agent-Based Model that could predict the future adoption of LZETs as well as fleet proportions of LZETs.

10.2.2 Deep dive into industry beliefs, understanding, and attitudes.

The Choice Experiment and Modelling undertaken in this study have provided some important insights but also highlighted current knowledge gaps about how freight operators think about LZETs. A surprising insight is that there are distinctly different perceptions of BETs and FCETs, with many study participants showing a preference for FCETs. The reasons behind this discrepancy are still unclear, and the follow-up survey showed that most freight operators use a diverse mix but also relatively unreliable sources of information, when doing their exploration on which types of truck to purchase. In our research, we also identified that there are two main groups of decision-makers, with the first smaller but not insignificant group having a strong preference for the status quo (i.e., Diesel trucks), and the second relatively larger group being quite open to transitioning towards LZETs. The underlying reasons for this polarisation of views are still unclear. To deal with these issues (i.e., the unexpected preference for FCETs, and the polarisation of the freight industry on this topic) we suggest an investigation based on in-depth interviews with about 20-30 freight operators, to clarify the underlying causes. This would also provide an opportunity to further explore the issue of perceived risk, and how this risk could be reduced through various types of government support. This research would aim to answer the following questions:

- What is driving the polarisation of views and preferences on the topic of LZETs?
- What is driving the relative preference for FCETs over BETs?
- What is the opportunity for reducing misinformation in the industry on this topic and thereby influencing freight operators through education and information campaigns?
- What type of additional resources, training, or support could help induce more operators to purchase LZETs?

10.2.3 Ongoing monitoring of Willingness to Pay for LZETs

The Choice Experiment and Modelling undertaken in this study has been informative in the sense of taking the pulse of industry sentiments, and their willingness to pay for LZETs. We have shown that, at the very least, industry willingness is no major impediment to large-scale adoption of LZETs. Whilst some of the industry still prefer the status quo, most decision-makers are willing to make the switch, if there are appropriate truck options on sale that will help them effectively carry out their truck tasks. With financial performance being what primarily drives decision-making, we have also shown that financial incentives are likely to have an impact on adoption rates. We do note, however, that this is a point-in-time estimate of willingness to pay, and that this is a dynamic situation that is likely to change as more and more freight operators choose to use LZETs. As LZETs are normalised in the industry, and infrastructure becomes more adapted to this new technology, preferences are likely to follow, unless major obstacles appear. This has implications for choice of appropriate policy settings, and whether there is a net benefit of government's investment in subsidies. Therefore, we suggest that there is an ongoing monitoring of willingness to pay for LZETs that also better accounts for key performance parameters like range and access to infrastructure. This research activity would explore the questions:

- How does the willingness to pay for LZETs change over time?
- How can we better account for the range of the truck and access to charging infrastructure when measuring willingness to pay?

10.2.4 Industry willingness to invest in charging infrastructure

It is clear, both from the Choice Experiment but also especially from the follow-up survey, that access to charging infrastructure is a key consideration when freight operators decide to invest in LZETs. There are many types of actors that may invest in such charging infrastructure, including freight operators themselves, petrol station operators, warehouse operators, or even new actors entering the market through novel business models. Whilst it is recognised that this is a key part of the transition towards large-scale adoption of LZETs, further knowledge is required to understand the potential role of government in supporting such investment decisions. Therefore, we propose a study to explore the willingness and economic drivers that would lead various industry actors to invest in charging infrastructure. Specifically, we suggest that this research would explore the following questions:

- Is there a legitimate way that TfNSW can intervene to increase the rate of rollout?
- What is the business model behind such roll-out of infrastructure?

10.2.5 Performance Based Standards and High Productivity Trucks

There may be immediate benefits of PBS/HPV as options for limiting emissions mainly in the large classes (ARTS) until LZETs catch up in cost and viability. In future work, it is recommended that these truck types are included in the modelling as separate categories to diesel trucks as they are more likely to be greener and more efficient. Future studies should also look to undertake field studies and operational performance to establish their emissions profiles.

10.2.6 Update emissions factors to reflect EURO VI/VII standards

The Australian Government has adopted Australian Design Rule 80/04 mandating Euro VI for all new approved heavy vehicle models supplied from 1 November 2024. The EURO VII standards are proposed internationally for 2027 but are probably not expected to be applied in Australia before 2030-2032. Future work should consider inclusion of these standards into emissions estimation models taking into consideration the timeframe expected for their introduction.

10.2.7 Update emissions models to include cargo and payload data

Current emissions estimation models only consider the total VKT by each type and subclass of trucks. Given that large trucks carry heavier loads, consideration of VKT alone is not sufficient and needs to be complemented with information on payload and tonne-km of travel for each truck subclass.

10.2.8 Multi-region comparative analysis

Building upon this research, a compelling direction for future exploration is a multi-region comparative analysis spanning several Australian states. By investigating the regional nuances in emissions and the economic repercussions of decarbonisation efforts, a better understanding of the varied challenges and opportunities faced across the nation can be gained. Beyond offering a holistic national overview, this comprehensive research can identify synergies between states, allowing for more targeted interventions. Diving deeper, such an analysis could elucidate the varying readiness and barriers each state faces, fostering opportunities for collaboration. This could pave the way for tailored, state-specific policy interventions, and more importantly, unified action. With such a combined effort, Australia would be better poised to take decisive and harmonised steps toward its broader emission reduction ambitions.

10.2.9 Modal shift analysis

Investigating the potential emissions reductions and economic benefits of shifting freight from road to rail or other alternative modes. Factors such as infrastructure investment, operational efficiency, and environmental impacts could be explored in depth.

- Evaluate factors such as fuel efficiency, payload capacity, transit times, reliability, and flexibility across different transport modes.
- Evaluate potential emission reductions and environmental benefits of moving freight to rail.
- Assess the feasibility of different freight tasks for mode shift, identifying which could transition quickly and which might face challenges, providing insights for policy makers on where immediate and efficient mode shifts can be realised.
- Examine potential economic gains, considering reduced road maintenance and congestion costs.
- Gather views of freight operators, logistics companies, and end-users on feasibility.
- Identify policy measures that could encourage a shift from road to rail.
- Explore technological innovations to make rail freight more efficient and attractive.

10.2.10 Integration with renewable energy

Studying the synergies between freight decarbonisation efforts and the expansion of renewable energy and renewable energy zones (REZ) could be highly relevant. Exploring ways to align energy generation and consumption patterns for optimal sustainability would be insightful.

- Analysis of locations and capacities of REZs in proximity to major freight routes and hubs.
- Opportunities for freight depots as renewable energy hubs.

- Evaluating the potential for battery electric or hydrogen-powered freight vehicles to act as energy storage.
- Identifying potential policy incentives to promote synergy between freight decarbonisation and renewable energy expansion.
- Exploring the potential role of smart grids and energy management systems in balancing renewable energy demand and supply for freight.

10.2.11 Lifecycle analysis

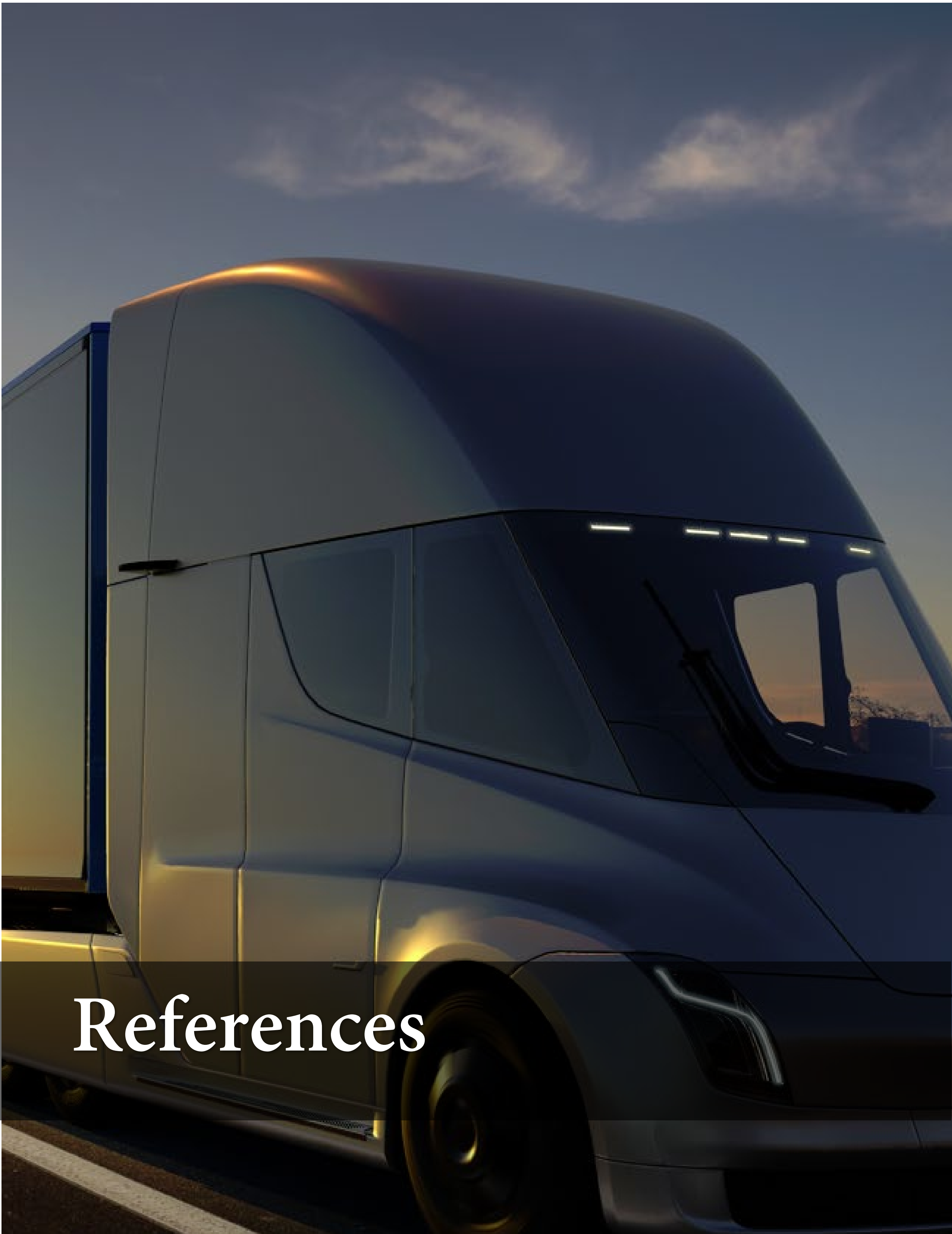
A comprehensive lifecycle assessment of various freight modes and technologies, considering not only direct emissions but also broader environmental and social impacts.

