Vehicle Emissions Prediction Model:
VEPM 6.2 update technical report

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Executive summary

The Vehicle Emissions Prediction Model (**VEPM**) has been developed by Waka Kotahi NZ Transport Agency (**Waka Kotahi**) and Auckland Council to predict emissions from vehicles in the New Zealand fleet under typical road, traffic and operating conditions. The model provides estimates that are suitable for air quality assessments and regional emissions inventories. Since its release in 2008, VEPM has been successfully used in Auckland and around New Zealand to estimate vehicle emissions in air quality assessments for road projects. An important feature of the model is the ability to estimate changes to vehicle emissions in future years (from 2001 to 2050).

The emission factor databases that VEPM utilises to derive New Zealand-relevant factors are constantly being updated with improved factors for new technologies, emerging issues and real-world effects. The current version of VEPM (**VEPM 6.1**) was last updated in September 2020 (Metcalfe & Peeters, 2020). Since then, further developments have occurred prompting Waka Kotahi to commission Emission Impossible Ltd to undertake a new update in 2021. This report discusses the methodology we followed to update VEPM to include the following:

- Updating the fleet profile based on updated vehicle kilometres travelled (**VKT**) data from the Vehicle Fleet Emission Model (**VFEM3**) provided by Ministry of Transport
- Revising the assumed date of introduction of Euro 6/VI standards in VEPM
- Improving the assumptions in VEPM to split heavy commercial vehicle VKT between rigid and articulated truck categories
- Providing methane (**CH_4**) and nitrous oxide (**N_2O**) emission factors and calculation of carbon dioxide equivalent (**CO_2-e**) emission factors
- Incorporating updated emission factors from the latest version of COPERT (the EU standard vehicle emissions calculator)
- Updating degradation factors for light duty vehicle carbon monoxide (**CO**) and nitrogen oxides (**NO_X**) emissions
- Updating light duty gradient correction factors.

In addition to the above, we investigated the likely impact of:

- Using actual fuel quality parameters rather than fuels specifications on adjustment factors
- Including biofuels as separate fuel options
- Revising the assumptions for tampering with exhaust emissions control equipment
- Updating other degradation factors
- Improving the real-world fuel consumption adjustment factors.

Where sufficient data exist, changes have been made to VEPM to create a new version (**VEPM 6.2**). However, some areas (principally in the five investigation areas) have been identified as requiring further work before we will be able to justify/recommend additional changes.

Significant changes to fleet-weighted emission factors as a result of changes implemented in VEPM 6.2 are summarised as follows:

- Fleet-weighted emissions of CO, HC and NO_X are lower in VEPM 6.2 compared with VEPM 6.1 which is primarily due to changes in light duty emission degradation factors
- Fleet-weighted emissions of PM are similar in VEPM 6.2 compared with VEPM 6.1
- Fleet-weighted average fuel consumption is higher in VEPM 6.2 compared with VEPM 6.1 from 2030 onwards. This is due to a lower proportion of electric vehicles in the projected fleet.

Contents

Glossary of terms and abbreviations

A Train	A rigid vehicle connected to a semi-trailer that tows a full trailer
Articulated vehicle	An articulated vehicle has a driver's position, a steering system, motive power and two rigid sections that articulate relative to each other
B Train	A rigid vehicle attached to two semi-trailers
B7	A diesel blend with 7 % by volume biodiesel
B100	A diesel blend comprising 100 % by volume biodiesel
CH_4	Methane, a greenhouse gas
CO	Carbon monoxide
CO_2	Carbon dioxide, a greenhouse gas
CO_2-e	Carbon dioxide equivalent, a way to express the impact of each different greenhouse gas in terms of the amount of CO_2 that would create the same amount of warming
COPERT	The European Computer Model to Calculate Emissions from Road Transport
E10	A petrol blend with 10 % by volume ethanol
E85	A petrol blend with 85 % by volume ethanol
EMEP/EEA	European Monitoring and Evaluation Programme/European Environment Agency
EPEFE	European Programme on Emissions, Fuels and Engine Technologies
g/km	Grams per kilometre
GVM	Gross vehicle mass
GCM	Gross combined mass, which is the combined mass of a truck including the mass of any trailers
HC	Total hydrocarbons

HCV	Heavy commercial vehicle, a commercial vehicle with a GVM >3.5 tonnes
LCV	Light commercial vehicle, a commercial vehicle with a GVM <3.5 tonnes
LPV	Light passenger vehicle, a passenger vehicle with a GVM <3.5 tonnes
MoT	Ministry of Transport
MVR	Motor Vehicle Register
NO_X	Oxides of nitrogen
NO_2	Nitrogen dioxide, an air quality pollutant
N_2O	Nitrous oxide, a greenhouse gas (not to be confused with NO_2 which is an air quality pollutant)
NVED	National Vehicle Emissions Dataset
PM	Particulate matter
Remote sensing	A device that measures the concentration of key pollutants in vehicle exhausts by shining light through the exhaust plume as a vehicle passes
Rigid vehicle	A rigid vehicle has two axle sets, a driver’s position, a steering system, motive power and a single rigid chassis.
RUC	Road user charges
SCR	Selective catalytic reduction, an exhaust treatment system which coverts NO_X emissions to N_2 and O_2 thereby dramatically reducing the harmful effects
VEMT	Vehicle Emissions Mapping Tool, developed by Waka Kotahi developed by Waka Kotahi to estimate vehicle emissions from motor vehicles travelling on all public roads in New Zealand
VEPM	Vehicle Emissions Prediction Model, developed by Waka Kotahi to predict air emissions and fuel consumption for the New Zealand fleet
VFEM	Vehicle Fleet Emissions Model, developed by MoT to predict the makeup, travel, energy (fuel and electricity) use and greenhouse gas emissions of the future New Zealand vehicle fleet

VKT	Vehicle kilometres travelled
WiM	Weigh in motion, devices designed to capture and record the axle weights and gross vehicle weights as vehicles drive over a measurement site

1. Introduction

1.1 Background

The Vehicle Emissions Prediction Model (**VEPM**) has been developed by Waka Kotahi NZ Transport Agency (**Waka Kotahi**) and Auckland Council to predict emissions from vehicles in the New Zealand fleet under typical road, traffic and operating conditions. The model provides estimates that are suitable for air quality assessments and regional emissions inventories. VEPM has been successfully used in Auckland and around New Zealand to estimate vehicle emissions in air quality assessments for road projects. An important feature of the model is the ability to estimate changes to vehicle emissions in future years (from 2001 to 2050).

VEPM is an average speed model which predicts emission factors for New Zealand fleet, based on the different vehicle types/technologies present and the relative kilometres travelled by each vehicle class. Fleet-weighted emission factors are calculated by multiplying the emissions factors in grams per kilometre (**g/km**) for each vehicle class by the proportion of kilometres travelled by that class for any given year.

VEPM derives New Zealand-relevant factors based on emissions factors from the European COPERT model, which is published by the European Environment Agency in a spreadsheet (EEA 2020). The emission factors are constantly being updated with improved factors for new technologies, emerging issues and real-world effects. Since its original release in 2008, VEPM has undergone regular reviews and updates to ensure its predictions reflect the changing emissions profile of the New Zealand fleet.

The current version of VEPM (**VEPM 6.1**) was last updated in September 2020 (Metcalfe & Peeters, 2020) to:

- Improve bulk run processing times and rationalise the spreadsheet model
- Update the existing Euro emission factors with those from the most current version of COPERT (the EU standard vehicle emissions calculator)
- Incorporate articulated truck emission factors and associated VKT estimates
- Enhance the range of bus classes covered by emission factors
- Develop New Zealand real-world fuel consumption correction factors for diesel passenger cars and diesel light commercial vehicles.

Since then, further developments have occurred prompting Waka Kotahi to commission Emission Impossible Ltd to undertake a new update in 2021.

1.2 Purpose and scope of this report

The purpose of the 2021 update is to keep VEPM current by:

- continuing with the regular updating of the fleet profile and the latest emission factors from COPERT,

- incorporating emission factors for methane (CH_4), nitrous oxide (N_2O) and carbon dioxide equivalent (CO_2-e) to enable a broader range of greenhouse gases to be assessed
- reviewing how VEPM accounts for current parameters (such as degradation, gradient, tampering and fuel quality) in the emissions factors and identifying whether changes or additional factors need to be made to improve predictions.

1.3 Report structure

This report is structured as follows:

- Chapter 2 outlines the updates that have been implemented to develop VEPM 6.2
- Chapter 3 discusses the additional areas investigated that have been identified as requiring further work before updates can be recommended
- Chapter 4 compares the fleet-weighted emissions factors now predicted by VEPM 6.2 versus those from the previous version VEPM 6.1
- Chapter 5 highlights areas of future work.

The report discusses the methodology followed to update VEPM and includes all assumptions and revised calculations.

All references are included at the end, with additional details presented in a series of technical appendices at the end.

Further information and technical reports relating to development of the Vehicle Emission Prediction Model are available on the Transport Agency's Highways Information Portal website[1].

[1] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/air-quality-climate/planning-and-assessment/vehicle-emissions-prediction-model/

2. Updates

This chapter describes updates that have been implemented to develop VEPM 6.2. The areas covered include:

- Spreadsheet and data processing
- Fleet profile
- Euro 6/VI vehicle introduction dates
- Split between rigid and articulated truck VKT
- Other greenhouse gases and estimation of CO_2-e emissions
- Light duty CO and NO_X degradation factors
- Catalytic converter removal
- Light duty gradient correction.

2.1 Spreadsheet and data processing improvements

Changes were made to the VEPM spreadsheet model to:

- Rationalise various worksheets to make them easier to understand and update
- Fix a number of minor errors.

Significant changes are summarised in the *Changelog* worksheet of VEPM 6.2.

Note: These changes did not affect the emission factors themselves – only the operation of the model.

2.2 Vehicle fleet

Vehicle kilometres travelled (**VKT**) data are used in VEPM to calculate the proportions of VKT travelled for each vehicle category. VEPM 6.1 includes actual travel data to end 2017 with projections for years to 2050 but more recent data are now available.

2.2.1 Updated VKT data

Updated VKT values from the Vehicle Fleet Emission Model (**VFEM3**)[2] were provided by Ministry of Transport (**MoT**), including historical fleet and actual travel data up to end 2019 with projections to 2050.

[2] The VFEM model is described on the Ministry of Transport website at https://www.transport.govt.nz/assets/Uploads/Data/Transport-outlook-updated/Vehicle-Fleet-Emissions-Model-Documentation-20190719.pdf. The model has been updated since the publication of this documentation with updated fleet data and new electric vehicle uptake projections. However, at the time of writing, updated documentation was not available.

The revised data covered all years from 2001 to 2050 broken down by:

- vehicle type
- fuel type
- engine capacity (light duty vehicles) or vehicle mass (heavy duty vehicles)
- year of manufacture.

Note: The revised VFEM3 fleet projections to 2050 are a base case 'no new policies' scenario. Since the development of the base case fleet projection, the government has introduced a clean car policy package to incentivise the uptake of low emission vehicles. The effect of this policy package will be considered in future updates of VFEM.

2.2.2 Overall fleet breakdown

Table 1 contrasts the overall default fleet composition (in terms of %VKT) in VEPM 6.1 with the updated fleet composition in VEPM 6.2 (see

Table 2).

Figure 1 and Figure 2 show the change in the overall proportions of light duty petrol, light duty diesel, light duty hybrid/electric and heavy duty diesel vehicles from 2001 to 2050 for both of the default fleets. The trends are similar but VEPM 6.2 now predicts a slightly slower uptake in electric vehicles by 2050 relative to what was predicted in VEPM 6.1.

Table 1: Default fleet (% VKT by vehicle class) in VEPM 6.1

	Light duty vehicles <3.5tonnes										Heavy vehicles >3.5tonnes			
Year	**Car petrol**	**Car diesel**	**Car hybrid**	**Car plug-in hybrid**	**Car electric**	**LCV petrol**	**LCV diesel**	**LCV hybrid**	**LCV plug-in**	**LCV electric**	**Diesel HCV**	**Diesel Buses**	**Electric HCV**	**Electric Buses**
2001	72.5%	6.9%	0.0%	0.0%	0.0%	6.4%	7.9%	0.0%	0.0%	0.0%	6.0%	0.4%	0.0%	0.0%
2005	71.0%	7.9%	0.0%	0.0%	0.0%	5.0%	9.1%	0.0%	0.0%	0.0%	6.5%	0.5%	0.0%	0.0%
2010	70.1%	7.6%	0.2%	0.0%	0.0%	4.1%	11.0%	0.0%	0.0%	0.0%	6.4%	0.6%	0.0%	0.0%
2015	67.5%	7.8%	0.6%	0.0%	0.0%	3.5%	13.4%	0.0%	0.0%	0.0%	6.5%	0.6%	0.0%	0.0%
2020	64.2%	7.8%	1.2%	0.1%	0.3%	3.1%	16.0%	0.0%	0.0%	0.0%	6.5%	0.7%	0.0%	0.0%
2025	61.4%	7.6%	1.9%	0.7%	1.7%	3.1%	16.1%	0.0%	0.0%	0.2%	6.3%	0.7%	0.0%	0.0%
2030	54.5%	6.5%	3.0%	1.4%	7.8%	3.2%	15.5%	0.0%	0.0%	1.1%	6.0%	0.7%	0.3%	0.1%
2035	40.5%	4.5%	3.6%	2.2%	22.1%	3.1%	13.9%	0.0%	0.0%	3.2%	5.5%	0.7%	0.5%	0.1%
2040	26.6%	2.8%	3.1%	2.5%	37.7%	2.7%	11.3%	0.0%	0.0%	6.6%	4.8%	0.7%	1.0%	0.2%
2045	17.2%	1.7%	2.5%	2.5%	48.4%	2.2%	8.4%	0.0%	0.0%	10.4%	4.0%	0.6%	1.6%	0.4%
2050	12.5%	1.1%	1.8%	2.3%	54.3%	1.9%	6.3%	0.0%	0.1%	13.2%	3.2%	0.5%	2.2%	0.6%

Table 2: Updated default fleet (% VKT by vehicle class) in VEPM 6.2

	Light duty vehicles <3.5tonnes										Heavy vehicles >3.5tonnes			
Year	Car petrol	Car diesel	Car hybrid	Car plug-in hybrid	Car electric	LCV petrol	LCV diesel	LCV hybrid	LCV plug-in	LCV electric	Diesel HCV	Diesel Buses	Electric HCV	Electric Buses
2001	72.5%	6.9%	0.0%	0.0%	0.0%	6.4%	7.9%	0.0%	0.0%	0.0%	5.9%	0.4%	0.0%	0.0%
2005	71.1%	7.9%	0.0%	0.0%	0.0%	5.0%	9.1%	0.0%	0.0%	0.0%	6.4%	0.5%	0.0%	0.0%
2010	70.2%	7.6%	0.2%	0.0%	0.0%	4.1%	11.0%	0.0%	0.0%	0.0%	6.3%	0.6%	0.0%	0.0%
2015	67.6%	7.8%	0.6%	0.0%	0.0%	3.5%	13.4%	0.0%	0.0%	0.0%	6.4%	0.6%	0.0%	0.0%
2020	63.3%	7.7%	2.1%	0.1%	0.3%	2.8%	16.5%	0.0%	0.0%	0.0%	6.4%	0.7%	0.0%	0.0%
2025	58.6%	7.4%	6.1%	0.5%	1.0%	2.7%	17.0%	0.0%	0.0%	0.1%	5.9%	0.7%	0.0%	0.0%
2030	52.7%	6.7%	10.0%	1.1%	2.8%	2.6%	17.0%	0.1%	0.1%	0.3%	5.7%	0.7%	0.1%	0.1%
2035	45.1%	5.5%	12.3%	1.8%	8.4%	2.6%	16.2%	0.2%	0.1%	1.4%	5.5%	0.7%	0.1%	0.1%
2040	34.5%	4.0%	11.2%	2.5%	20.7%	2.3%	14.3%	0.3%	0.2%	3.7%	5.2%	0.8%	0.2%	0.1%
2045	22.0%	2.7%	7.6%	2.8%	37.7%	2.0%	11.8%	0.2%	0.2%	6.8%	4.9%	0.8%	0.4%	0.2%
2050	14.0%	1.7%	4.1%	2.6%	50.2%	1.7%	9.5%	0.2%	0.2%	9.6%	4.5%	0.8%	0.6%	0.3%

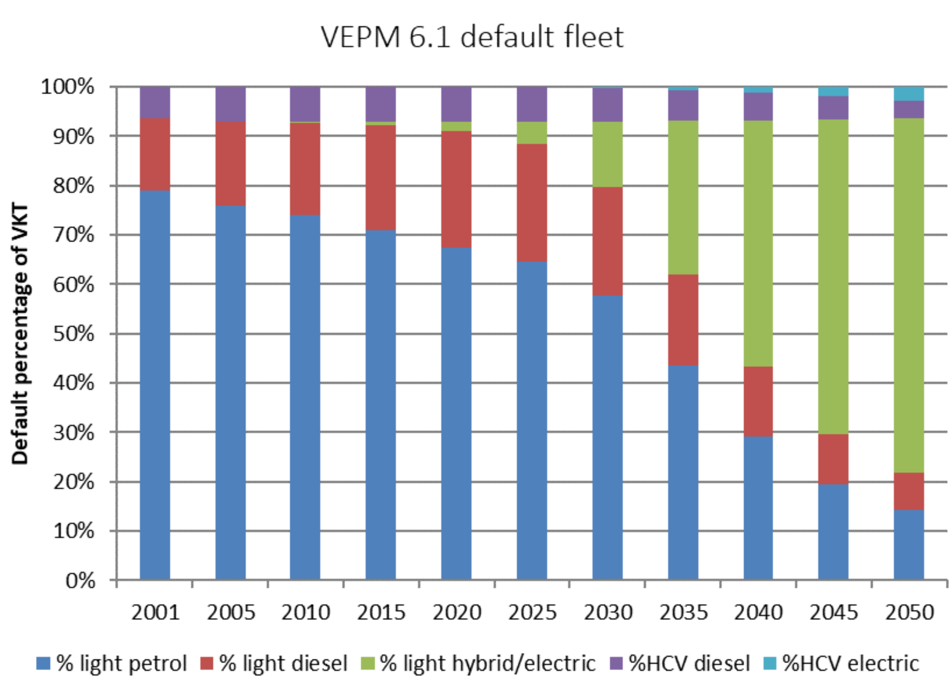

Figure 1: Default fleet (%VKT by vehicle class) in VEPM 6.1. Note that HCV includes buses

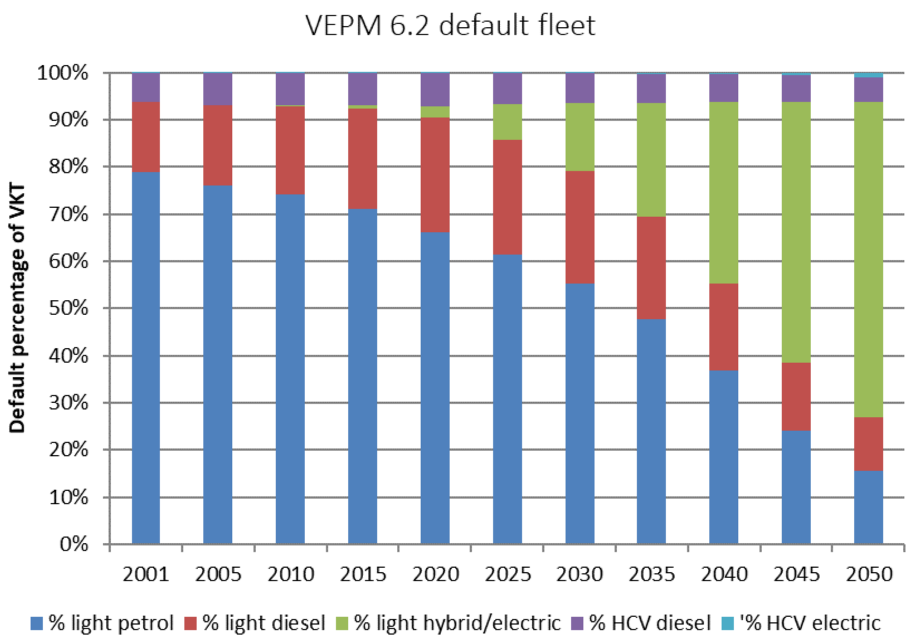

Figure 2: Default fleet (%VKT by vehicle class) in VEPM 6.2. Note that HCV includes buses

2.3 Euro 6/VI introduction dates

Previous versions of VEPM assumed a four-to-five-year delay in the introduction of European emission standards in New Zealand (Sridhar & Metcalfe, 2017). On this basis, it was assumed that all new vehicle imports from 2020 would meet Euro 6 and Euro VI standards.

However, as of June 2021, Euro 6 and Euro VI standards are yet to be adopted in New Zealand emissions regulations. MoT data show that some new vehicle imports are built to Euro 6 standards, however the vast majority are still Euro 5 (Figure 3).

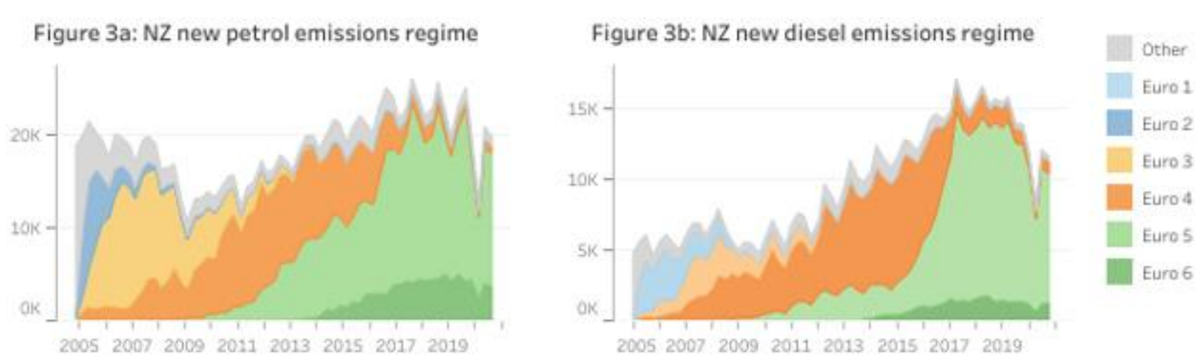

Figure 3: Emission standards of light registrations. Source: Ministry of Transport Quarterly Fleet Statistics, January to March 2021[3]

[3] https://www.transport.govt.nz/statistics-and-insights/fleet-statistics/quarterly-fleet-statistics/

At the time of writing, MoT have Cabinet approval to propose regulations for the implementation of Euro 6 and Euro VI emission standards. However, the time frames are not confirmed.

For this VEPM update, we assume that Euro 6 and Euro VI standards will be implemented in 2025 to the standard regulated in Europe five years earlier. The assumed dates of introduction for light and heavy vehicles are shown in Table 3 and Table 4, respectively.

VEPM assumes that the same emission standards apply to Japanese and European vehicles for the same year of manufacture for all years from 2010 onwards. Further work is recommended to investigate whether this assumption is still valid as a result of changes in the assumed date of introduction of Euro 6 and Euro VI vehicles in New Zealand.

Table 3: Assumed date of implementation of Euro 6 emissions standards in VEPM 6.2 for light duty vehicles (European implementation dates from Table 2.2 of EEA 2019)

Euro standard	**Date of implementation in Europe**	**Assumed date of introduction in VEPM for new vehicles**
Passenger vehicles		
Euro 6 a/b/c	2014-2019	N/A
Euro 6 d-temp	2019-2020	2025
Euro 6 d	2021+	>=2026
Light commercial vehicles		
Euro 6 a/b/c	2016 – 2017	N/A
Euro 6 d-temp	2018 - 2020	2025-2026
Euro 6 d	2021+	>=2027

Table 4: Assumed date of introduction of Euro VI emissions standards in VEPM 6.2 for heavy duty vehicles (European implementation dates from Table 2.2 of EEA 2019)

Euro Standard	**Date of implementation in Europe**	**Assumed date of introduction in VEPM for new vehicles**
Euro VI A/B/C	2013-2019	N/A
Euro VI D/E	2019+	=>2025

2.4 Rigid versus articulated trucks and trailers

Heavy commercial vehicle (HCV) VKT data from the MoT VFEM3 model is broken down by vehicle weight category according to the gross vehicle mass (GVM) of the powered unit (truck) only. The weight of any separately registered trailer unit/s is not included in the GVM, and there is no breakdown in VFEM3 to indicate whether vehicles have trailers or not.

Emission factors are provided in COPERT for rigid and articulated trucks separately. The articulated truck emission factors are based on the Gross Combined Mass (**GCM**) which is the combined mass of the truck and trailer(s).

To ensure that trailer travel is accounted for in VEPM, we estimated VKT undertaken by trucks towing a trailer based on road user charges (**RUC**) data. All VKT undertaken by trucks towing a trailer was assigned to an articulated truck category in VEPM. This means that the "articulated" truck category in VEPM includes articulated trucks as well as rigid trucks towing a trailer.

All remaining truck VKT was assigned to the rigid truck category in VEPM based on the GVM in VFEM.

The following sections describe the assumptions and methodology to estimate values for:

1. The overall proportion of VKT travelled by trucks towing a **trailer**
2. The proportion of VKT travelled by trucks towing a trailer that is taken from each GVM category in VFEM (with the remainder being assigned to the corresponding **rigid** truck category in VEPM)
3. The proportion of VKT for trucks towing a trailer from each GVM category in VFEM that is assigned to each **articulated** truck GCM category.

These estimates were used to split heavy vehicle VKT between rigid and articulated truck categories in VEPM as described in Section 2.4.4.

2.4.1 Overall proportion of VKT travelled by trucks towing a trailer

Estimated total VKT by trucks and trailers are published in the MoT annual fleet statistics (MoT 2020). These estimates are based on RUC data. MoT provided a more detailed breakdown of these truck and trailer VKT by RUC type for 2001 to 2018. These data were broken down by RUC types shown in Table 5.

Table 5: Truck and trailer types in road user charges (RUC) data

RUC type	Description
2, 6, 14, 19	Powered vehicles (i.e. trucks). For example, RUC type 14: 
29, 30, 33, 37, 43, 951	Unpowered vehicles (i.e. trailers). For example, RUC type 37: 
929, 939	Leading trailers. For example, RUC type 929: 

To estimate VKT by trucks towing a trailer, we assumed that:

- all trailer travel is undertaken by a truck towing a single trailer, except for leading trailers (RUC types 929 and 939), and
- leading trailers are always towed with another trailer.

On this basis, VKT of leading trailers (RUC type 929 and 939) was subtracted from total trailer VKT to derive the percentage of total truck VKT that is undertaken by trucks towing trailers as shown in Table 6.

In VEPM all trucks towing a trailer are assigned to the articulated truck category. This includes articulated trucks **and** rigid trucks towing trailers.

Table 6: Proportion of heavy duty VKT assigned to trucks towing a trailer derived from RUC data

Year	RUC Truck VKT (millions)	RUC Trailer VKT (millions)	RUC Leading Trailer VKT (millions)	RUC Trucks with Trailers VKT (millions)	**% of heavy duty VKT assigned to trucks towing a trailer**
2001	2,229	988	0	988	44%
2002	2,353	1,042	0	1042	44%
2003	2,436	1,078	0	1078	44%
2004	2,601	1,148	0	1148	44%
2005	2,652	1,146	0	1146	43%
2006	2,652	1,149	0	1149	43%
2007	2,753	1,185	0	1185	43%
2008	2,734	1,194	0	1194	44%
2009	2,591	1,098	0	1098	42%
2010	2,653	1,175	0	1175	44%
2011	2,675	1,222	0	1222	46%
2012	2,738	1,247	38	1209	44%
2013	2,665	1,238	94	1144	43%
2014	2,831	1,309	99	1210	43%
2015	2,787	1,275	100	1175	42%
2016	2,809	1,284	104	1180	42%
2017	2,982	1,383	119	1264	42%
2018	3,079	1,384	119	1265	41%

2.4.2 Proportion of VKT travelled by trucks towing a trailer assigned to each VEPM heavy duty GVM category

We used several data sources and assumptions estimate the proportion of VKT travelled by trucks towing a trailer in each GVM category.