- Comparing the full environmental footprint of different freight modes, from production to disposal.
- Understanding the end-of-life impacts and potential for recycling or repurposing of freight infrastructure and vehicles.

10.2.12 Long-term infrastructure planning

Analysing the long-term infrastructure requirements and investments needed to support a decarbonised freight sector – considerations such as charging stations, alternative fuel infrastructure, and smart transportation systems could be explored in detail.

- Assess the placement, density, and capacity needs for charging stations to support electric freight vehicles.
- Determine the demand and optimal distribution of hydrogen refuelling stations across regions.
- Explore the role of smart traffic management and real-time logistics solutions in reducing emissions.
- Analyse the policy changes required to guide infrastructural development in line with decarbonisation goals.



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Appendices

Appendix A: International case studies

A few different international case studies on LZET fleet deployments are reviewed in this chapter. Case studies are examined to assess the demonstration, acceptance, and performance of different LZETs in other jurisdictions. These case studies also help us understand the challenges and opportunities experienced by countries with more advanced decarbonisation in the freight sector.

Battery electric trucks

Volvo LIGHTS – Southern California, USA

The Volvo LIGHTS (Low Impact Green Heavy Transport Solutions) project was a three-year, $90 million initiative that began in February 2020 with the goal of demonstrating the reliability of electric trucks for moving freight between ports and distribution points in Los Angeles while reducing noise and emissions (**Figure 160)**. The project was led by the Volvo Group and South Coast Air Quality Management District (AQMD), and involved multiple partners, including CALSTART, The Port of Los Angeles, Port of Long Beach, NFI Industries, Dependable Supply Chain Services, TEC Equipment, and Shell Recharge Solutions (formerly Greenlots). The project aimed to introduce heavy-duty zero-emission vehicles while developing and testing different configurations of Class 8 electric trucks using a common battery-based platform. The University of California, Riverside CE-CERT was involved in the project and focused on vehicle performance evaluation and optimization, as well as fleet management and charging. The goal of the project was to demonstrate the commercial viability of heavy duty zero emission trucks and support California's air quality and climate change goals (Volvo Group North America, 2022).

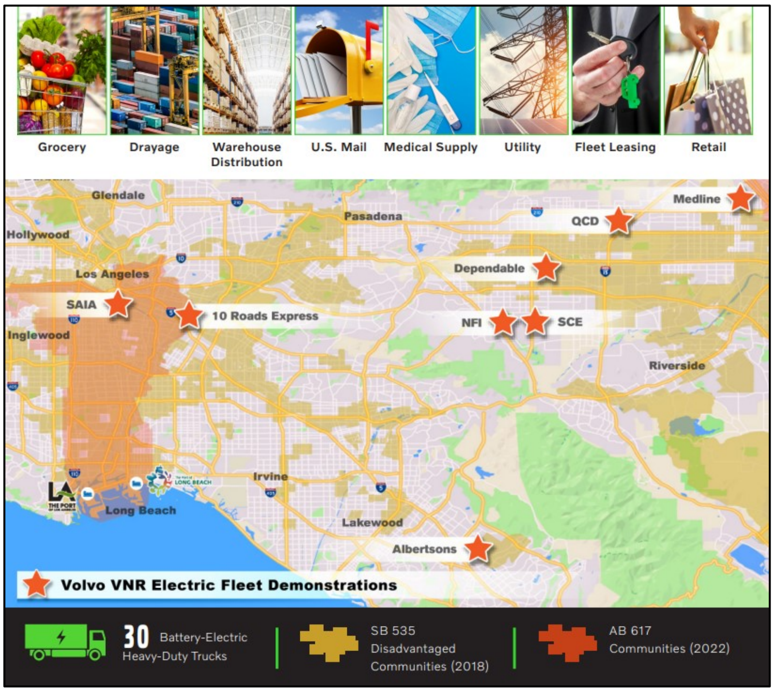

Figure 160: Volvo LIGHTS project class 8 (HDT) battery electric trucks

In 2021, local fleet customers from diverse sectors were given the opportunity to lease the Volvo VNR electric trucks to gain hands-on operating experience and determine the best fit for battery-electric trucks in their routes (**Figure 161**). A variety of businesses utilised these trucks in commercial operation as part of the Volvo LIGHTS project, hauling freight 120 – 240 km per day. The project deployed a total of 30 battery-electric trucks through the Volvo LIGHTS project, with funding from an EPA Clean Air Technology Initiative Grant.

Figure 161: Volvo VNR zero-tailpipe battery electric trucks

The University of California, Riverside CE-CERT conducted evaluations on the performance of the Volvo VNR Electric using a heavy-duty chassis dynamometer and performed an environmental LCA of its well-to-wheel impact. The results of the study showed that the Volvo VNR Electric saves 65% in total energy, 81% in fossil energy, and significantly reduces emissions by over 80% in comparison to baseline vehicles evaluated in the study, including reductions in GHG emissions and criteria pollutants/toxics, shown in **Figure 162** (University of California, Riverside CE-CERT, 2022).

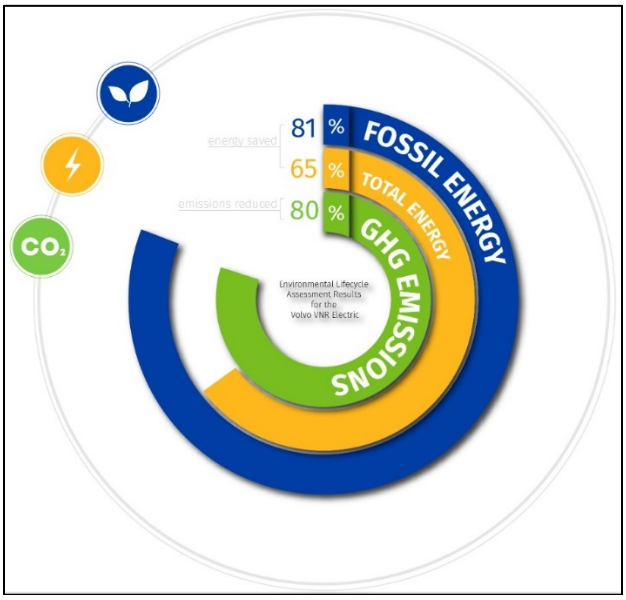

Figure 162: Volvo LIGHTS project performance- energy/emissions reductions
Source: (University of California, Riverside CE-CERT, 2022)

Throughout the three-year project, the partners of Volvo LIGHTS created a comprehensive plan for the necessary ecosystem to efficiently deploy commercial battery-electric freight trucks, shown in **Figure 163** (Volvo Group North America, 2022). Although the project was solely conducted in Southern California, the knowledge gained from the project can be applied to any region to aid fleets in transitioning to electromobility solutions. The project highlighted the importance of collaboration and engagement from all stakeholders, emphasising the interdependence among them for success.

Figure 163: Necessary ecosystem for efficient deployment of commercial BETs

The Volvo LIGHTS project was a part of **California Climate Investments**, a program that uses **Cap-and-Trade funds** to decrease GHG emissions, bolster the economy, and improve public health and the environment, with a specific focus on disadvantaged communities. The total cost of the project was $90 million, with a funding award of $44.8 million. Volvo Trucks is now replicating this partnership model with customers, infrastructure partners, dealerships, and communities as it delivers trucks to more and more fleets. An overall summary of the project is demonstrated in **Figure 164**.