Motor vehicle register

MoT provided a breakdown of truck VKT based on analysis of Motor Vehicle Register (**MVR**) data. The proportion of annual VKT undertaken by trucks with a 'Body type' variable of 'Articulated truck' was calculated by GVM category. This analysis included articulated trucks but did not include rigid trucks towing a trailer.

As seen in Figure 4, this approach shows that articulated trucks are predominantly in the 20-25 and 25-30 tonne GVM categories.

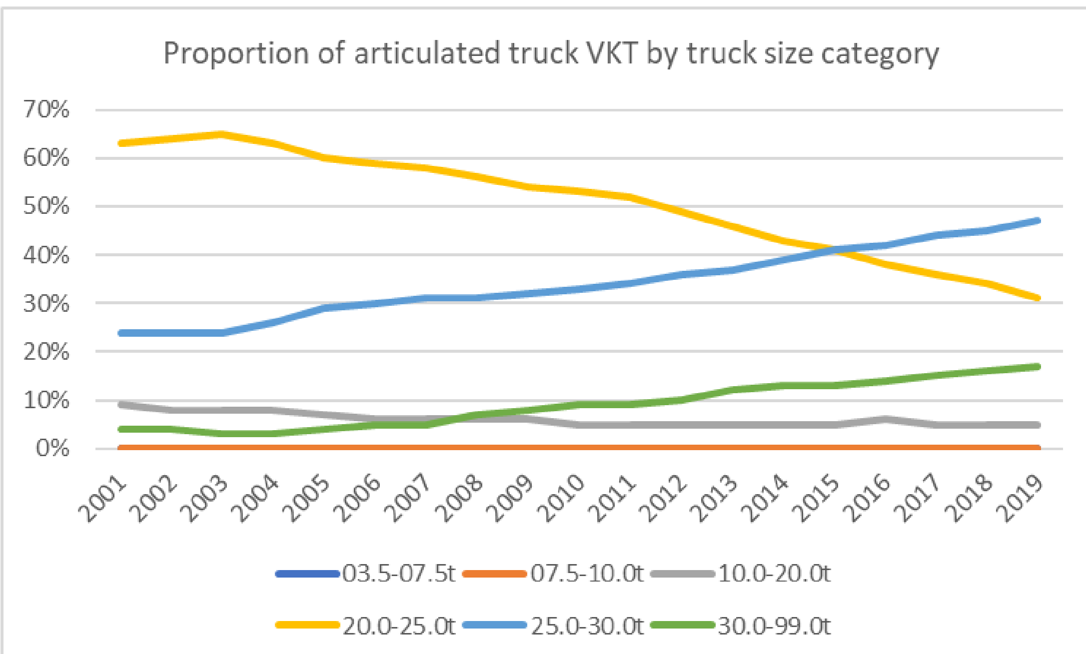

Figure 4: Proportion of articulated truck VKT by truck size category from the motor vehicle register. Source: Ministry of Transport

We tested a scenario where it was assumed that the proportion of VKT for trucks towing a trailer was assigned to (i.e. taken from) each VEPM heavy duty GVM category based on the proportions of articulated trucks from each category. However, the VKT in these categories was insufficient to account for all VKT by trucks towing a trailer.

Weigh in Motion

Waka Kotahi operates Weigh-in-Motion (**WiM**) sites on major state highways around the country. Annual WiM reports provide a range of statistics including vehicle mass. The vehicle mass includes fully laden, partly laden and empty vehicles so it isn't directly relevant to the estimation of gross vehicle mass.

However, the reports provide some useful insight. The 2017 WiM (Waka Kotahi, 2018) report estimates that rigid vehicles accounted for 40% of VKT, articulated vehicles 16%, truck and trailers 38% and A&B trains 6% of VKT.

Detailed analysis of WiM data undertaken for Waka Kotahi in 2012 (TERNZ 2012) estimated the average laden weight of trucks in the most common truck trailer combinations. This work found that the average weight of laden trucks in truck trailer combinations ranged from 17 tonne to 24 tonnes. On this basis, we consider it is reasonable to assume that truck trailer VKT is primarily from the 10-20, 20-25 and 25-30 tonne GVM categories.

To estimate the proportion of VKT travelled by trucks towing a trailer from each VFEM heavy duty GVM category, we assumed that:

- The proportion of VKT taken from >30 tonne trucks is the same as the proportion of articulated truck travel undertaken by >30 tonne trucks, based on analysis of MVR data (Figure 4). This increased from 4% in 2001 to 17% in 2019 and is assumed to remain at 17% for future years.
- The proportion of VKT taken from 7.5-10 tonne trucks is 1% for all years. This is based on the proportion of articulated truck travel undertaken by 7.5-10 tonne trucks from analysis of MVR data (Figure 4), which is less than 1%.
- The remaining 82% of VKT travelled by trucks towing a trailer is split between the 10-20, 20-25 and 25-30 tonne categories in proportion to the total VKT in each category.

The estimated annual proportions of VKT travelled by trucks towing a trailer taken from each VFEM heavy duty GVM category up to 2020 are shown in Table 7. The remaining VKT in each GVM category is assigned to the corresponding rigid truck category in VEPM.

Table 7: Estimated proportion of VKT travelled by trucks towing a trailer taken from each heavy duty GVM category

Year	% of trucks towing trailer VKT from each VEPM heavy duty GVM category					
	3.5-7.5t	7.5-10t	10-20t	20-25t	25-30t	>30t
2001	0%	1%	27%	38%	30%	4%
2002	0%	1%	26%	38%	31%	4%
2003	0%	1%	26%	39%	31%	3%
2004	0%	1%	26%	38%	32%	3%
2005	0%	1%	25%	38%	33%	4%
2006	0%	1%	24%	37%	33%	5%
2007	0%	1%	24%	37%	33%	5%
2008	0%	1%	23%	36%	33%	7%
2009	0%	1%	23%	34%	34%	8%
2010	0%	1%	23%	34%	34%	9%
2011	0%	1%	22%	34%	34%	9%

Year	% of trucks towing trailer VKT from each VEPM heavy duty GVM category					
	3.5-7.5t	7.5-10t	10-20t	20-25t	25-30t	>30t
2012	0%	1%	22%	32%	35%	10%
2013	0%	1%	22%	31%	34%	12%
2014	0%	1%	22%	30%	35%	13%
2015	0%	1%	22%	29%	35%	13%
2016	0%	1%	23%	27%	35%	14%
2017	0%	1%	22%	26%	36%	15%
2018	0%	1%	22%	25%	37%	16%
2019	0%	1%	21%	23%	38%	17%
2020	0%	1%	21%	22%	39%	17%

2.4.3 Proportion of VKT travelled by trucks towing a trailer from each GVM category that is assigned to each articulated truck GCM category

Analysis of EROAD data was commissioned to help understand the GCM of trucks towing a trailer and how this relates to the GVM of the truck. EROAD is the largest provider of electronic road user charges (RUC) compliance in New Zealand. As such, they have a large database of vehicle and trailer weight and associated GPS data. MoT has used EROAD data to develop real world fuel consumption factors for heavy duty vehicles in New Zealand and has found their data to be fairly representative of the NZ heavy truck fleet (Wang *et al* 2019).

EROAD used GPS data to match trailers with trucks. The GVM of the truck and the trailers was added to estimate the combined mass of truck and trailers associated with each truck GVM category. The results are shown in Table 8.

Table 8: Proportion of VKT associated with combined total mass of truck and trailer(s) by weight from 2019 EROAD data

Truck GVM	Proportion of VKT associated with combined total mass of truck and trailer(s) by weight						
	14-20t	20-28t	28-34t	34-40t	40-50t	50-60t	Grand Total
03.5-07.5t	2%	59%	14%	23%	2%	0%	100.0%
07.5-10.0t	1%	31%	27%	30%	11%	0%	100.0%
10.0-20.0t	0%	10%	58%	21%	7%	4%	100.0%
20.0-25.0t	0%	0%	0%	29%	48%	23%	100.0%
25.0-30.0t	0%	0%	0%	1%	33%	66%	100.0%
30.0-99.0t	0%	0%	0%	0%	0%	100%	100.0%
Grand Total	0%	0%	1%	9%	31%	59%	100.0%

These data suggest that most truck and trailer combinations have a gross combined mass over 50 tonnes. However, while the theoretical combined weight might be above 50 tonnes, it is likely that a significant proportion of vehicles are operationally limited to less than 50 tonnes due to legal weight limits.

Detailed analysis of WiM data undertaken for Waka Kotahi in 2012 (TERNZ 2012) estimated the average laden weight of the most common truck trailer combinations as between 40 and 47 tonnes.

Figure 5 shows that approximately 3% of vehicles at WIM stations in 2017 were heavier than 50 tonnes (Waka Kotahi 2018). This size class has increased from virtually zero in 2012, due to changes in legislation. Weigh in motion data include fully laden, partly laden and empty vehicles so the proportion of vehicles with a GCM above 50 tonnes would be expected to be significantly higher than the proportion in the WiM data. If we assume that vehicles are only fully laden half of the time then around 6% of the heavy duty fleet could have a GCM above 50 tonnes.

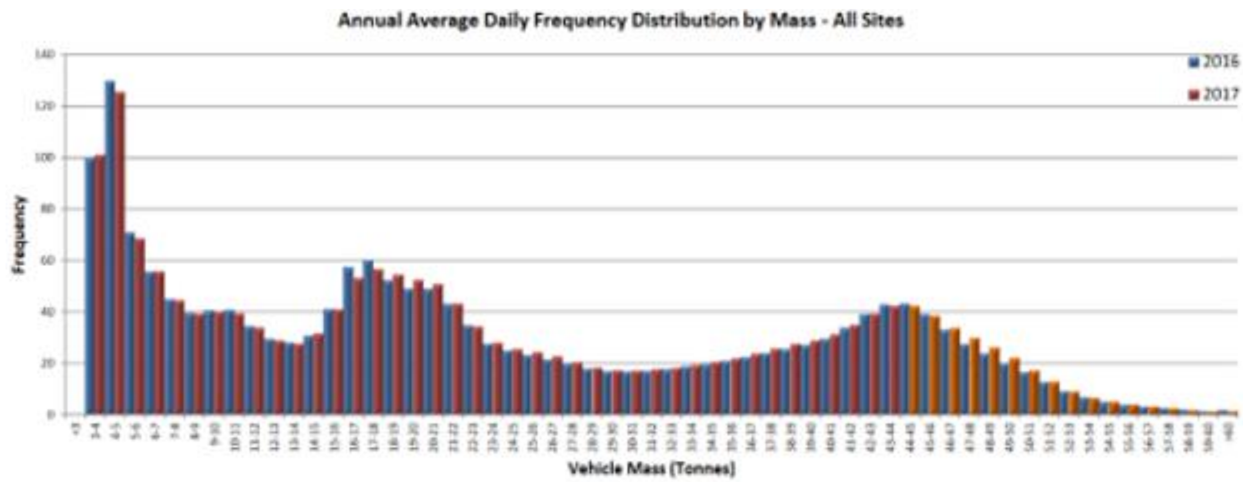

Figure 5: Waka Kotahi WiM data showing frequency distribution by measured vehicle mass across all monitoring sites. Source: Chart 12 from Waka Kotahi (2018).

To estimate the proportion of VKT for trucks towing a trailer assigned to each articulated truck GCM category, we adjusted EROAD data (as shown in Table 8) as follows:

- To account for possible over-estimation of the proportion of vehicle in the 50-60 tonne category, half of the vehicles with a GCM above 50 tonnes in the EROAD data (as shown in Table 8) are assigned to the 40-50 tonne category from 2019 onwards. This assumption results in an overall proportion of heavy duty VKT from trucks on the 50-60 tonne category of around 10% in 2019, which seems reasonable compared with the weigh in motion data.
- For all years up to 2012, it is assumed that there are no trucks greater than 50 tonnes
- It is assumed that all of the 7.5 to 10 tonne GVM trucks are allocated to the 14 to 20 tonne GCM category to simplify the allocation. This is reasonable because this category accounts for just 1% of VKT for trucks towing a trailer.

The assumed proportion of VKT for trucks towing a trailer that is assigned from each GVM category to each articulated truck GCM category is shown in Table 9 for all years from 2019 and in Table 10 for all years up to 2012. Between 2012 and 2019 the values are interpolated.

Table 9: Assumed proportion of VKT for trucks towing a trailer from each GVM category that is assigned to each articulated truck GCM category for 2019 and onwards

Truck GVM	Assumed proportion of VKT for trucks towing a trailer that is assigned to each articulated truck GCM category						
	14-20t	20-28t	28-34t	34-40t	40-50t	50-60t	Grand Total
03.5-07.5t	0%	0%	0%	0%	0%	0%	0%
07.5-10.0t	100%	0%	0%	0%	0%	0%	100.0%
10.0-20.0t	0%	10%	58%	21%	9%	2%	100.0%
20.0-25.0t	0%	0%	0%	29%	60%	12%	100.0%
25.0-30.0t	0%	0%	0%	1%	66%	34%	100.0%
30.0-99.0t	0%	0%	0%	0%	50%	50%	100.0%

Table 10: Assumed proportion of VKT for trucks towing a trailer from each GVM category that is assigned to each articulated truck GCM category up to and including 2012

Truck GVM	Assumed proportion of VKT for trucks towing a trailer that is assigned to each articulated truck GCM category						
	14-20t	20-28t	28-34t	34-40t	40-50t	50-60t	Grand Total
03.5-07.5t	0%	0%	0%	0%	0%	0%	0%
07.5-10.0t	100%	0%	0%	0%	0%	0%	100.0%
10.0-20.0t	0%	10%	58%	21%	11%	0%	100.0%
20.0-25.0t	0%	0%	0%	29%	72%	0%	100.0%
25.0-30.0t	0%	0%	0%	1%	99%	0%	100.0%
30.0-99.0t	0%	0%	0%	0%	100%	0%	100.0%

2.4.4 Overall method to split heavy duty VKT in VEPM between rigid and articulated truck categories

This section describes how the assumptions described in previous sections are applied in VEPM to split VKT between rigid and articulated truck categories.

To account for trailer travel in VEPM the total VKT that is undertaken by trucks towing a trailer is estimated based on the overall proportion of VKT travelled by trucks towing a trailer (from Section 2.4.1) as follows:

$$VKT_{TTT} = VKT \times P_{TTT} \quad \text{Equation 1}$$

Where:

VKT_{TTT}= VKT for trucks towing a trailer – total across all vehicle size categories

VKT = VKT for heavy duty vehicles (from VFEM3) – total across all vehicle size categories

P_{TTT} = the proportion of heavy duty vehicle travel that is undertaken by trucks towing a trailer (shown in Table 6 in Section 2.4.1).

The VKT that is assigned to trucks towing a trailer **from each GVM category** is then estimated (with the remainder being assigned to the corresponding rigid truck category in VEPM), based on the proportions from Section 2.4.2 as follows:

$$VKT_{TTT,GVM} = VKT_{TTT} \times P_{TTT,GVM} \quad \text{Equation 2}$$

Where:

$VKT_{TTT,GVM}$ = VKT that are assigned to trucks towing trailer(s) from the GVM category

VKT_{TTT} is the total VKT for heavy duty vehicles heavy duty trucks towing trailer(s) (Equation 1)

$P_{TTT,GVM}$ is the proportion of VKT for trucks towing trailers that is taken from each GVM category (shown in Table 7 in Section 2.4.2)

VKT is then assigned to articulated truck categories in VEPM based on the estimated gross combined mass of the truck and trailer(s) as follows based on the proportions estimated in Section 0 as follows:

$$VKT_{ARTIC,GCM} = \sum_{GVM} VKT_{TTT,GVM} \times P_{ARTIC,GCM,GVM} \quad \text{Equation 3}$$

Where:

$VKT_{ARTIC,GCM}$ is the VKT for each articulated truck GCM category in VEPM

$VKT_{TTT,GVM}$ is the VKT for trucks towing trailer(s) in each GVM category

$P_{ARTIC,GCM,GVM}$ is the proportion of VKT for trucks towing a trailer from each GVM category that is assigned to each articulated truck GCM category (as described in Section 0).

The remaining heavy vehicle VKT for each GVM size category is allocated to the corresponding rigid truck category in VEPM as follows:

$$VKT_{RIGID,GVM} = VKT_{GVM} - VKT_{TTT,GVM} \quad \text{Equation 4}$$

Where:

$VKT_{RIGID,GVM}$ = VKT for rigid heavy duty vehicles in the GVM category

VKT_{GVM} = total VKT for heavy duty vehicles in the GVM category (from VFEM3)

$VKT_{TTT,GVM}$ = VKT that are assigned to trucks towing trailer(s) from the GVM category (Equation 2)

2.5 Emission factors

Changes to emission factors in VEPM 6.2 include:

- CH_4, N_2O and CO_2-e emission factors have been added to VEPM 6.2.
- Light duty CO and NO_X degradation factors have been updated in VEPM 6.2. A review of degradation factors (EMM 2020) concluded that the factors in VEPM 6.1 were outdated.
- The default assumption for the percentage of catalytic converters removed from old vehicles has been changed from 15% to 0%, due to a lack of supporting data.
- Light duty vehicle gradient correction factors in VEPM 6.1 were based on an old version of PIARC guidance. These factors have been updated based on the latest version (PIARC 2019).

Appendix 1 summarises the sources of emission factors and correction factors in VEPM 6.1 and VEPM 6.2. The source of emission factors and correction factors in VEPM 6.1 was described fully in previous technical reports (EFRU 2008, EFRU 2011, Sridhar & Metcalfe 2017, Sridhar & Metcalfe 2019, Metcalfe & Peeters 2020).

In VEPM 6.2, **all hot emission factors for all vehicle classes are consistent with COPERT emission factors,** which are published in the latest version of the EMEP/EEA guidebook (EEA 2019, EEA 2020).

2.5.1 CH_4, N_2O and CO_2-e emission factors

CH_4 and N_2O emission factors have been added to VEPM 6.2. These emission factors enable subsequent calculation of CO_2-e emission factors.

Emission factors are calculated based on the methodology described in the EEA guidebook (EEA 2019).

Hot emission factors CH_4 and N_2O

The EEA guidebook provides CH_4 and N_2O factors for urban, rural and highway road classes (unlike other emission factors, which are calculated based on average speed). Emission factors are assigned in VEPM based on the speeds that are considered representative for each EEA road class as shown in Table 11.

Table 11: Assumed road classes for assigning CH_4 and N_2O emission factors based on speed

Min Speed (km/h)	Max Speed (km/h)	Assumed road class
0	54	Urban Peak
55	79	Rural
80	140	Highway

Cold start penalty factors CH_4 and N_20

The calculation of cold start emission factors for all pollutants in VEPM is based on the methodology described in the EEA guidebook as follows:

$$E_{cold} = \beta \times e_{hot} \times (\rho - 1) \qquad \text{Equation 5}$$

Where:

E_{cold} is the cold start penalty factor which is added to the hot emission factor if cold start is applied

β is the fraction of mileage driven under cold start conditions

E_{hot} is the hot running emission factor

ρ is the ratio of cold start to hot running emissions (e_{cold}/e_{hot})

The EEA guidebook provides hot and cold emission factors for N_20 and CH_4 (unlike other emission factors, where the ρ ratio is provided). Equation 5 is rearranged for calculation of N_20 and CH_4 cold start penalty in VEPM as follows:

$$E_{cold} = \beta \times e_{hot} \times \left(\frac{e_{cold}}{e_{hot}} - 1\right) \qquad \text{Equation 6}$$

So:

$$E_{cold} = \beta \times (e_{cold} - e_{hot}) \qquad \text{Equation 7}$$

Adjustment factors N_2O

N_2O emissions are particularly important for vehicles equipped with catalysts and are dependent on catalyst temperature and aging. Furthermore, catalyst aging is dependent on fuel sulphur level. The EEA guidebook provides parameters to calculate N_2O emission factors for light duty vehicles based on cumulative mileage and fuel sulphur content as follows:

$$EF_{N2O} = [a \times Mileage + b] \times EF_{base}$$ Equation 8

Where:

EF_{N2O} is the N_2O emission factor

a and b are parameters defined in the EEA guidebook by vehicle category, emission standard and fuel sulphur content

EF_{base} is the base emission factor from the EEA guidebook for the vehicle category, emission standard and fuel sulphur content

Mileage is the mean mileage of the vehicle class

Equation 8 is used to calculate N_2O emission factors for each light duty vehicle category in VEPM based on the average cumulative mileage for each vehicle class at the assessment year[4] and the fuel sulphur content at the assessment year.

Additional assumptions for calculation of N_2O emission factors in VEPM 6.2 are as follows:

- The fuel correction factor, degradation correction factor and gradient correction factor are all assumed to be 1 (i.e. no additional corrections are applied to the estimated emission factor) for all vehicle classes
- Japanese vehicle emission standard equivalencies are assumed to be the same as those for NO_X equivalencies.

Adjustment factors CH_4

Additional assumptions for calculation of CH_4 emission factors in VEPM 6.2 are as follows:

- The fuel correction factor and degradation correction factor are assumed to be the same as the VOC correction factors
- For heavy duty vehicles a gradient correction factor is derived from the hot emission factor for VOC at the corresponding gradient divided by the hot emission factor for VOC at zero percent gradient for each vehicle class.
- No gradient correction factor is applied to light duty emission factors (this is consistent with the assumption for VOC).
- Japanese vehicle emission standard equivalencies are assumed to be the same as those for VOC equivalencies.

Calculation of CO_2-e

CO_2-equivalent (CO_2-e) emission factors are calculated in VEPM 6.2 as follows:

$$CO_{2-e} = CO_2 + (298 \times N_2O) + (25 \times CH_4)$$ Equation 9

[4] Cumulative mileage is estimated in VEPM based on vehicle age for calculation of degradation factors.

Equation 9 is based on global warming potentials used by Ministry for the Environment, which are from the IPCC Fourth Assessment Report (MfE 2020).

CO_2, CH_4 and N_2O emission factors are shown in the *VEPM* worksheet and the *Fleet Emission Factors* worksheet. However, the *Bulk Run Output* sheet shows only CO_2-e factors to keep the worksheet manageable in size.

2.5.2 Degradation factors

Light duty CO and NO_X degradation factors have been updated in VEPM 6.2 based on the European CONOX report (Carslaw *et al* 2019).

The updated degradation factors and the effect of the updated factors on emission factors are described in this section. These updates are intended as an interim measure until better information becomes available. Further work to improve degradation factors is recommended as described in Section 3.

Degradation factors are applied in VEPM as described in EFRU (2008), as follows:

$$s(m) = s(m = 0) + m \times \left(\frac{\delta s}{\delta m}\right) \qquad \text{Equation 10}$$

Where:

s(m) is the degradation factor (s) at mileage (m)

s(m=0) is the degradation factor of a brand new vehicle (zero mileage)

m is the mean mileage of the vehicle class up to a maximum stabilisation mileage, where it is assumed that no further degradation occurs

δs/δm is the degradation rate

As described in Appendix 3, the CONOX report (Carslaw *et al* 2019) proposes CO and NO_X degradation factors at 50,000 km, 100,000 km and 200,000 km based on the results of remote sensing in Europe. The updated degradation factors applied in VEPM 6.2 are shown in **Error! Reference source not found.**. These are based on the following assumptions:

- A linear rate of degradation between 0 km and 200,000 km.
- Euro 5 degradation rates apply to Euro 6 vehicles
- All updated factors are from the CONOX report (summarised in Appendix 3) except for Euro 1 and Euro 2 diesel vehicles, which are taken from Chen & Borken-Kleenfeld (2016) as quoted in the CONOX report
- All other degradation factors in VEPM 6.2 are unchanged from VEPM 6.1.

Table 12: Updated degradation factors assumed in VEPM 6.2

Vehicle class	Emission standard	Degradation factor at 50,000 km		Stabilised degradation factor at 200,000 km	
		CO	NO_X	CO	NO_X
Petrol Car	Euro 3	1	1	2	2.9
	Euro 4	1	1	2	2
	Euro 5	1	1	2	2.5
	Euro 6	1	1	2	2.5
Diesel car	Euro 1	1	1	1	1
	Euro 2	1	1	1	1.25
	Euro 3	1	1	1	1.2
	Euro 4	1	1	1.3	1.06
	Euro 5	1	1	1.3	1.03
	Euro 6	1	1	1.3	1.03

The degradation rate is calculated from the stabilised degradation factor assuming that the degradation rate is 1 at 50,000km and stabilised at 200,000 km as follows:

$$\left(\frac{\delta s}{\delta m}\right) = \frac{s(200{,}000) - s(50{,}000)}{200{,}000 - 50{,}000}$$ Equation 11

The degradation factor at 50,000 km is 1. This means that the degradation factor at 0 km is less than 1 and is calculated as follows:

$$s(m = 0) = 1 - \left(\frac{\delta s}{\delta m}\right) \times 50{,}000$$ Equation 12

For example, for Euro 3 petrol cars, the NO_X degradation rate at 200,000 km is 2.9 so the degradation rate is calculated as follows:

$$\left(\frac{\delta s}{\delta m}\right) = \frac{2.9 - 1}{150000} = 1.27 \times 10^{-5}$$

And the degradation factor at 0 km is calculated as follows

$$s(m = 0) = 1 - (1.27 \times 10^{-5}) \times 50{,}000 = 0.367$$

Effect of updated light duty CO and NO_X degradation factors.

For petrol vehicles, the updated degradation factors (from Carslaw *et a*l 2019) are higher than the degradation factors previously assumed in VEPM 6.1. However, for diesel vehicles, the updated degradation factors (from Carslaw *et al* 2019) are lower than the degradation factors previously assumed in VEPM 6.1.

Table 14 shows the percentage difference in fleet-weighted emission factors from VEPM 6.2 incorporating updated degradation factors compared with VEPM 6.2 incorporating the original VEPM 6.1 degradation factors. To calculate the effect of the updated factors, VEPM 6.2 was run for 2020 at 50 km/hour with all settings at default.

As shown in Table 13, the overall effect of the updated CO and NO_X degradation factors is to increase fleet-weighted CO emissions by around 3% and decrease fleet-weighted NO_X emissions by around 9%. The effect of the updated degradation factors for each vehicle class is summarised in Table 14.

Table 13: Effect of changes to CO and NO_X degradation factors on fleet-weighted emission factors based on VEPM 6.2 emission factors at 50 km/hour for 2020 with all settings at default.

	% Difference in fleet-weighted emission factors with updated degradation factors*	
	CO	**NO_X**
Fleet-weighted	+3%	-9%
Petrol car	+5%	+13%
Diesel car	-30%	-27%
Petrol LCV	+5%	+4%
Diesel LCV	-27%	-26%

* percentage difference calculated as (updated factor – original factor)/original factor

2.5.3 Catalytic converter removal

For the VEPM 6.2 update, we have changed the default assumption for the % of catalysts not working (on old petrol vehicles) to zero. This is because there is little data to support the previous VEPM 6.1 assumption of 15% (as discussed in Section 3). In addition, the light duty degradation factors for CO and NO_X emissions from petrol vehicles have now been updated based on remote sensing data so these factors will incorporate the effects of any tampering or emission control equipment failure, at least in the European fleet.