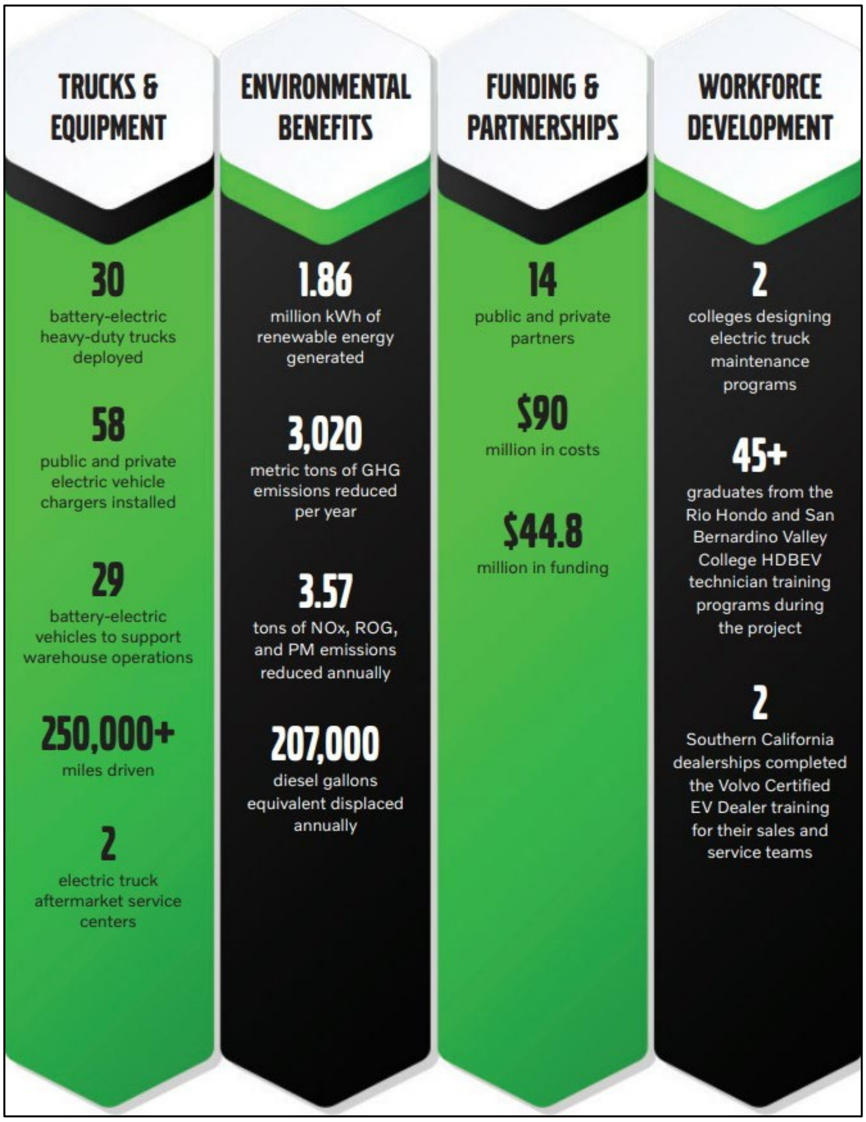

Figure 164: Synopsis of the Volvo LIGHTS project

DHL – Towards a sustainable future with BETs

In 2017, DHL set a goal to achieve zero emissions by 2050, shown in **Figure 165**. They are making a steady progress towards this goal with a current fleet of more than 15,000 battery electric vehicles and access to over 19,000 charging stations. By 2024, DHL's fleet will increase to over 20,000 electric vehicles and by 2030, more than 80,000 vehicles will be electric. Additionally, 60% of their last-mile delivery vehicles will be electric by 2030 (DHL, 2021). In 2019, DHL began testing a fleet of electric trucks in the city of Frankfurt, with the goal of reducing emissions and improving air quality in urban areas. The trucks, which were manufactured by the German company StreetScooter, had a range of approximately 150 km on a single charge, and could carry a payload of up to three tons.

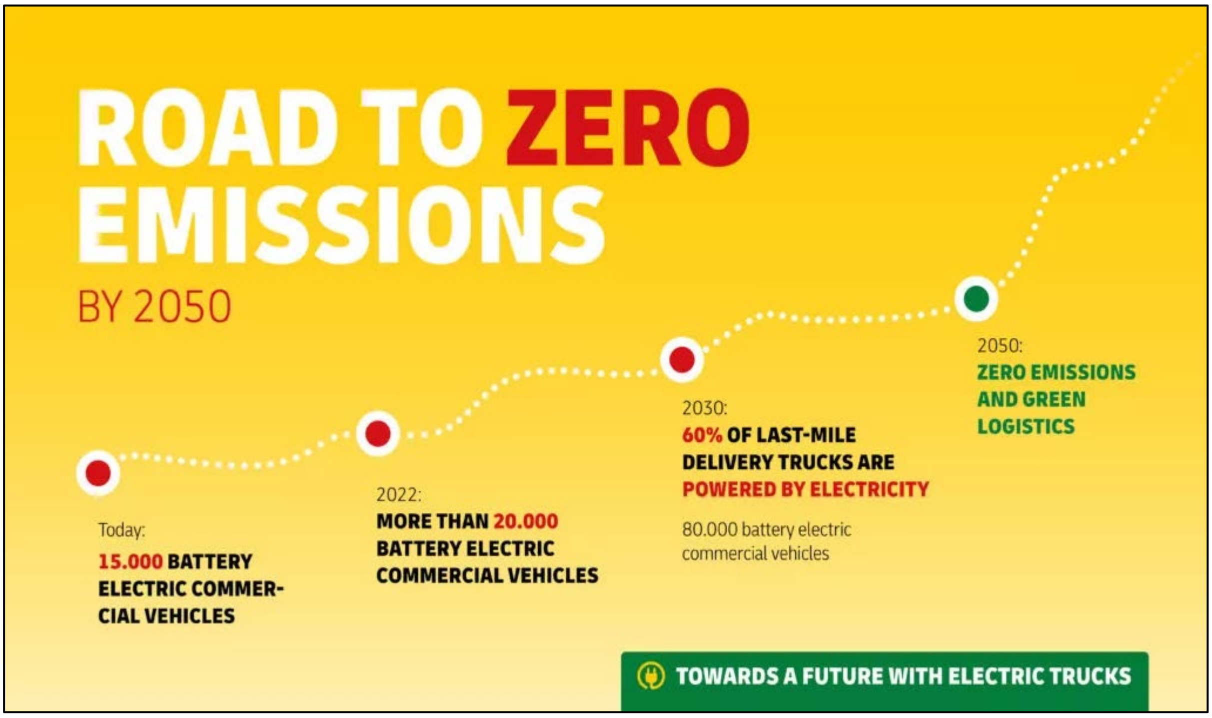

Figure 165: Sustainability roadmap of DHL – towards a future with electric trucks
Source: (DHL, 2021)

Examples of DHL's sustainability initiatives include (DHL, 2021):

- In Berlin, DHL conducted a two-year test of the first all-electric Daimler truck, the FUSO eCanter, between 2018 and 2020. This helped to advance urban transportation and delivery while reducing local emissions and noise.
- In Sweden, DHL began testing an all-electric Volvo FH 60t truck in January 2021. The truck operates between two DHL Freight logistics terminals separated by 150 km. This test will helps optimise the balance between distance, load weight and charging points for daily road freight operations.
- DHL is also participating in the CiLo Charging project, which involves research on integrating BETs into less-than-truckload and general cargo distribution operations, in partnership with Siemens, Technical University of Munich, Dortmund University of Applied Sciences, and STTech GmbH.
- In the Netherlands and the UK, DHL has already started using BETs in major operations.
- DHL plans to accelerate the adoption of heavy electric trucks by deploying a total of 44 new Volvo FE, FL, and FM electric trucks on routes in Europe (**Figure 166**). The first trucks have already been ordered, with six by DHL Parcel UK and two by DHL Freight. This will result in annual savings of nearly 600 tons of CO_2 and nearly 225,000 litres of diesel fuel for Deutsche Post DHL Group (DHL, 2022).

Figure 166: DHL and Volvo zero emission cooperation (DHL, 2022)

Hydrogen fuel cell trucks

ZANZEFF "Shore to Store" project – Southern California, USA

The ZANZEFF (Zero- and Near-Zero Emissions Freight Facilities) "Shore to Store" project was an initiative by Toyota Motor North America, Kenworth Truck Company, and Shell to create a fleet of 10 heavy-duty HFCTs for use in Southern California (**Figure 167**). This initiative began in 2017 and was the first of its kind in the United States (Toyota Newsroom, 2022).

The fleet was built by Toyota and Kenworth, with Toyota providing the fuel cell powertrain and Kenworth building the truck chassis. The trucks were operated by Southern California's Toyota Logistics Services (TLS), UPS, and trucking companies Total Transportation Services Inc. (TTSI) and Southern Counties Express (SCE). All 10 HFCTs were used to transport goods between the ports of Los Angeles and Long Beach and regional warehouses (Electrive.com, 2021).

Figure 167: "Shore to Store" project in Southern California – HFCTs
Source: (Toyota Newsroom, 2022)

The primary objective of the project was to create a sustainable solution in heavy-duty transportation, by developing a HFCT that could match the performance of diesel-powered drayage trucks while emitting zero tail-pipe emissions. The truck, named the Toyota-Kenworth T680, was designed to have a range of 480+ km when fully loaded to 37 t, and with a quick 15–20-minute fill-time, it could run multiple shifts a day, covering up to 650 to 800 km. The T680 HFCTs, codenamed "Ocean", were able to reduce GHG emissions by 74.66 tonne of CO_2 per truck annually compared to the baseline diesel engine (Toyota Newsroom, 2022).

The recently completed "Shore to Store" project was funded by a $41.1 million grant from CARB under the ZANZEFF program. The grant was part of the California Climate Investments, a state-wide initiative that invests billions of dollars from the state's Cap-and-Trade program to reduce GHG emissions, improve public health, and strengthen the economy. Project partners also contributed $41.4 million in financial and in-kind support. The "Shore to Store" project provided one of the largest real-world demonstrations of the practical application of hydrogen-powered fuel cell technology on a large scale and served as a framework for freight facilities to structure operations for future goods movement from the "Shore to the Store" in the world.

The main challenge faced by this initiative was the lack of hydrogen fuelling infrastructure in Southern California. To overcome this, Toyota and Kenworth worked with several partners to establish several new hydrogen fuelling stations in the region (Electrive.com, 2021). Overall, the initiative was considered a success, as the fuel cell trucks were able to complete their intended freight operations while also demonstrating the potential for hydrogen fuel cell technology in heavy-duty trucking applications. The project was also a part of Toyota's efforts to promote hydrogen fuel cell technology and to reduce its environmental impact (**Figure 168**).

Figure 168: High-capacity hydrogen fuelling stations
Source: (Electrive.com, 2021)

H2Accelerate collaboration – Europe

The H2Accelerate collaboration, which was launched in 2018, has been formed by truck manufacturers Daimler Truck, IVECO, and Volvo Group, and hydrogen infrastructure providers Linde, OMV, Shell, and TotalEnergies (**Figure 169**). The main goal of the partnership is to create awareness of the benefits of the use of green hydrogen for trucking, and the challenges in scaling-up the sector up to and beyond 2030 (H2Accelerate, 2022). To achieve this, it is important to consider and fulfil the needs and expectations of fleet operators and drivers, who play a vital role in the success of the rollout. This will be done by maintaining regular communication between the hardware suppliers, like those in the H2Accelerate collaboration, and the end-user groups.

Figure 169: H2Accelerate partnership of green hydrogen for trucking

H2Accelerate has been regularly publishing white papers outlining the necessity for hydrogen trucking and the projected growth of the fuel cell truck market. The group also released a policy position paper discussing the needs from Alternative Fuel Infrastructure Regulation in February 2022. These papers aim to educate end-users, policymakers, and regulators on the advantages of hydrogen trucking and the policy requirements necessary to implement the deployment of trucks and infrastructure (H2Accelerate, 2022).

Some of the key findings from the H2Accelerate whitepapers include (H2Accelerate, 2022):

- The members of the collaboration anticipate a gradual transition through three phases: a "learning" phase before 2025, when a low number of trucks are deployed at a relatively high cost due to low production volume. This will be followed by a series of expansions producing thousands of trucks per year and then tens of thousands of trucks per year, leading to a full industrialization phase where only a slight cost increase is expected. The analysis suggests that hydrogen and fuel cell vehicles have the potential for lower ownership costs compared to diesel if certain cost and performance metrics can be met.
- Organisations with public-facing decarbonisation targets understand that hydrogen freight is necessary to fully decarbonise their operations. This is particularly true for long-haul applications, where the advantage of fast refuelling over battery electric alternatives is emphasised, as well as for transport in areas with limited electrical grid or in situations where vehicles are used for double shifts.
- End-users were willing to accept that vehicles may be more expensive and infrastructure more limited in the early stages of roll-out compared to the incumbent diesel trucking system.
- End-users stated that while they would be willing to pay more in the short term to trial a small number of HFCTs, their business model requires that in the long term, scale improvements and supportive policy allow hydrogen trucks to achieve parity with diesel.
- It is expected that in the long term, network design, station availability, and vehicle maintenance will develop to allow end-users to achieve similar operational convenience and flexibility to diesel.

The white paper examines various policy options being considered throughout Europe and highlights the measures that are most likely to support each phase of the roll-out of hydrogen fuel cell trucks. **Figure 170** shows types of support that will be required in each phase (H2Accelerate, 2021).

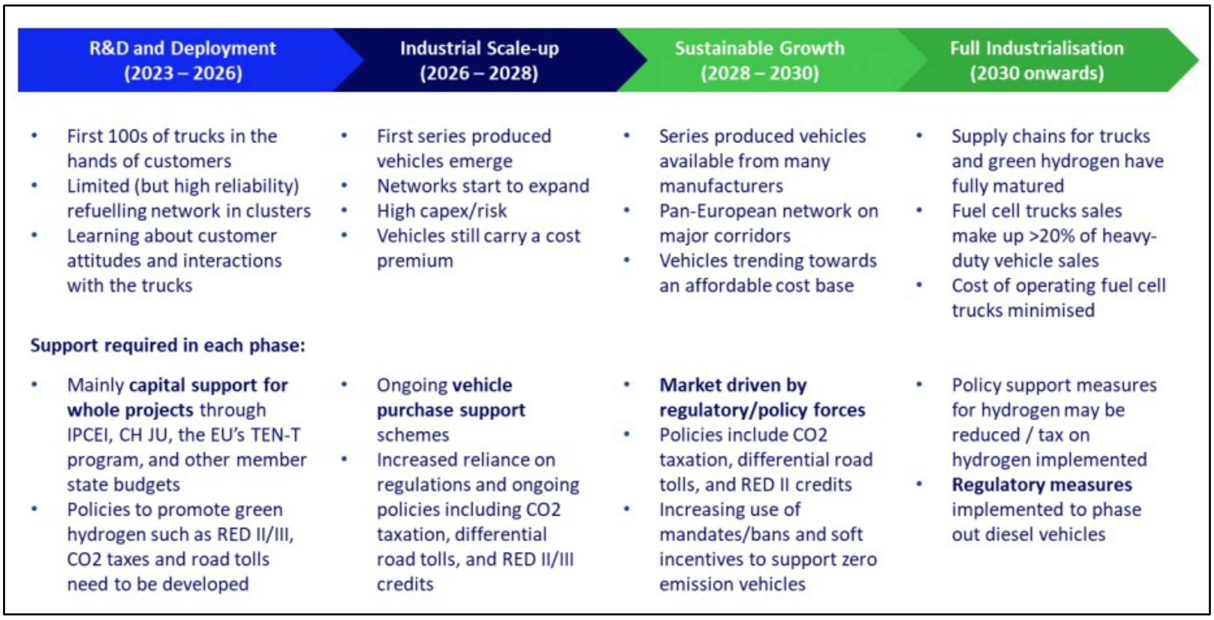

Figure 170: Policy mechanisms to support HFCTs (H2Accelerate, 2021)

The policy paper quantifies specific policy measures that will create the conditions for a thriving hydrogen truck market for Europe (H2Accelerate, 2021):

- The collaboration members emphasise the importance of favourable regulations under the Renewable Energy Directive II (RED II) framework for hydrogen.
- Additionally, they suggest the inclusion of a long-term and ambitious transport sub-target for Renewable Fuels of Non-Biological Origin (RFNBOs) within the proposals for RED III. This would help create and sustain the business case for green hydrogen production and hydrogen refuelling stations.
- The introduction of differential road tolls that favour hydrogen and other zero-emission options over fossil fuel-based vehicles. The modelling suggests road tolls of €0.40/km for diesel vehicles and €0.10/km for zero-emission vehicles would be sufficient to create demand for hydrogen trucks, shown in **Figure 171**.
- Taxation of fuels that recognises the shift towards more decarbonised and zero-carbon fuels and zero-emission vehicles, without putting hydrogen and other sustainable fuels at a disadvantage until their business case is established.
- The imposition of a carbon tax on diesel applied through the new Emissions Trading System (ETS) proposed in the "Fit for 55" package, in addition to the excise tax currently applied on diesel today.