Further work is recommended to investigate whether New Zealand remote sensing and other emission test results could be used to understand the effects of degradation and tampering in the New Zealand fleet. This is discussed further in Section 3.

2.5.4 Gradient correction factors

Heavy duty vehicle gradient corrections in VEPM are based on adjustment factors from the EMEP/EEA guidebook (EEA 2019 and EEA 2020). No changes were made to heavy duty vehicle gradient correction factors in VEPM 6.2.

Light duty vehicle gradient correction factors in VEPM are derived from PIARC guidance because correction factors are not included in the EMEP/EEA guidebook (EEA 2019). Gradient adjustment factors were developed for VEPM in 2012 (EFRU 2012) based on 2004 PIARC guidance. However, updated guidance is now available (PIARC 2019).

VEPM 6.2 updates

Light duty gradient correction factors have been updated to reflect the latest version of PIARC guidance (PIARC 2019) in this VEPM 6.2 update.

Gradient factors for light duty vehicles are derived from PIARC emission factors (PIARC 2019[5]) for three pollutants: CO, NO_X and PM. There is a PIARC emission factor for each European emissions standard, for 0, ±2, ±4 and ±6% gradient, based on speed but with no discrimination for engine size. PIARC tabulates the factors by speed, with the emissions factors expressed in grams per hour. There is a separate table for each combination of vehicle class, fuel type and pollutant. For example, Table 14 shows CO emission factors for Euro 3 petrol cars.

Table 14: PIARC CO emission factors for Euro 3 petrol cars in g/km, for speeds from 0 to 130 km/hr (PIARC 2019)

Gradient	Speed (km/hour)													
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**
-6%	1	5	9	4	4	4	4	7	4	6	10	15	24	42
-4%	1	5	13	7	7	7	6	11	6	9	16	29	52	91
-2%	1	7	19	9	10	10	9	14	12	17	33	57	89	148
0%	1	9	25	13	17	15	21	25	32	44	61	104	157	300
2%	1	12	47	22	30	24	36	46	63	100	133	234	416	885
4%	1	15	68	35	48	38	55	97	130	211	281	620	1317	2399
6%	1	18	103	51	79	65	90	161	271	466	730	1599	2742	3431

Emission ratios from these tables were used to develop gradient adjustment factors. The emission ratio for a particular gradient and speed is the ratio of the emission factor for that gradient and speed divided by the corresponding 0% gradient emission factor at the same speed. For example, Table 15 shows the CO emission ratios for Euro 3 petrol cars.

[5] At section 11.1.2 pages 38 to 56 of PIARC 2019

Table 15: CO emission ratios relative to 0% gradient for Euro 3 petrol cars, from 0 to 130 km/hr

Gradient	Speed (km/hour)													
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**
-6%	1.00	0.50	0.34	0.33	0.25	0.26	0.19	0.26	0.13	0.14	0.16	0.14	0.15	0.14
-4%	1.00	0.58	0.50	0.50	0.39	0.46	0.29	0.43	0.19	0.21	0.26	0.28	0.33	0.30
-2%	1.00	0.74	0.73	0.69	0.60	0.69	0.41	0.57	0.36	0.38	0.54	0.55	0.57	0.49
0%	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2%	1.00	1.24	1.84	1.71	1.78	1.59	1.70	1.84	1.95	2.30	2.19	2.26	2.65	2.95
4%	1.00	1.59	2.68	2.69	2.84	2.53	2.60	3.86	4.01	4.86	4.62	5.98	8.40	7.99
6%	1.00	1.97	4.06	3.89	4.68	4.33	4.30	6.42	8.38	10.71	12.02	15.43	17.48	11.42

These emission ratios, for each of the non-zero gradients, were then plotted and fitted with 4th degree polynomials to enable interpolation between the discrete speeds. For example, Figure 6 shows the fitted polynomial curve for CO emissions from Euro 3 petrol cars.

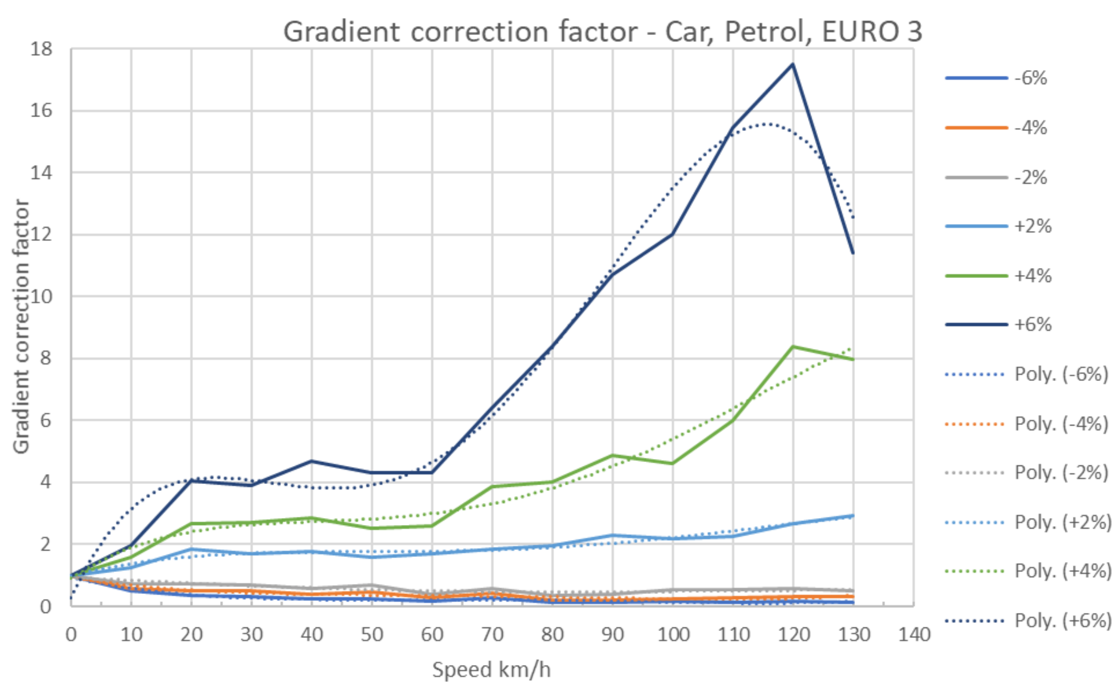

Figure 6: Fitted polynomial curves to derive gradient correction factors for CO from Euro 3 petrol cars

These equations are used in VEPM to calculate gradient correction factors based on actual speed and gradient. The gradient correction factors are applied as a multiplier to scale hot emission factors.

Japanese vehicle emission standard equivalencies for gradient adjustment factors are assumed to be the same as hot emission factor equivalencies.

3. Investigations

This section summarises investigations into fuel quality adjustment factors, biofuel adjustment factors, the treatment of vehicle emissions control equipment tampering in VEPM, degradation factors and real-world fuel consumption adjustment factors.

Apart from updates to light duty CO and NO_X degradation factors (described in Section 2), no changes have been made in VEPM 6.2 as a result of these investigations, however further work is recommended.

3.1 Fuel quality factors

3.1.1 Current situation

Emission factors in VEPM are based on measurements from in-service vehicles operating with typical production fuels. Studies have shown that changes in fuel properties result in changes in emissions from vehicles, regardless of their technology and make.

Fuel effects are modelled in VEPM to account for:

- Differences in fuel specifications for fuel available in New Zealand versus base or reference fuels used in the emissions testing
- Introduction of new and improved specification fuels.

VEPM uses algorithms developed from the European Programme on Emissions, Fuels and Engine Technologies (**EPEFE**) data, which generate fuel correction factors to compensate for fuel effects. Only **hot emission factors** are adjusted for fuel effects.

The base emissions factor (E_{base}) is adjusted by the ratio of the fuel correction factor of the actual fuel ($FCorr_{actual}$) to the fuel correction factor of the base fuel ($FCorr_{base}$) as shown below:

$$E_{hot} = E_{base} \times \left(\frac{FCorr_{actual}}{FCorr_{base}}\right) = E_{base} \times FCorr$$ Equation 13

Where:

E_{hot} is the base emissions factors after fuel correction

E_{base} is the base emission factor (essentially E_{hot} without fuel corrections applied)

$FCorr_{actual}$ is the fuel correction of the actual fuel

$FCorr_{base}$ is the fuel correction of the base fuel

FCorr is the fuel correction factor

Table 16, Table 17 and Table 18 outline the fuel correction factors applied to different passenger cars, light commercial vehicles and heavy duty diesel vehicles used in COPERT (EEA 2019).

Table 16: Fuel correction factors for petrol passenger cars and light duty commercial vehicles

Pollutant	Correction factor equation
CO	FCorr = [2.459 – 0.05513 x (E100) + 0.0005343 x $(E100)^2$ + 0.009226 x (ARO)-0.0003101 x (97-S)] x [1-0.037 x (OXY – 1.75)] x [1-0.008 x (E150 – 90.2)]
HC	FCorr = [0.1347 + 0.0005489 x (ARO) + 25.7 x (ARO) x $e^{(-0.2642\ (E100))}$ – 0.0000406 x (97-S)] x [1-0.004 x (OLE – 4.97)] x [1-0.022 x (OXY – 1.75)] x [1-0.01 x (E150 – 90.2)]
NO_X	FCorr = [0.1884 – 0.001438 x (ARO) + 0.00001959 x (ARO) x (E100) – 0.00005302 x (97 – S)] x [1+0.004 x (OLE – 4.97)] x [1+0.001 x (OXY – 1.75)] x [1+0.008 x (E150 – 90.2)]
PM CO_2 FC	FCorr = 1

Note: ARO = aromatic content in %, E100 = mid range volatility in %, E150 = tail end volatility in %, OLE = olefin content in %, OXY = oxygenates in %, S = sulphur content in ppm

Table 17: Fuel correction factors for diesel passenger cars and light duty commercial vehicles

Pollutant	Correction factor equation
CO	FCorr=-1.3250726 + 0.003037 x DEN – 0.0025643 x PAH – 0.015856 x CN + 0.0001706 x T95
HC	FCorr =-0.293192 + 0.0006759 x DEN – 0.0007306 x PAH – 0.0032733 x CN – 0.000038 x T95
NO_X	FCorr = 1.0039726 – 0.0003113 x DEN + 0.0027263 x PAH – 0.0000883 x CN – 0.0005805 x T95
PM	FCorr = (-0.3879873 + 0.0004677 x DEN + 0.0004488 x PAH + 0.0004098 x CN + 0.0000788 x T95) x [1 – 0.015 x (450 – S)/100]
CO_2 FC	FCorr = 1

Note: CN = cetane number, DEN = density at 15°C in kg/m^3, PAH = polycyclic aromatic hydrocarbon content in %, S = sulphur content in ppm, T95 = back end distillation in °C

Table 18: Fuel correction factors for diesel heavy duty commercial vehicles

Pollutant	Correction factor equation
CO	FCorr = 2.24407 – 0.0011 x DEN + 0.00007 x PAH – 0.00768 x CN – 0.00087 x T95
HC	FCorr = 1.61466 – 0.00123 x DEN + 0.00133 x PAH – 0.00181 x CN – 0.00068 x T95
NO_X	FCorr = -1.75444 + 0.00906 x DEN – 0.0163 x PAH + 0.00493 x CN + 0.00266 x T95
PM	FCorr = [0.06959 + 0.00006 x DEN + 0.00065 x PAH – 0.00001 x CN] x [1-0.0086 x (450 – S)/100]
CO_2 FC	FCorr = 1

Note: CN = cetane number, DEN = density at 15°C in kg/m^3, PAH = polycyclic aromatic hydrocarbon content in %, S = sulphur content in ppm, T95 = back end distillation in °C

VEPM currently utilises the fuel properties shown in Table 19 and Table 20 **based on the fuel specifications in the regulations** at the time to calculate the fuel correction factors.

The resultant fuel correction factors **are applied equally to all vehicles in the fleet**, irrespective of their technology, based on the year assessed in VEPM.

Table 19: Properties of petrol fuel in VEPM, based on fuel specifications

Type	Description	Sulphur (ppm)	Aromatics (% by vol)	Oxygenates (% by wt)	Olefins (% by vol)	E100 (%)	E150 (%)
0	Base fuel	165	39	0.4	10	52	86
1	Pre-Sep 2002	500	48	0.1	8.2	56	89
2	Sep 2002-Dec 2003	350	42	1	8.2	57.5	89
3	Jan 2004-Dec 2005	350	42	1	25	57.5	75
4	Jan 2006-Dec 2007	150	42	1	18	57.5	75
5	Jan 2008–Dec 2011	50	42	1	18	57.5	75
6	Jan 2012-Jun 2018	50	42	2.7	18	57.5	75
7	Jul 2018 onwards	10	42	2.7	18	57.5	75

Table 20: Properties of diesel fuel in VEPM, based on fuel specifications

Type	Description	Sulphur (ppm)	Density (kg/m^3)	PAHs (% by wt)	Cetane Number	T95 (°C)
0	Base fuel	400	840	9	51	350
1	Pre-Sep 2002	3000	835	11	45	370
2	Sep 2002-Dec 2003	1561	840	11	47	370
3	Jan 2004-Dec 2005	500	835	11	49	370
4	Jan 2006-Dec 2008	50	835	11	51	360
5	Jan 2009 onwards	10	835	11	51	360

3.1.2 Future developments

Effect of actual versus specification fuel properties

Smit *et al* (2021) note in their report that the actual fuel properties can differ appreciably from the fuel specifications and thereby influence the fuel correction factors. In response, we undertook a preliminary assessment of the potential impact of actual fuel properties versus fuel specification properties using fuel quality monitoring reports from 2011 onwards (Trading Standards NZ 2021).

Table 21 compares the correction factors used in VEPM (based on fuel specifications) for assessment years from 2009 onwards with those that would be applied using actual fuel properties (averaged from fuel quality monitoring reports between 2011 and 2019).