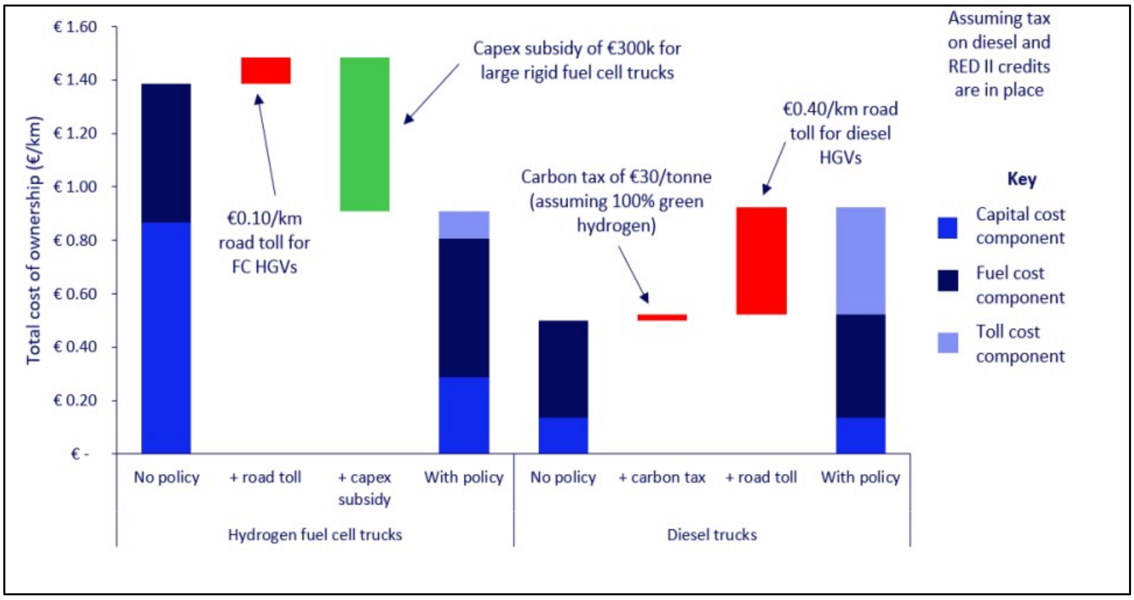

Figure 171: Policy support for HFCTs in R&D and deployment phase
Source: (H2Accelerate, 2021)

Government support required to make hydrogen truck fleet a viable option.

Overall, hydrogen truck deployment projects demonstrate that while HFCTs have the potential to reduce emissions and improve air quality, work still needs to be done in terms of producing and distributing green hydrogen fuel, building refuelling infrastructure, and providing government support to make hydrogen truck fleet a viable option.

Electric road system

ERS demonstration and pilot projects – Sweden

In Sweden, four different ERS projects have been successfully demonstrated on public roads. These include one demonstration using overhead lines (OCERS), two demonstrations using various types of road-based rails (ICERS), and a fourth demonstration utilizing wireless technology (WIERS). All four of these demonstration projects have received partial funding from Trafikverket, the National Swedish Transport Authority.

E16 Electric Road: Utilises overhead lines (OCERS) provided by Siemens along 2 km of motorway E16 in the vicinity of Sandviken in Region Gävleborg. The project began in June 2016 and ended in April 2020. Three vehicles were used for transportation of goods from various industries to the port of Gävle (RISE Research Institutes of Sweden, 2020) . In addition to trials in the EU, Siemens has also completed a successful trial of OCERS in Carsen, California, USA (Forbes, 2018).

Siemens propose implementing its e-highway solution on the core highways in Germany as well to create an infrastructure backbone to support energy efficient, low cost, zero-emissions trucking that is complementary to BETs, HFCTs and hybrid trucks. Siemens claim that if 30% of truck traffic on German highways could be electrified using their infrastructure, this would lead to an annual reduction in transport emissions of 7 million tonnes (Siemens Mobility, 2017). Siemens also claim an efficiency of more than 80% can be achieved with OCERS (Siemens

Mobility, 2017), as compared to 15-30% efficiency achieved from diesel or hydrogen fuel cell trucks, shown in **Figure 172**.

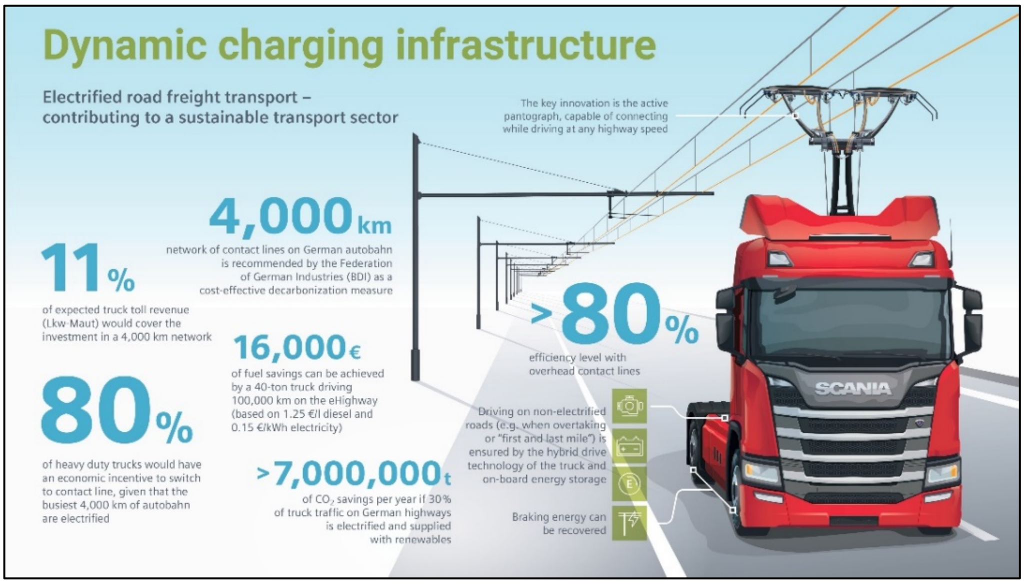

Figure 172: Siemens e-highway/OCERS highlights (Siemens, 2021)

eRoadArlanda: Utilises conductive rail (ICERS) provided by Elways on a 2 km stretch of Road 893 near Stockholm Arlanda Airport, shown in **Figure 173**. The project began in April 2018 and features an 18-tonne electric truck in shuttle operation between Arlanda Cargo Terminal and the Rosersberg logistics area. The project is being carried out by a consortium of companies, including Trafikverket, Vattenfall, and the vehicle manufacturer Scania (RISE Research Institutes of Sweden, 2020).

Figure 173: Electric road near Arlanda Airport utilizing In-road Conductive ERS
Source: (The Local, 2018)

EVolutionRoad: Utilises conductive rails (ICERS) provided by Elonroad along a street in the city of Lund in the Skåne Region. The project began in June 2020, and it is claimed that the Elonroad conductive road concept could enable a reduction in the vehicle battery size by 20 to 70%. It is the first electric road with a ground-level feeding system tested for a city bus and other vehicles, including trucks in the city environment. The total cost of the project is around 8 million Euros (Elonroad, 2020).

The new generation of ground mounted and smart ERS enables several sustainability benefits – environmental, economic, and social:

- Charging while driving, which eliminates the need for downtime to recharge.
- Reduced battery sizes by 20 – 70% which reduces environmental impact and cost.
- Energy efficiency, enabling lighter vehicles with smaller batteries.
- Charging of most types of electric vehicles: cars, trucks, utility vehicles and buses.

Elonroad can deliver up to 300 kW while driving, with this power rate being sufficient for both propulsion and charging simultaneously. The company claims that 1 km of driving on the electric road results in the transfer of energy sufficient to drive 3 km. As a result, the electric road only needs to be installed along 30 to 50% of the highway network. The rail is powered by power stations located at the edges of the road, like OCERS. Each station can deliver up to 3 MW to the rail, which is enough for ten trucks running on the connected electric road (Elonroad, 2020).

Smartroad Gotland: Utilises coils for wireless power transfer (WIERS) provided by Electreon along a 1.6 km of electric road on a 4.1 km section between Visby Airport and the city of Visby on the island of Gotland (**Figure 174**). The project features a medium-sized electric truck and an electric passenger shuttle bus as demonstration vehicles. The truck has been tested on part of the route since March 2020 and full-scale operation is scheduled to begin during the autumn of 2020 (Smart City Sweden, 2021).

Figure 174: Smartroad Gotland project utilizing Wireless Inductive ERS
Source: (Smart City Sweden, 2021)

Biofuel trucks

Neste renewable diesel fuelled truck deployments

DHL Freight in Europe: HVO (renewable diesel) is frequently used in Europe to reduce emissions from heavy vehicles such as buses, trucks, and construction equipment. As was discussed previously, renewable diesel or HVO is made from 100% renewable raw materials, mostly from waste or residues, and can reduce carbon emissions by up to 90% compared to regular diesel. One example of a renewable diesel truck fleet deployment is the project undertaken by the Finnish renewable diesel producer, Neste and DHL Freight (**Figure 175**). The project, which began in 2018, involved the deployment of a fleet of DHL delivery trucks that were powered by Neste's renewable diesel fuel, which is made from sustainable biomass such as waste and residue raw materials. The project aimed to reduce the carbon footprint of DHL's delivery operations while also increasing the use of renewable fuel in the transportation sector. The project was successful, with the renewable diesel fuel reducing GHG emissions by up to 90% compared to traditional diesel fuel. As a result of the project, DHL has committed to using Neste's renewable diesel fuel in a significant portion of its delivery fleet and plans to expand the use of renewable diesel fuel to other regions in the future (**Figure 176**).

Figure 175: DHL Parcel in the Netherlands operate 200 vehicles on HVO100
Source: (TTM NL, 2021)

As of Q1 2019, DHL Freight just in Sweden had 677 heavy vehicles running on the 26% HVO blend and an additional 171 trucks running on either 50% or 100% HVO (DHL, 2019). DHL Parcel in the Netherlands operate more than 200 vehicles running on HVO100 renewable diesel. DHL Parcel aims to switch their entire fleet to HVO diesel as soon as possible and is in talks with fuel suppliers to expand the number of HVO filling stations in the Netherlands to accelerate the rate of expansion (TTM NL, 2021).

Europe has traditionally been the largest market for renewable diesel due to early acceptance of the product in the region and government focus on replacing carbon-emitting sources with bio-based alternatives. The adoption of the Renewable Energy Directive (RED) II has played a significant role in the growth of renewable diesel production (Bryan, 2021).

Multiple projects in the USA: Neste MY Renewable Diesel is available in the US at more than 1,400 delivery points across California and Oregon (Transport Topics, 2021). This renewable diesel is produced from sustainable waste and residue raw materials, such as tallow and UCO, and it can be used in any diesel engine without modification.

Figure 176: Neste MY Renewable Diesel at more than 1,400 delivery points
Source: (Transport Topics, 2021)

Renewable diesel production is more expensive than traditional fossil diesel and requires policy support to make it commercially viable. The Renewable Fuel Standard, the biomass-based diesel blenders tax credit, and state-level incentives such as the California Low Carbon Fuel Standard and the Oregon Clean Fuels Program are key policy instruments in the United States that support renewable diesel producers (Research and Markets, 2022).

Ecology Switches 600 Trucks to Renewable Diesel

Ecology, a California-based transportation firm has converted its fleet of over 600 trucks to operate on Neste MY renewable diesel (NGT News, 2018). As a result, the company has seen improvements such as cleaner fuel filters, fewer maintenance issues, and a decrease in tailpipe emissions. As one of the leading trucking and transportation companies in the western United States, Ecology specialises in bulk waste and recyclables, heavy haul and oversize loads, and container transportation to and from the ports of Los Angeles and Long Beach (**Figure 177**). Additionally, the company plays a significant role in the transport of bulk waste and recycling materials, moving large quantities to disposal or recycling facilities on a regular basis. By converting its fleet of 600 trucks to run on Neste MY renewable diesel, Ecology can achieve a significant reduction in GHG emissions. On average, these trucks drive 40,000 km per year at a fuel efficiency of 1.06 km/L. This translates to an environmental benefit equivalent to taking 9,600 cars off the road or preserving an area of forest the size of 53,000 acres.

Figure 177: Trucks in California refuelling with Neste MY Renewable Diesel

Appendix B: Impacts of lower / higher discount Rates

Table 49: Societal economic assessment of iMOVE2-iMOVE11, lower discount rate (3% SDR)

Scenario	iMOVE 2	iMOVE3	iMOVE 4	iMOVE 5*	iMOVE 6	iMOVE7	iMOVE8	iMOVE9	iMOVE 10	iMOVE 11
Societal analysis										
NPV Total Benefits (million, $)	$1,809	$409	$608	$374	$3,946	$67	$139	$194	$6,073	$5,465
NPV Total Costs (million, $)	$1,294	$530	$790	$251	$2,099	$69	$155	$131	$3,628	$3,283
NPV Net Benefits (million, $)	$516	-$121	-$182	$124	$1,847	-$2	-$15	$63	$2,445	$2,182
Societal B/C	1.40	0.77	0.77	1.49	1.88	0.94	0.90	1.48	1.67	1.66

Note: * Results should be treated with caution. Provision of road access to reserved lanes, zero-emission zones will likely have real resource implications that are not captured in this analysis.

Table 50: Public economic assessment of iMOVE2-iMOVE11, lower discount rate (3% SDR)

Scenario	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5*	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10	iMOVE 11
Public sector analysis										
NPV Public/Transport Benefits (million, $)	$994	$91	$135	$192	$2,227	$63	$143	$98	$3,119	$3,108
NPV Public/Transport Cost (million, $)	$10	$2,929	$4,442	$2	$29	$468	$1,043	$98	$7,402	$1,442
NPV Net Public/Transport Benefits	$984	*-$2,838*	*-$4,307*	$190	$2,195	*-$405*	*-$901*	$0	*-$4,282*	$1,667
Net societal benefit per/public $	$51.59	*-$0.04*	*-$0.04*	$67.03	$64.34	$0.00	*-$0.01*	$0.64	$0.33	$1.51

Note: * Results should be treated with caution. Provision of road access to reserved lanes, zero-emission zones will likely have real resource and financial implications that are not captured in this analysis.

Table 51: Societal economic assessment of iMOVE2-iMOVE11, upper discount rate (7% SDR)

Scenario	iMOVE 2	iMOVE3	iMOVE 4	iMOVE 5*	iMOVE 6	iMOVE7	iMOVE8	iMOVE9	iMOVE 10	iMOVE 11
Societal analysis										
NPV Total Benefits (million, $)	$696	$157	$233	$159	$1,951	$36	$75	$82	$2,848	$2,616
NPV Total Costs (million, $)	$641	$221	$329	$140	$1,391	$46	$104	$73	$2,184	$2,075
NPV Net Benefits (million, $)	$55	*-$64*	*-$96*	$19	$559	*-$11*	*-$29*	$9	$664	$541
Societal B/C	1.09	0.71	0.71	1.13	1.40	0.77	0.72	1.13	1.30	1.26

Note: * Results should be treated with caution. Provision of road access to reserved lanes, zero-emission zones will likely have real resource implications that are not captured in this analysis.

Table 52: Public economic assessment of iMOVE2-iMOVE11, upper discount rate (7% SDR)

Scenario	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5*	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10	iMOVE 11
Public sector analysis										
NPV Public/Transport Benefits (million, $)	$375	$39	$58	$79	$1,054	$30	$68	$40	$1,434	$1,430
NPV Public/Transport Cost (million, $)	$5	$1,708	$2,592	$1	$20	$313	$701	$58	$4,511	$982
NPV Net Public/Transport Benefits	$369	*-$1,669*	*-$2,534*	$78	$1,035	*-$283*	*-$633*	*-$17*	*-$3,078*	$448
Net societal benefit per/public $	$10.24	*-$0.04*	*-$0.04*	$17.36	$28.40	*-$0.03*	*-$0.04*	$0.16	$0.15	$0.55

Note: * Results should be treated with caution. Provision of road access to reserved lanes, zero-emission zones will have real resource and financial implications that are not captured in this analysis.

Table 53: Comparison of emissions impact per ICE freight subclass

Note: DPE fleet model assumptions and Drives data

					CO₂ emissions per vehicle (average VKT)				Damage cost per vehicle (CO₂) ($)			
	ICE EF g CO_2-e/km		Average VKT		DPE emissions		Drives emissions		DPE emissions (CO_2)		Drives emission (CO_2)	
	DPE model	Drives	DPE-BITRE	Fleet model	DPE-BITRE	Fleet model	DPE-BITRE	Fleet model	DPE-BITRE	Fleet model	DPE-BITRE	Fleet model
RIG-S	366	454	23,561	25,591	8.6	9.4	10.7	11.6	$1,058	$1,156	$1,316	$1,427
RIG-SM	392	486	21,113	22,933	8.3	9.0	10.3	11.1	$1,021	$1,107	$1,267	$1,365
RIG-M	602	748	20,957	22,763	12.6	13.7	15.7	17.0	$1,550	$1,685	$1,931	$2,091
RIG-ML	641	795	21,899	23,786	14.0	15.2	17.4	18.9	$1,722	$1,870	$2,140	$2,325
RIG-L	938	1,164	23,591	25,624	22.1	24.0	27.5	29.8	$2,718	$2,952	$3,383	$3,665
ART-S	1,438	2,086	73,561	104,168	105.8	149.8	153.5	217.3	$13,013	$18,425	$18,881	$26,728
ART-M	1,311	1,902	60,899	86,237	79.9	113.1	115.8	164.0	$9,828	$13,911	$14,243	$20,172
ART-L	1,652	2,397	66,670	94,410	110.2	156.0	159.8	226.3	$13,555	$19,188	$19,655	$27,835

Source: Authors' calculations from DPE Fleet Model and Drives data inputs.

Note on emissions factors: DPE model operates with an average 525.43 g CO_2-e per km for rigid trucks and 1415.50 g CO_2-e per km for articulated trucks (2023 values) but does not provide emissions factors by subclass. Drives data provides emissions values by subclass, but these are not identical to DPE values. The weighted (by DPE-BITRE VKT travelled) equivalent emissions factors are 652.16 and 2053.16 g CO_2-e per km, respectively. This generates an equivalence conversion factor of 0.80568 and 0.68942 for rigid and articulated trucks, respectively (values in columns 2 and 3 are rounded to nearest whole number).

Note on average VKT: DPE model uses BITRE estimates of total VKT by truck type (rigid and articulated trucks). The VKT estimates generated by the DPE fleet model itself differ from the BITRE estimates. In column 4 and 5 the average VKT based on BITRE and DPE fleet model are provided.

Note on stock numbers: The DPE model provides stock numbers for each subclass. The same stock number was used across the different calculation methods in **Table 52.**

Note on carbon price: set at $123 (2023 level).