Table 21: Comparison of the fuel correction factors based on actual or specification data for different vehicle types from 2009 onwards

Type	Description	CO	CO_2	HC	NO_X	PM	FC
Light duty petrol	*VEPM fuel specifications (2012-2017)*	*1.00*	*1*	*0.99*	*0.92*	*1*	*1*
	Actual fuel properties (2011-2017)	0.84	1	0.87	1.00	1	1
	VEPM fuel specifications (2018-)	*1.00*	*1*	*0.98*	*0.91*	*1*	*1*
	Actual fuel properties (2018-2019)	0.85	1	0.89	0.98	1	1
Light duty diesel	*VEPM fuel specifications (2009-)*	*0.96*	*1*	*0.94*	*1.00*	*0.93*	*1*
	Actual fuel properties (2011-2019)	0.84	1	0.84	0.97	0.90	1
Heavy duty diesel	*VEPM fuel specifications (2009-)*	*1.00*	*1*	*1.01*	*0.99*	*0.97*	*1*
	Actual fuel properties (2011-2019)	0.94	1	0.94	1.02	0.93	1

The results suggest that using actual fuel properties would slightly reduce hot emissions factors for CO, HC and PM for petrol and diesel vehicles and slightly increase NO_X. Changing the fuel corrections from being based on specifications to actuals would require accessing earlier fuel quality monitoring data (we have a request pending) and also agreeing on how future years would be handled.

The impact on predicted emissions factors of using actual fuel quality monitoring data to develop the fuel correction factors warrants further investigation.

Application of the fuel correction factors

As mentioned, VEPM currently applies the fuel correction factors to hot emissions only equally across the fleet, irrespective of technology. In addition, the fuel correction factors are developed relative to the base type 0 fuels (applicable in 1996).

The latest EMEP/EEA guide (EEA 2019) suggests applying improvements to **both hot and cold-start emissions**. In addition, it recommends applying improved fuel qualities according to the **phasing in of the various vehicle technologies** as shown in Table 22 for Europe.

Based on the introduction dates for improved fuels and vehicle technology in New Zealand, the equivalent phasing for VEPM would be as shown Table 23 (for petrol) and Table 24 (for diesel). The fuel correction factors would then be calculated relative to the applicable base fuel for the vehicle technology and not just the base type 0 fuels.

We recommend updating the application of fuel correction factors to reflect EMEP/EEA guidance in the next VEPM update.

Table 22: Base fuels used to correct fuel quality for each vehicle technology class in Europe

Vehicle Technology	Base Fuel	Available Improved Fuel Qualities
Pre-Euro 3	1996 base fuel	Fuel 2000, Fuel 2005
Euro 3	Fuel 2000	Fuel 2005
Euro 4	Fuel 2005	Fuel 2009
Euro 5 and later	Fuel 2009	-

Table 23: Proposed base fuels used to correct petrol fuel quality for each vehicle technology class in VEPM

Vehicle Technology	Base Fuel	Available Improved Fuel Qualities (from Table 19)
Pre-Euro 3	Base (petrol type 0)	Petrol types 1-7
Euro 3	Jan 2006 (petrol type 4)	Petrol types 5-7
Euro 4	Jan 2012 (petrol type 6)	Petrol type 7
Euro 5 and later	Jul 2018 (petrol type 7)	-

Table 24: Proposed base fuels used to correct diesel fuel quality for each vehicle technology class in VEPM

Vehicle Technology	Base Fuel	Available Improved Fuel Qualities (from Table 20)
Pre-Euro 3	Base (diesel type 0)	Diesel types 1-5
Euro 3	Jan 2004 (diesel type 3)	Diesel types 4-5
Euro 4	Jan 2006 (diesel type 4)	Diesel type 5
Euro 5 and later	Jan 2009 (diesel type 5)	-

3.2 Biofuels

3.2.1 Current situation

VEPM does not currently compensate for any effects associated with the use of biofuels.

The *Engine Fuels Specifications Regulations 2011*, amended in 2017[6], allow for up to 10 % by volume of ethanol in retail petrol (**E10**) and 7 % by volume of fatty acid methyl ester in retail diesel (**B7**). The specifications also include requirements for fuel ethanol (**E85**) and full biodiesel (**B100**).

[6] https://www.legislation.govt.nz/regulation/public/2011/0352/latest/whole.html

The EMEP/EEA guide notes that higher blend biodiesels, in particular, are likely to lead to changes in emissions (as shown in Table 25). The factors shown are more applicable to older diesel technologies, i.e. Euro 3 and earlier, and should be used with care for more recent technologies.

Table 25: Effect of biodiesel blends on diesel vehicle emissions

Pollutant	Vehicle type	B10	B20	B100
CO_2	Passenger cars Light commercial vehicles Heavy duty vehicles	-1.5% -0.7% 0.2%	-2.0% -1.5% 0.0%	0.1%
NO_X	Passenger cars Light commercial vehicles Heavy duty vehicles	0.4% 1.7% 3.0%	1.0% 2.0% 3.5%	9.0%
PM	Passenger cars Light commercial vehicles Heavy duty vehicles	-13.0% -15.0% -10.0%	-20.0% -20.0% -15.0%	-47.0%
CO	Passenger cars Light commercial vehicles Heavy duty vehicles	0.0% 0.0% -5.0%	-5.0% -6.0% -9.0%	-20.0%
HC	Passenger cars Light commercial vehicles Heavy duty vehicles	0.0% -10.0% -10.0%	-10.0% -15.0% -15.0%	-17.0%

Appreciable improvements in emissions are predicted for almost all pollutants (with the exception of NO_X) for vehicle technologies up to and including Euro 3 – if not beyond.

3.2.2 Future developments

Higher blend biofuels are currently provided for in the *Engine Fuels Specification Regulations 2011* and are being promoted as tool to help New Zealand meet greenhouse gas emissions targets associated with the transport sector.

The inclusion of capability to assess biofuel impacts into VEPM warrants further investigation.

3.3 Tampering with emission control equipment

Smit *et al* (2021) identified tampering by vehicle owners as an emerging issue for future investigations. This section briefly reviews the current situation and describes work that has already been undertaken in New Zealand.

3.3.1 Current situation

Two major kinds of tampering exist. The first is the removal or bypassing of filters and catalysts if they become clogged or otherwise damaged, rather than replacing these. The other kind of tampering relates to use of diesel emissions fluids, such as AdBlue. AdBlue is a mix of urea and water that is injected into the exhaust stream of diesel engines. The resulting chemical reactions convert NO_X into harmless substances. This process is referred to as selective catalyst reduction (**SCR**). While the SCR process works well in reducing NO_X emissions, it requires drivers to purchase AdBlue on a regular basis. This places a direct cost to the operator of the vehicle and there is therefore an ongoing financial incentive to avoid the use of AdBlue. Tampering in this context usually involves making changes to software installed in vehicles that monitor levels of AdBlue and indicate when a vehicle needs to refill.

In previous versions of VEPM, the default assumption was that 15% of "old" petrol vehicles (defined as passenger cars and light commercial vehicles 11 years or older) do not have functioning catalysts but that all "new" (10 years or younger) petrol vehicles do have emission control equipment which is still working. Users are able to manually input values between 0 and 100 %. Removal of exhaust treatment devices from diesel vehicles is not considered in VEPM, as the addition of after treatment devices on modern diesel vehicles is relatively recent and it is less likely that these devices would be removed.

The challenge is that little data exist to support the 15 % assumption or to establish more valid estimates of tampering in the New Zealand fleet.

Worldwide, claims of widespread tampering with vehicle emission control technology have been steadily increasing. The VW emissions scandal to one side, the next most pressing concern has been the rise in technology being offered aftermarket to bypass the use of exhaust treatments (such as AdBlue) which are integral to ensuring vehicles meet Euro 4/IV and better emission standards for NO_X. Articles from Europe[7], the United Kingdom[8], Australia[9], United States[10], Canada[11] and New Zealand[12] all report that defeat devices are widely available on the web, especially for use in heavy duty diesel trucks. The difficulty is in knowing exactly how widespread the tampering is and its likely effect on fleet emissions and subsequent health effects.

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[7] EU Observer (2016). *Car lobby complained about emissions tampering by others*, European Union, 29 July 2016, available from https://euobserver.com/dieselgate/134523

[8] Transport Operator (2015). *Truck manufacturers lobby for ban on SCR cheat devices*, United Kingdom, 10 November 2015, available from http://transportoperator.co.uk/2015/11/10/truck-manufacturers-lobby-for-ban-on-scr-cheat-devices/

[9] Fully Loaded (2012). *Major states in warning on AdBlue blockers*, Australia, 15 November 2012, available from https://www.fullyloaded.com.au/product-news/1211/major-states-in-warning-on-adblue-blockers

[10] Arrow Truck (2016). *Tampering Not New, But Dirties Exhaust and Can Damage Engines, Reps Say*, United States of America, accessed 10 November 2016, available from www.arrowtruck.com/pdf/Tampering.pdf

[11] Truck News (2013). *Truck News investigation finds widespread tampering of emissions systems*, Canada, 17 March 2013, available from http://www.trucknews.com/regulations/special-report-truck-news-investigation-finds-widespread-tampering-of-emissions-systems/1002145949/

[12] Sunday Star Times (2016). *Truckies tampering with emission testing to save dollars,* New Zealand, 7 August 2016, available from http://www.stuff.co.nz/motoring/nz-trucking/82625673/Truckies-tampering-with-emission-testing-to-save-dollars

In New Zealand, all vehicles entering the fleet are required to meet minimum emission standards on entry[13] which are currently:

- Euro 5/V or equivalent for all new petrol and diesel light/heavy vehicles and
- Euro 4/IV equivalent for all used petrol and diesel light/heavy vehicles

Once in service a vehicle's exhaust emission system or control equipment must not be modified so as to prevent the vehicle being able to a pass a metered test[14] which sets limits for:

- Carbon monoxide (CO) and hydrocarbons (HC) for petrol vehicles
- Opacity (a proxy for particulate matter) for diesel vehicles

All vehicles must also pass a visible smoke check to be issued with a certificate or warrant of fitness.

3.3.2 Future developments

In 2017, MoT commissioned Emission Impossible Ltd to gather information on the potential scale and impact of tampering with exhaust emissions equipment in New Zealand.

The key findings from this preliminary assessment (using 2016 fleet data) were:

- Vehicle emissions are a product of vehicle travel (i.e. VKT) rather than the total number of vehicles, as older vehicles tend to travel less. In this context, about 90 % of the total VKT of the fleet is by vehicles at risk of tampering.

- 30 % of fleet VKT is driven annually by Japanese used vehicles, of which nearly all could be impacted by tampering.

- The balance of 70 % fleet VKT is driven by Euro/NZ New vehicles, of which 60 % of the fleet VKT could be subject to tampering.

- If tampering is occurring in all (i.e. 100 %) of the vulnerable vehicles in the fleet then the social costs could be up to $737 million per annum due to increased health effects from additional emissions.

- However, it is more likely that the prevalence is lower, probably in the order of 15-30 % based on international findings. In this case, social costs may be in the range of $111 million to $222 million per annum.

One of the main outputs of the work was the development of a draft working model of likely tampering effects (based on VEPM 5.1) which enables testing of various tampering scenarios (from 2001-2030). The intention was to workshop this draft model with key stakeholders to get feedback on key assumptions

[13] *Land Transport Rule: Vehicle Exhaust Emissions 2007*, consolidated rule 33001/2, available from https://www.nzta.govt.nz/resources/rules/vehicle-exhaust-emissions-2007-index.html

[14] The metered test requirements do not include limits for NO_X as this requires dynamic testing

and design a sampling programme to gain field data for validation. However, the work was not progressed or published due to other priorities at the time.

Improving VEPM's ability to assess tampering scenarios warrants further investigation, given the importance of functioning emission control equipment in addressing ongoing concerns with health effects associated with PM and NO_X.

3.4 Degradation factors

3.4.1 Current situation

Degradation factors are applied to baseline emission factors in VEPM to account for performance deterioration due to vehicle age. The EMEP/EEA guidebook includes degradation factors for light duty petrol vehicles built to Euro 1 to Euro 4. VEPM uses factors from several published literature sources to estimate degradation effects for other vehicle categories. Degradation factors in VEPM have not been updated since 2012 (EFRU 2012).

A review in 2020 found that the degradation factors in VEPM were outdated and recommended further work (EMM 2020). A brief further review to identify any significant new information was commissioned for this 2021 update (see Appendix 2). A recent Waka Kotahi research report also noted some discrepancies between the degradation factors described in VEPM technical reports and those in the VEPM 6.1 spreadsheet (Smit *et al* 2021).

In response, we investigated the origins of the degradation factors in VEPM 6.1 to resolve discrepancies in the documentation. The sources of degradation factors in VEPM 6.1 (and VEPM 6.2 where factors have been updated as described in Section 2) are summarised in Table 26.

Table 26: Sources of emission degradation factors in VEPM 6.1 and VEPM 6.2

Sources of emission degradation factors in VEPM 6.1					**Source VEPM 6.2 if changed from VEPM 6.1**
Vehicle class	**Fuel**	**Region of origin**	**Emission standard/YOM**	**Source VEPM 6.1**	
Car	Petrol	Europe	Pre-Euro 1	FORS (1996)*	
			Euro 1-2	EEA (2019)**	
			Euro 3-6	EEA (2019)** with Euro 4 factors applied to Euro 5 and 6	Carslaw *et al* (2019) for CO and NO_X
		Japan	Up to YOM 1974	FORS (1996)*	
			Up to YOM 2010	JCAP (2001)	
	Diesel	Europe	Euro 1 and later	NO_X, CO, HC unclear. Report cites European Auto Oil study PM based on Ubanwa *et al* 2003	Carslaw *et al* (2019) for CO and NO_X
		Japan	J86 and later		

Sources of emission degradation factors in VEPM 6.1					**Source VEPM 6.2 if changed from VEPM 6.1**
Vehicle class	**Fuel**	**Region of origin**	**Emission standard/YOM**	**Source VEPM 6.1**	
LCV	Petrol	Europe	Pre-Euro 1	FORS (1996)	
			Euro 1-2	EEA (2019)*	
			Euro 3-6	EEA (2019)* with Euro 4 factors applied to Euro 5 and 6	Carslaw *et al* (2019) for CO and NO_X
		Japan	Up to YOM 2010	JCAP (2001)	
	Diesel	Europe	Euro 1 and later	NO_X, CO, HC unclear. Report cites European Auto Oil study. PM based on Ubanwa *et al* (2003).	Carslaw *et al* (2019) for CO and NO_X
		Japan	J77 and later		
HDV	Diesel	Europe	All	Ubanwa *et al* (2003) for PM; Lindhjem & Jackson (1999) for CO, HC and NO_X	
		Japan	All		

* Stabilised degradation factors at 400,000 are assumed to be 1.39 for HC, 1.25 for CO, and 1.0 for NO_X. These are derived from Figures 2-15 to 2-17 of FORS (1996).

** Note that, as described in EFRU 2008, a simplified approach is applied in VEPM where the EEA degradation rates at <19km/hour have been applied regardless of speed.

CO, NO_X and HC light duty degradation factors

In previous versions of VEPM, the **stabilised degradation factors** for all light duty diesel vehicles at 80,000 km were assumed to be 1.6 for CO and NO_X, and 1.3 for HC (i.e. CO and NO_X emissions are assumed to increase by 60% from 0 to 80,000 km and then remain stable). The technical report describes the source of these degradation factors as a European Auto-Oil study, however the technical report (EFRU 2008) does not clearly reference the source and we have not been able to find further information.

The EMM (2020) review found a wealth of new degradation data, particularly for light duty vehicles based on the results of European remote sensing campaigns Of note was the CONOX report (Carslaw *et al* 2019) which includes deterioration factors for CO and NO_X emissions for light duty petrol and diesel vehicles. The EMM summary of the CONOX report is reproduced in Appendix 3.

At the time of the EMM (2020) review, the degradation factors in COPERT were expected to be updated within 12 months. For the 2021 update (Appendix 2), EMM contacted Emisia (the developers of COPERT) and received the following response regarding progress:

> "There is a plan to update the degradation factors reasonably soon, hopefully by spring next year[15]. The priority is for latest technology (Euro 5 and 6) passenger cars (petrol + diesel) and possibly light commercial vehicles too. CONOX is one of the sources that we will consult. More

[15] We expect that this would be around April 2022

data will come from ongoing on-road testing projects (with PEMS). Eventually, the results of this exercise will be transferred to COPERT."

Light duty CO and NO_X emission degradation factors have been updated in VEPM 6.2 to ensure that light duty diesel degradation factors are robust and can be referenced. For consistency, petrol and diesel factors have been updated based on the CONOX report (Carslaw *et al* 2019) as described in Section 2.5.2.

While the Carslaw *et al* (2019) study does not specifically propose degradation factors for HC, it does present deterioration scaling factors based on mileage for HC (see Figure 7).

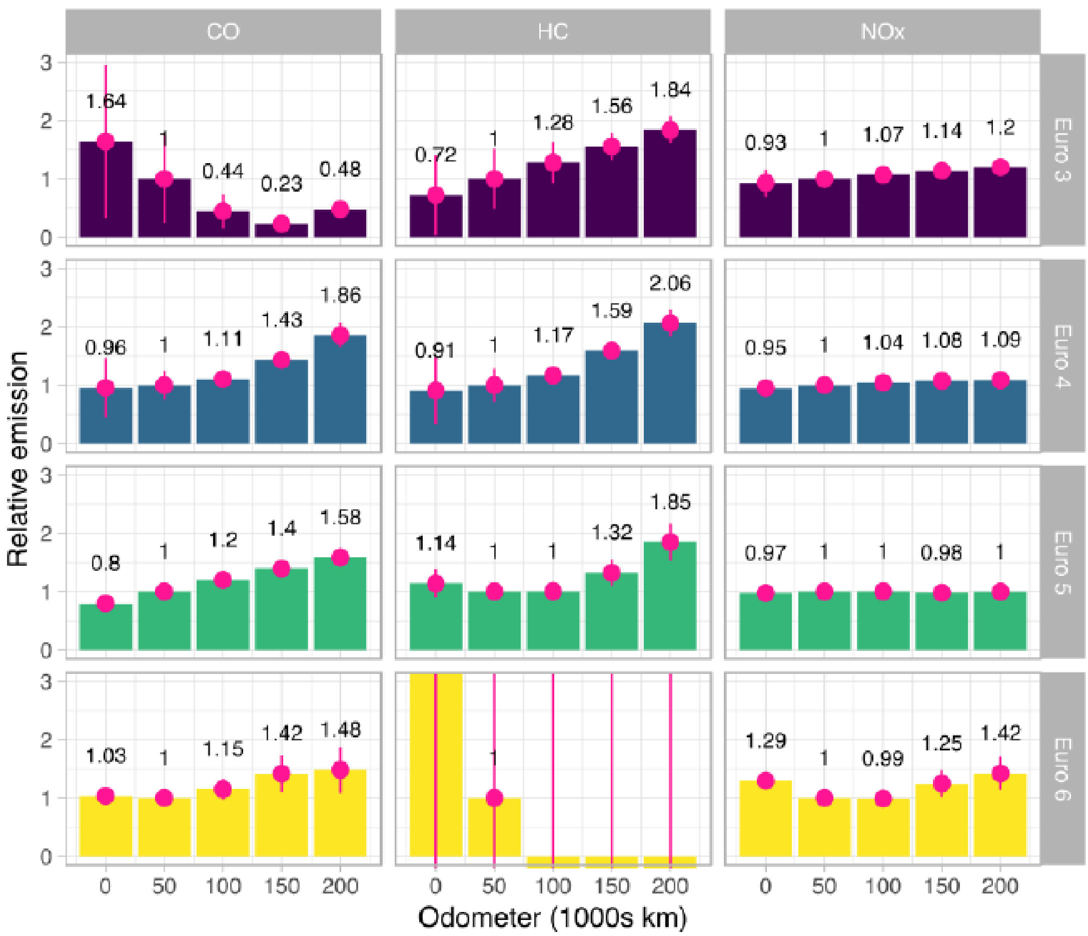

Figure 7: Mileage scaling values for diesel cars by Euro status and pollutant. Source: Carslaw *et al* (2019), Figure 10.

The **stabilised degradation factor** for HC from diesel vehicles in VEPM is currently assumed to be 1.3 at 80,000 km (i.e. HC emissions are assumed to increase by 30% from 0 to 80,000 km and then remain stable). From Figure 7, the Carslaw *et al* (2019) analysis of European remote sensing data shows that HC emissions from diesel vehicles increase with mileage for Euro 3 to 5 diesel vehicles. The HC emissions from Euro 6 vehicles are highly uncertain. Based on the deterioration scaling factors shown in Figure 7, the current degradation factor in VEPM may under-estimate the effects of degradation, however it does not seem unreasonable.

For petrol vehicles, Carslaw *et al* (2019) found that HC emissions show a mixed response to increased mileage. Degradation factors for HC emissions from petrol vehicles are currently based on the EMEP/EEA guidebook (EEA 2019).

Light duty PM degradation factors

The stabilised degradation factor for diesel vehicles in VEPM is currently assumed to be 2 at 80,000 km (i.e. it is assumed that PM emissions double from 0 to 80,000 km and then remain stable). This factor is from Ubanwa *et al* (2003), which is relatively old and is based on testing of American vehicles. However updated degradation factors are not available (EMM 2020 and Appendix 2) so PM degradation factors have not been updated in VEPM 6.2.

Analysis of European remote sensing data (Carslaw 2018) suggests that particulate emissions from Euro 5 and Euro 6 diesel vehicles, which are fitted with particulate filters, do not significantly increase with vehicle mileage. However, there is evidence that emissions increase with mileage for Euro 4 vehicles as shown in Figure 8.

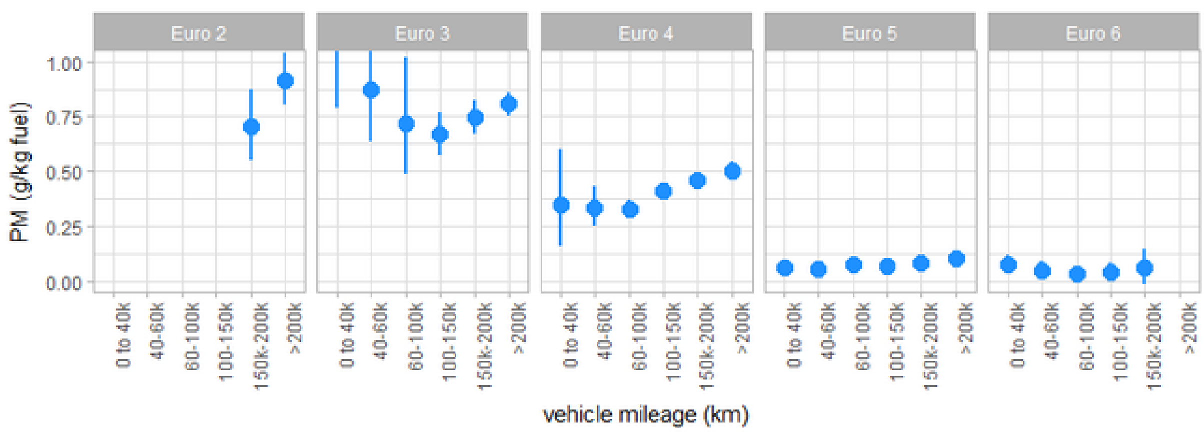

Figure 8: Effect of vehicle mileage on emissions of PM for diesel passenger cars split by Euro standard from Carslaw (2018)

New Zealand data for light duty emissions degradation

Some analysis of emissions degradation has previously been undertaken with remote sensing data in New Zealand (Kuschel *et al* 2012). The analysis compares emissions from vehicles with "high mileage" (upper quartile odometer readings) and "low mileage" (lower quartile odometer readings) in each emission standard category.

The results are reproduced in Table 27 (New Zealand new diesel vehicles) and Table 28 (Japanese used diesel vehicles). These show,for example, that uvSmoke (which is a proxy for PM) is significantly higher for high mileage vehicles compared with low mileage vehicles, at least for some emission standard categories. However, this analysis cannot be used directly to derive degradation factors because the values for high and low mileage are not consistent across each emission standard category.

Table 27: Comparison of the emissions of the monitored high and low mileage New Zealand new diesel vehicles by emission standard. Source: Kuschel *et al* (2012), Table 6.4

Emission Standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-2003	Mean	0.02	0.04	**89**	**127**	579	573	0.198	0.280
	Median	0.01	0.02	56	90	463	495	0.138	0.153
2003+	Mean	0.03	0.02	**68**	**84**	**468**	**616**	**0.085**	**0.149**
	Median	0.00	0.01	49	58	464	472	0.074	0.114
Euro 2	Mean	0.02	0.01	67	57	646	641	0.121	0.093
	Median	0.00	0.01	42	49	389	548	0.071	0.076
Euro 3	Mean	0.00	0.01	**49**	**69**	**440**	**590**	**0.067**	**0.116**
	Median	0.00	0.00	47	57	286	481	0.054	0.071
Euro 4	Mean	0.01	0.00	61	60	482	500	0.089	0.091
	Median	0.00	0.00	52	47	335	317	0.049	0.067
Euro 5	Mean	0.00	0.08	27	27	704	665	0.008	0.007
	Median	0.00	0.00	13	14	798	533	0.014	0.004

* Note the values shown in **bold** and highlighted are statistically significantly different from each other

Table 28: Comparison of the emissions of the monitored high and low mileage Japanese used diesel vehicles by emission standard. Source: Kuschel *et al* (2012), Table 6.8

Emission Standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-1993	Mean	0.03	0.03	121	114	434	518	0.267	0.268
	Median	0.02	0.01	85	85	397	422	0.201	0.185
1993-94	Mean	**0.02**	**0.05**	97	116	377	400	**0.157**	**0.237**
	Median	0.01	0.02	77	87	393	393	0.112	0.161
1997-99	Mean	0.02	0.02	56	65	**650**	**432**	0.090	0.078
	Median	0.01	0.01	51	58	444	407	0.077	0.063
2000-02	Mean	**0.00**	**0.07**	52	131	654	709	0.041	0.079
	Median	0.01	0.02	37	42	698	608	0.050	0.104
2005	Mean	0.02	0.02	177	61	305	419	0.000	0.100
	Median	0.00	0.02	145	61	135	419	0.000	0.100

* Note the values shown in **bold** and highlighted are statistically significantly different from each other

We understand that remote sensing data, including uvSmoke measurements, will be considered for development of degradation factors for COPERT Australia. Further work is recommended to determine whether degradation factors can be estimated from New Zealand remote sensing data.

Heavy duty degradation factors

Based on recommendations from EMM (Appendix 2), heavy duty vehicle emission degradation factors have not been updated in this VEPM 6.2 update. However, the factors are old and should be updated when degradation factors in COPERT are updated.

3.4.2 Future developments

We recommend that all degradation factors in VEPM should be reviewed and updated when COPERT is updated. The relevance of any COPERT Australia updates should also be considered.

The updated light duty CO and NO_X degradation rates in VEPM 6.2 are based on analysis of European remote sensing data.

Further work is recommended to investigate whether New Zealand remote sensing data and emission test results could be used to:

- compare with international degradation factors
- develop New Zealand specific degradation factors for CO, NO_X, HC and PM
- investigate the effects of tampering.

EMM (2020) suggest that VEPM could be modified to allow the user to select different sets of degradation factors for sensitivity analyses. We also recommend this for consideration in future updates.

3.5 Real world fuel consumption correction factors

3.5.1 Current situation

VEPM incorporates real world fuel consumption adjustment factors for diesel passenger cars and diesel light commercial vehicles (**LCVs**). These were developed for VEPM 6.1 based on MoT real-world fuel consumption estimates for vehicles manufactured between 2010 and 2014, as described in Metcalfe *et al* (2020). Further work was recommended to undertake analysis for other years.