Table 53 compares the CO_2-e emissions per truck based on emissions factors (columns 2 and 3) from the data sources (DPE Fleet model and Drives data), and the average VKT (columns 4 and 5) per truck subclass from the two data sources (DPE-BITRE and DPE Fleet Model). Columns 6-9 provide per truck CO_2-e emissions if travelling the average distance. Based on the different assumptions there is a considerable spread in the CO_2-e emissions and the associated social damage cost. Using the Drives (2021-2022) data as the basis for emissions factors and DPE Fleet Model average VKT the annual CO_2-e emission for large articulated trucks is twice as large as the results based on DPE emissions factors and DPE-BITRE average VKT. Similarly, the damage cost for large articulated trucks ranges from $13,013to $27,835. It is noted that the Drives data only provides a snapshot of vehicles, whereas the DPE Fleet Model incorporates more dynamic assessment of input values over time. The two calculation methods thus primarily provide a measure of the range of likely values.

Appendix C: Modelled uptake for a range of scenarios

Table 54: iMOVE scenarios - percent in stock for LZET rigid

Scenario	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
2023	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2024	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2025	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2026	1	1	1	1	1	1	1	1	1	2	2	1	2	2	2	2	2	2	2	2
2027	1	1	1	1	1	2	1	1	1	3	3	2	2	2	3	2	3	3	2	3
2028	2	2	2	2	2	4	2	2	2	5	4	4	4	4	5	4	4	5	4	4
2029	2	2	2	2	2	6	2	3	2	7	7	6	7	7	7	7	7	7	7	7
2030	4	4	4	4	4	10	4	4	4	11	11	10	10	10	11	10	10	11	10	10
2031	6	6	6	6	6	13	6	6	6	14	14	13	13	13	14	13	14	14	13	14
2032	8	8	9	9	9	16	8	9	8	18	17	16	17	16	17	16	17	17	16	17
2033	11	11	12	12	12	19	11	12	11	21	21	19	20	20	20	19	20	21	20	20
2034	14	14	15	15	15	22	15	15	15	24	24	22	23	22	23	22	23	24	22	23
2035	18	18	18	18	18	25	18	18	18	27	27	25	26	25	26	25	26	27	25	26
2036	21	22	21	22	21	28	21	21	21	31	30	28	29	29	30	29	30	30	28	29
2037	24	26	24	25	24	30	24	24	24	34	34	32	33	33	33	33	33	34	31	32
2038	26	29	27	28	27	33	27	27	27	38	37	35	36	36	37	36	36	37	34	34
2039	29	33	30	30	30	36	30	30	30	41	40	39	39	39	40	39	40	40	36	37
2040	32	36	33	33	33	39	32	33	33	44	43	42	42	42	43	42	42	43	39	40
2041	35	39	35	36	36	41	35	35	35	46	46	45	45	45	45	45	45	46	42	42
2042	37	42	38	39	38	44	38	38	38	49	49	47	48	48	48	48	48	49	44	45
2043	40	45	41	41	41	46	40	40	40	52	51	50	51	50	51	50	51	51	47	47
2044	42	48	43	44	43	49	43	43	43	54	54	52	53	53	53	53	53	54	49	50
2045	45	50	46	46	46	51	45	45	45	56	56	55	55	55	56	55	55	56	51	52
2046	47	53	48	48	48	53	47	48	48	58	58	57	58	57	58	57	58	58	54	54

2047	49	55	50	50	50	55	50	50	50	60	60	59	60	59	60	59	60	60	56	56
2048	52	57	52	53	53	57	52	52	52	62	62	61	62	61	62	61	62	62	58	58
2049	54	59	54	55	55	59	54	54	54	64	64	63	64	63	64	63	64	64	60	60
2050	56	61	57	57	57	61	56	56	56	66	66	65	65	65	65	65	65	66	62	62
2051	58	63	59	59	59	63	58	58	59	68	68	67	67	67	67	67	67	67	64	64
2052	60	65	61	61	61	65	60	60	61	69	69	68	69	69	69	68	69	69	65	66
2053	62	67	63	63	63	67	62	62	63	71	71	70	70	70	70	70	70	71	67	68
2054	64	69	65	65	65	69	64	64	64	72	72	71	72	72	72	72	72	72	69	69
2055	66	70	66	67	67	70	66	66	66	74	73	73	73	73	73	73	73	73	70	71
2056	67	72	68	68	68	72	68	68	68	75	75	74	74	74	75	74	74	75	72	72
2057	69	73	70	70	70	73	69	69	69	76	76	75	76	76	76	76	76	76	73	74
2058	71	74	71	71	71	74	71	71	71	77	77	77	77	77	77	77	77	77	75	75
2059	72	76	72	73	73	76	72	72	72	79	78	78	78	78	78	78	78	78	76	76
2060	73	77	74	74	74	77	74	74	74	80	79	79	79	79	79	79	79	79	77	77
2061	75	79	76	76	76	79	76	76	76	81	81	80	80	80	80	80	80	80	78	78

Table 55: iMOVE scenarios - percent in stock for LZET articulated.

Scenario	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15	s16	s17	s18	s19	s20
2023	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2024	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2025	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2026	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2027	1	1	1	1	1	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2
2028	1	1	1	1	1	2	1	1	1	2	3	2	2	2	3	2	2	3	2	2
2029	1	1	1	1	1	3	1	2	1	4	4	3	4	4	4	4	4	4	4	4
2030	2	2	2	2	2	6	2	2	2	7	7	6	6	6	7	6	6	7	6	6
2031	2	2	2	2	2	9	2	3	2	10	11	9	10	10	11	10	10	11	10	10
2032	3	3	3	3	3	13	3	4	3	14	15	13	14	14	14	13	14	15	14	14
2033	5	5	5	5	5	17	5	5	5	18	18	17	17	17	18	17	18	18	17	18
2034	7	7	7	7	7	20	7	7	7	22	22	20	21	21	22	21	21	22	21	21
2035	10	10	10	10	10	24	10	11	10	26	26	24	25	24	25	24	25	26	24	25
2036	13	15	13	14	14	27	14	14	14	30	30	28	29	29	29	28	29	30	28	28
2037	17	20	17	17	17	30	17	18	17	34	34	32	33	33	33	32	33	34	31	31
2038	20	24	21	21	21	33	21	21	21	37	37	36	37	36	37	36	37	37	34	35
2039	24	28	24	24	25	37	24	25	24	41	41	39	40	40	41	40	40	41	37	38
2040	28	33	28	28	28	40	28	28	28	44	44	43	44	43	44	43	44	44	40	41
2041	31	36	31	31	32	43	31	32	31	47	47	46	47	47	47	46	47	47	43	44
2042	34	40	35	35	35	46	35	35	35	50	50	49	50	50	50	49	50	50	46	47
2043	37	43	38	38	38	48	38	38	38	53	53	52	53	52	53	52	53	53	49	49
2044	40	46	41	41	41	51	41	41	41	56	56	55	55	55	56	55	55	56	52	52
2045	43	49	44	44	44	54	44	44	44	58	58	57	58	58	58	57	58	58	54	55
2046	46	52	46	47	47	56	46	47	47	61	61	60	60	60	60	60	60	61	57	57
2047	49	55	49	49	50	59	49	49	49	63	63	62	62	62	63	62	62	63	59	59

2048	51	58	52	52	52	61	52	52	52	65	65	64	64	64	65	64	65	65	61	62
2049	54	60	54	54	55	63	54	54	54	67	67	66	66	66	67	66	67	67	63	64
2050	56	62	56	57	57	65	56	57	57	69	69	68	68	68	69	68	68	69	65	66
2051	59	64	59	59	60	67	59	59	59	71	71	70	70	70	70	70	70	71	67	68
2052	61	66	61	61	62	69	61	61	61	72	72	71	72	72	72	72	72	72	69	69
2053	63	68	63	64	64	71	63	64	64	74	74	73	73	73	74	73	73	74	71	71
2054	65	70	65	66	66	72	65	66	66	75	75	75	75	75	75	75	75	75	72	73
2055	67	72	67	67	68	74	67	68	68	77	77	76	76	76	76	76	76	77	74	74
2056	69	73	69	69	70	75	69	69	69	78	78	77	78	78	78	78	78	78	76	76
2057	71	75	71	71	71	77	71	71	71	79	79	79	79	79	79	79	79	79	77	77
2058	72	76	73	73	73	78	73	73	73	80	80	80	80	80	80	80	80	80	78	78
2059	74	78	74	74	75	79	74	74	74	81	81	81	81	81	81	81	81	81	79	80
2060	75	79	76	76	76	80	76	76	76	82	83	82	82	82	82	82	82	82	81	81
2061	78	81	78	78	78	82	78	78	78	84	84	83	83	83	83	83	83	83	82	82

Table 56: Emissions reductions for iMOVE1-iMOVE20 scenarios

iMOVE Scenarios

OPEX subsidy	This is a $5 rebate on per 100km operating costs - approximately 16.6% rebate.
CAPEX subsidy	This is a %-age cover of the differential in purchase price between a ZEV and an ICE equivalent. (40% and 80%)
Road Access	This is a policy package consisting of reserved lanes, low emissions zones and relaxation of night time curfews for ZEVs
Phase out	This is the year beyond which ICE vehicles would no longer be available on the Australian market.

Scenario	iMOVE 1	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10	iMOVE 11	iMOVE 12	iMOVE 13	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19	iMOVE 20
OPEX subsidy	0	0	0	0	0	0	0	0	5	5	5	0	0	0	0	5	5	5	0	5
CAPEX subsidy	0	0	0	0	0	0	0.4	0.8	0	0	0.4	0	0	0.4	0.8	0	0.4	0.8	0.4	0.4
Availability	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Road access	0	0	0	0	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1
Discount	0	0	0.04	0.06	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0
Phase out	0	2035	0	0	0	0	0	0	0	2035	2035	2035	2035	2035	2035	2035	2035	2035	0	0

Results

	Baseline	Baseline - control																			
Emissions	DPE 2022 Current Policy	iMOVE 1	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10	iMOVE 11	iMOVE 12	iMOVE 13	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19	iMOVE 20
CO2-e (Mt)	177.95	177.95	168.39	177.10	176.69	176.15	157.98	177.39	176.67	177.03	149.69	149.80	152.52	151.28	151.62	150.47	151.89	151.01	149.88	157.00	156.03
NOx (Kt)	271.98	271.98	266.79	271.38	271.09	270.80	254.69	271.49	270.86	271.38	248.94	248.96	251.62	250.44	250.67	249.44	251.03	250.10	248.88	253.69	252.91
PM2.5 exhaust (Kt)	4.62	4.62	4.54	4.61	4.61	4.60	4.34	4.61	4.60	4.61	4.24	4.24	4.29	4.27	4.27	4.25	4.28	4.26	4.24	4.32	4.31
PM2.5 non-exhaust (K	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90	19.90
PM2.5 total (Kt)	24.52	24.52	24.44	24.51	24.51	24.50	24.24	24.52	24.51	24.51	24.14	24.15	24.19	24.17	24.17	24.15	24.18	24.16	24.14	24.22	24.21

Reductions on iMOVE 1	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10	iMOVE 11	iMOVE 12	iMOVE 13	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19	iMOVE 20
CO2-e reductions (Mt)	9.56	0.85	1.26	1.80	19.97	0.56	1.28	0.92	28.26	28.15	25.43	26.67	26.33	27.48	26.06	26.94	28.07	20.95	21.92
NOx reductions (Kt)	5.19	0.60	0.89	1.18	17.29	0.49	1.11	0.60	23.04	23.01	20.36	21.53	21.30	22.54	20.95	21.88	23.10	18.29	19.07
PM2.5 exhaust reductions (Kt)	0.09	0.01	0.02	0.02	0.28	0.01	0.02	0.01	0.38	0.38	0.33	0.35	0.35	0.37	0.34	0.36	0.38	0.30	0.31
PM2.5 non-exhaust reductions (Kt)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PM2.5 total reductions (Kt)	0.09	0.01	0.02	0.02	0.28	0.01	0.02	0.01	0.38	0.38	0.33	0.35	0.35	0.37	0.34	0.36	0.38	0.30	0.31

% Reductions on iMOVE 1	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10	iMOVE 11	iMOVE 12	iMOVE 13	iMOVE 14	iMOVE 15	iMOVE 16	iMOVE 17	iMOVE 18	iMOVE 19	iMOVE 20
CO2-e reductions	5.37%	0.48%	0.71%	1.01%	11.22%	0.32%	0.72%	0.52%	15.88%	15.82%	14.29%	14.99%	14.80%	15.44%	14.64%	15.14%	15.77%	11.77%	12.32%
NOx reductions	1.91%	0.22%	0.33%	0.43%	6.36%	0.18%	0.41%	0.22%	8.47%	8.46%	7.48%	7.92%	7.83%	8.29%	7.70%	8.05%	8.49%	6.73%	7.01%
PM2.5 exhaust reductions	1.89%	0.22%	0.33%	0.43%	6.11%	0.17%	0.40%	0.22%	8.20%	8.18%	7.22%	7.64%	7.56%	8.00%	7.44%	7.77%	8.20%	6.47%	6.75%
PM2.5 non-exhaust reductions	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
PM2.5 total reductions	0.36%	0.04%	0.06%	0.08%	1.15%	0.03%	0.07%	0.04%	1.55%	1.54%	1.36%	1.44%	1.43%	1.51%	1.40%	1.46%	1.55%	1.22%	1.27%

Table 57: Relative contribution of truck subclasses to overall emissions iMOVE1-iMOVE11

Vehicle Type	Emissions	iMOVE 1	iMOVE 2	iMOVE 3	iMOVE 4	iMOVE 5	iMOVE 6	iMOVE 7	iMOVE 8	iMOVE 9	iMOVE 10	iMOVE 11
Rigid trucks		52.266	50.894	51.630	51.327	51.403	51.005	52.011	51.735	51.741	46.142	46.967
RIG-S	Emissions Mt CO2-e	24.874	24.332	24.499	24.321	24.387	24.741	24.727	24.571	24.525	21.943	22.426
RIG-SM	Emissions Mt CO2-e	5.595	5.440	5.498	5.453	5.493	5.581	5.566	5.534	5.553	5.046	5.153
RIG-M	Emissions Mt CO2-e	8.360	8.134	8.284	8.248	8.246	8.073	8.329	8.296	8.297	7.454	7.567
RIG-ML	Emissions Mt CO2-e	5.088	4.925	5.042	5.020	5.026	4.786	5.070	5.050	5.065	4.471	4.533
RIG-L	Emissions Mt CO2-e	8.349	8.063	8.306	8.286	8.251	7.824	8.319	8.284	8.302	7.227	7.287
Articulated trucks		116.279	110.462	116.033	115.911	115.132	102.740	114.377	115.023	115.787	95.762	96.163
ART-S	Emissions Mt CO2-e	12.059	11.474	12.000	11.970	11.913	11.132	11.585	11.952	11.978	10.412	10.491
ART-M	Emissions Mt CO2-e	71.329	68.698	71.181	71.108	70.604	63.785	72.384	70.533	71.017	59.388	59.635
ART-L	Emissions Mt CO2-e	32.891	30.290	32.852	32.832	32.616	27.823	30.408	32.538	32.792	25.962	26.038
Reductions on iMOVE 1												
Rigid trucks			1.372	0.636	0.939	0.863	1.261	0.255	0.531	0.525	6.124	5.299
RIG-S	Emissions Mt CO2-e		0.542	0.375	0.553	0.487	0.133	0.147	0.303	0.349	2.931	2.448
RIG-SM	Emissions Mt CO2-e		0.156	0.097	0.143	0.102	0.015	0.029	0.061	0.043	0.549	0.443
RIG-M	Emissions Mt CO2-e		0.226	0.076	0.112	0.115	0.287	0.031	0.064	0.063	0.906	0.793
RIG-ML	Emissions Mt CO2-e		0.162	0.046	0.068	0.061	0.302	0.018	0.038	0.023	0.616	0.554
RIG-L	Emissions Mt CO2-e		0.286	0.042	0.063	0.098	0.525	0.030	0.065	0.047	1.122	1.062
Articulated trucks			5.817	0.246	0.368	1.147	13.538	1.902	1.256	0.491	20.517	20.115
ART-S	Emissions Mt CO2-e		0.585	0.059	0.089	0.146	0.927	0.474	0.107	0.081	1.647	1.568
ART-M	Emissions Mt CO2-e		2.631	0.147	0.220	0.725	7.543		0.796	0.312	11.940	11.694
ART-L	Emissions Mt CO2-e		2.601	0.039	0.059	0.275	5.068	2.483	0.353	0.099	6.929	6.853
% Reductions on iMOVE 1												
Rigid trucks			2.6%	1.2%	1.8%	1.7%	2.4%	0.5%	1.0%	1.0%	11.7%	10.1%
RIG-S	Emissions Mt CO2-e		2.2%	1.5%	2.2%	2.0%	0.5%	0.6%	1.2%	1.4%	11.8%	9.8%
RIG-SM	Emissions Mt CO2-e		2.8%	1.7%	2.5%	1.8%	0.3%	0.5%	1.1%	0.8%	9.8%	7.9%
RIG-M	Emissions Mt CO2-e		2.7%	0.9%	1.3%	1.4%	3.4%	0.4%	0.8%	0.8%	10.8%	9.5%
RIG-ML	Emissions Mt CO2-e		3.2%	0.9%	1.3%	1.2%	5.9%	0.3%	0.7%	0.4%	12.1%	10.9%
RIG-L	Emissions Mt CO2-e		3.4%	0.5%	0.8%	1.2%	6.3%	0.4%	0.8%	0.6%	13.4%	12.7%
Articulated trucks			5.0%	0.2%	0.3%	1.0%	11.6%	1.6%	1.1%	0.4%	17.6%	17.3%
ART-S	Emissions Mt CO2-e		4.8%	0.5%	0.7%	1.2%	7.7%	3.9%	0.9%	0.7%	13.7%	13.0%
ART-M	Emissions Mt CO2-e		3.7%	0.2%	0.3%	1.0%	10.6%		1.1%	0.4%	16.7%	16.4%
ART-L	Emissions Mt CO2-e		7.9%	0.1%	0.2%	0.8%	15.4%	7.5%	1.1%	0.3%	21.1%	20.8%