3.5.2 MoT real world fuel consumption estimates

This section describes the MoT real-world fuel consumption estimates, which have been used to develop adjustment factors in VEPM.

Real world fuel consumption factors for light duty vehicles

MoT estimated real-world fuel consumption factors for diesel and petrol vehicles in New Zealand using fuel consumption and travel data from a large dataset of fuel card transactions (Wang *et al* 2015). This is a detailed, “bottom up” estimate that provides real-world fuel consumption factors for individual vehicle categories. Wang *et al* (2015) found good correlations between engine size and fuel efficiency.

Figure 9 presents the correlation between engine size and fuel efficiency for light duty **diesel** vehicles, which is described below in Equation 14.

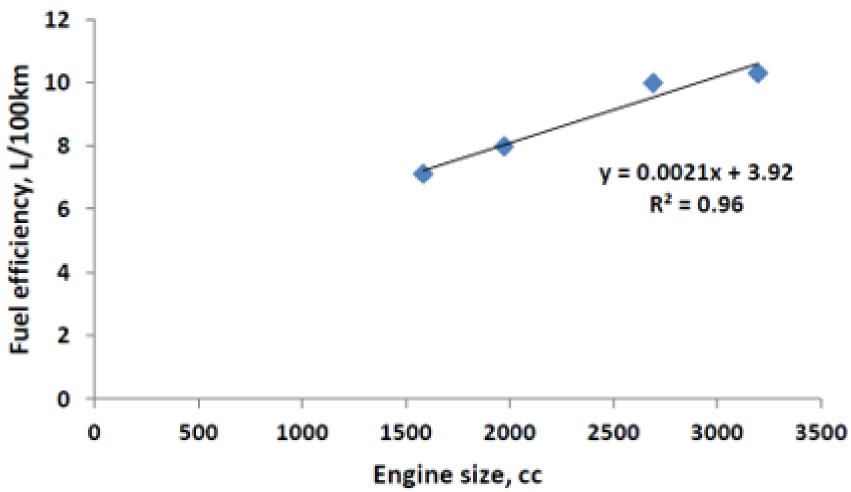

Figure 9: Relationship between mean fuel efficiency and average engine size of light duty diesel vehicles for different engine size bands (Wang *et al* 2015)

Fuel consumption (litres/100km) = 0.0021 x engine size (cc) + 3.92 Equation 14

The comparable correlation between engine size and fuel efficiency for light duty **petrol** vehicles is shown in Figure 10 and described in Equation 15.

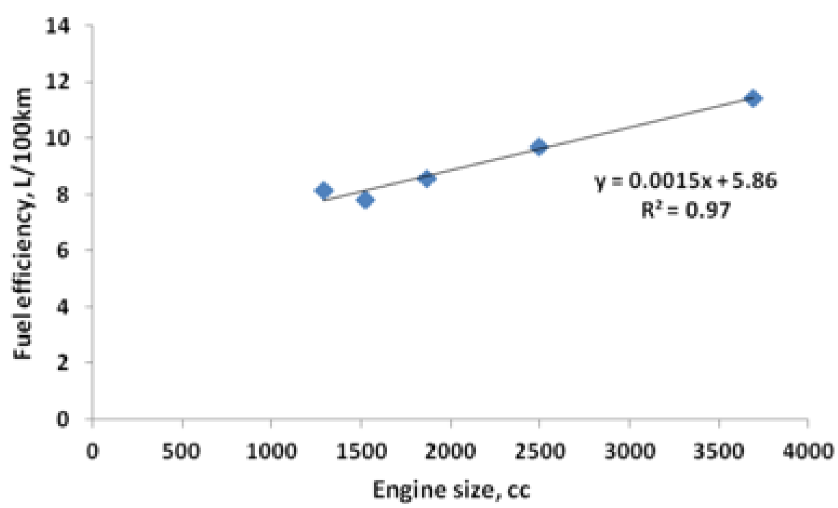

Figure 10: Relationship between mean fuel efficiency and average engine size of light duty diesel vehicles for different engine size bands (Wang *et al* 2015)

Fuel consumption (litres/100km) = 0.0015 x engine size (cc) + 5.86 Equation 15

VFEM

The MoT vehicle fleet emissions model (VFEM) is used for greenhouse gas reporting and policy development at a national level. VFEM estimates real-world fuel consumption factors for New Zealand fleet vehicles categorised by year of manufacture (from 1970 to 2050), fuel, technology (e.g. hybrid and plug in hybrid) and engine size.

Fuel consumption estimates from VFEM have been compared with fuel delivery data for historic years (2001 to 2017). The difference between estimated fuel consumption and delivered fuel consumption is less than 3% for petrol and up to 12% for diesel.

3.5.3 Comparison of NVED outputs with real world fuel consumption factors

As a starting point for this investigation, we compared fuel consumption estimates from the Waka Kotahi National Vehicle Emissions Dataset (**NVED**) with MoT real-world fuel consumption values.

The NVED values come from the Waka Kotahi Vehicle Emissions Mapping Tool (**VEMT**). VEMT calculates motor vehicle emissions for every public road in New Zealand using emission factors from VEPM 6.1 and detailed geospatial road activity data summarised in Table 29 (Waka Kotahi 2021).

Table 29: Geospatial input data for VEMT

Parameter	Data source	Notes
Traffic count	CoreLogic	It represents the annual average daily traffic of a particular road section
Fleet profile	CoreLogic	Heavy vehicle count for a particular road section is used to calculate the light/heavy ratio
Speed	Abley Ltd	Travel speed data taken from TomTom GPS data
Gradient	LINZ	This dataset has an elevation value every 25m. The road centre lines are overlaid to derive the gradient of 50m road sections.

Estimated VKT and CO_2 emissions for each vehicle class were extracted from NVED[16] and compared with estimated real-world fuel consumption factors based in the average engine size of vehicles in the New Zealand fleet using Equation 14 and Equation 15. The average engine size was estimated from analysis of motor vehicle register data as described in Metcalfe *et al* (2020). Table 30 compares the two sets of results for the 2017 fleet-weighted average fuel consumption for different light duty vehicles.

Table 30 shows that NVED under-estimates fuel consumption for both light duty diesel and light duty petrol vehicles. We would not necessarily expect NVED to provide realistic fuel consumption factors because it is based on average speed data. Further work is recommended to better understand the effect of speed assumptions in different traffic models. In the meantime, the comparison with NVED

[16] Provided by Jacobs. These outputs are from the 2020 NVED which is based on VEPM 6.1.

shows that any improvement in real-world fuel consumption factors needs to consider petrol as well as diesel vehicles.

Table 30: Estimated 2017 fleet-weighted fuel consumption for light duty vehicles from NVED compared with estimated real-world fuel consumption based on engine size

Vehicle	NVED outputs		NVED CO_2 (g/km)	NVED fuel consumption[17] (l/100km)	Average engine size of NZ fleet (cc)	Estimated real-world fuel consumption (l/100km)
	VKT/day	CO_2 (t/yr)				
Petrol car	79,440,260	5,495,991	190	**8.1**	2130	**9.1**
Diesel car	9,353,878	722,724	212	**7.9**	2467	**9.1**
Petrol LCV	3,982,859	343,581	236	**10.1**	2666	**9.9**
Diesel LCV	18,395,780	1,622,686	241	**9.0**	2784	**9.8**

3.5.4 Development of proposed adjustment factors

In VEPM 6.1, real-world fuel consumption factors in VEPM are applied to diesel passenger cars and diesel LCVs only, and the same factor is applied to all vehicles regardless of the year of manufacture.

In this update, the aim was to develop improved real-world fuel consumption adjustment factors for petrol and diesel light duty vehicles by year of manufacture using VFEM – however, recognising that VFEM provides only one average fuel consumption factor for each vehicle class operating in real-world conditions, regardless of speed and other parameters.

To calibrate VEPM fuel consumption factors with VFEM factors, we used a simple method to estimate average fuel consumption from VEPM over a long period of time, and across a wide range of driving conditions.

The steps were as follows:

1. Estimate a representative speed where VEPM predicts fleet-weighted fuel consumption that is equivalent to real-world fuel consumption for Euro 4 petrol vehicles form VFEM
2. Develop adjustment factors so that fuel consumption predicted by VEPM for equivalent vehicles at the "representative speed" estimated in Step 1, is equal to the MoT VFEM fuel consumption factor.

Step 1: Estimate a representative speed

Firstly, we selected a single average speed where VEPM 6.2 predicts realistic petrol consumption factors for a **Euro 4 petrol vehicle** when compared to MoT real-world fuel consumption factors. This method assumes good agreement between MoT real-world fuel consumption estimates and VEPM fuel

[17] Fuel consumption was estimated from CO_2 based on fuel properties in VEPM 6.1.

consumption estimates for **Euro 4 petrol vehicles**, which has been confirmed in previous research[18] (Kuschel et al 2019)[19].

We found that fuel consumption estimated from VEPM 6.2 at 48 km/h for Euro 4 petrol vehicles (8.9 litres/100km) matched the MoT real-world fuel consumption factors as shown in Table 31.

Table 31: Comparison of MoT real world fuel consumption estimates with VEPM fuel consumption predictions for Euro 4 petrol vehicles at an average speed of 48 km/hour

Vehicle type	Engine size	MoT real-world estimates		VEPM 6.2 factors	
		Fuel consumption (l/100km)	Category weighted fuel consumption (l/100km)	Fuel consumption (l/100km)	Category weighted fuel consumption (l/100km)
Petrol passenger car	<1350cc	8.1	8.9	6.5	8.9
	1350 - <1600cc	7.8		7.9	
	1600 - <2000cc	8.5			
	2000 - <3000cc	9.7		10.9	
	>3000cc	11.4			

Step 2: Develop proposed adjustment factors

From Table 31, we assumed that VEPM 6.2 should predict realistic fuel consumption estimates at 48 km/hour for **all vehicle classes**. We then developed adjustment factors so that fuel consumption predicted by VEPM for equivalent vehicles at 48 km/hour equalled the VFEM fuel consumption values.

To derive these adjustment factors:

- VFEM fuel consumption factors were averaged across model years and engine size categories to align with VEPM categories
- VFEM fuel consumption factors were averaged across five years to estimate factors for Euro 6 vehicles.

[18] The MoT real-world fuel consumption factors are based on data for vehicles manufactured between 2010 and 2014 (Wang *et al* 2015) so these were compared with fuel consumption for Euro 4 vehicles in VEPM.

[19] Note that this differs from the methodology used to estimate real world fuel adjustment factors for the **previous VEPM 6.1 update** (Metcalfe *et al* 2020). For the VEPM 6.1 update we selected a single speed where VEPM predicted realistic **fleet-weighted average** light duty petrol consumption factors when compared to fleet-weighted average fuel efficiency reported by MoT for 2012. This method assumed that VEPM would provide reasonably realistic fuel consumption factors for petrol vehicles of all years of manufacture. The updated method allows us to develop adjustment factors for petrol vehicles with different years of manufacture by using the Euro 4 vehicle as an anchor point.

The adjustment factors that have been developed are shown in Appendix 4 and are available as a separate Excel spreadsheet.

3.5.5 Future developments

While looking promising, the new adjustment factors are based on using a single speed in VEPM to represent real-world conditions and would therefore benefit from further testing to ensure they are truly applicable across the range of typical operating conditions.

Note: The proposed improved real-world fuel consumption adjustment factors **have not been incorporated** into VEPM 6.2 at this stage.

To gain the necessary confidence, we recommend investigating whether VEPM 6.2 incorporating the proposed adjustment factors produces reasonable estimates of fuel consumption at a:

- National level from the Waka Kotahi VEMT, which is based on average speed data
- Local or regional level using a more detailed traffic model which includes speed data for peak traffic periods.

4. VEPM 6.1 versus VEPM 6.2

This chapter compares the fleet-weighted emissions factors now predicted by VEPM 6.2 versus those from the previous version VEPM 6.1 to show the effect of the changes in assumptions and methodology.

4.1 Effect on fleet-weighted average emission factors

Figure 11 through to Figure 16 compare the fleet-weighted emission factors for carbon monoxide (CO), total hydrocarbons (HC), nitrogen oxides (NO_X), $PM_{2.5}$, brake and tyre and fuel consumption.

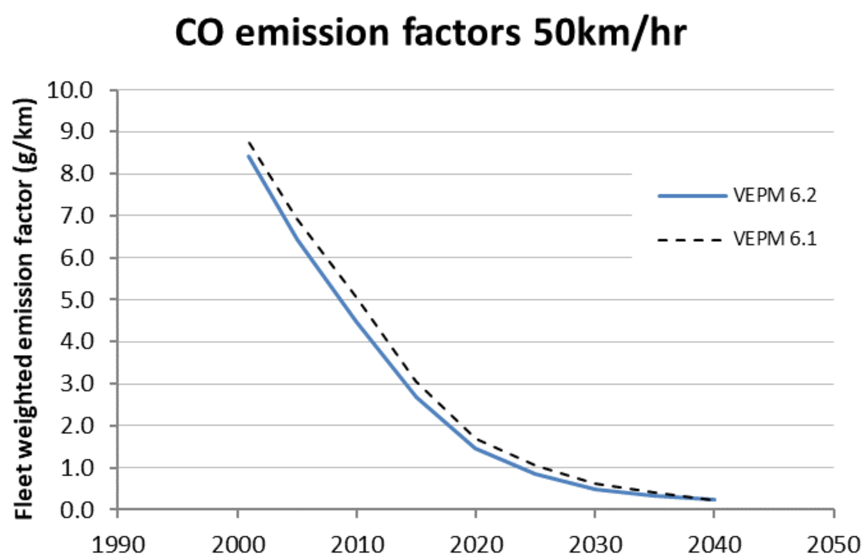

Figure 11: Comparison of CO emission factors from VEPM 6.1 and VEPM 6.2

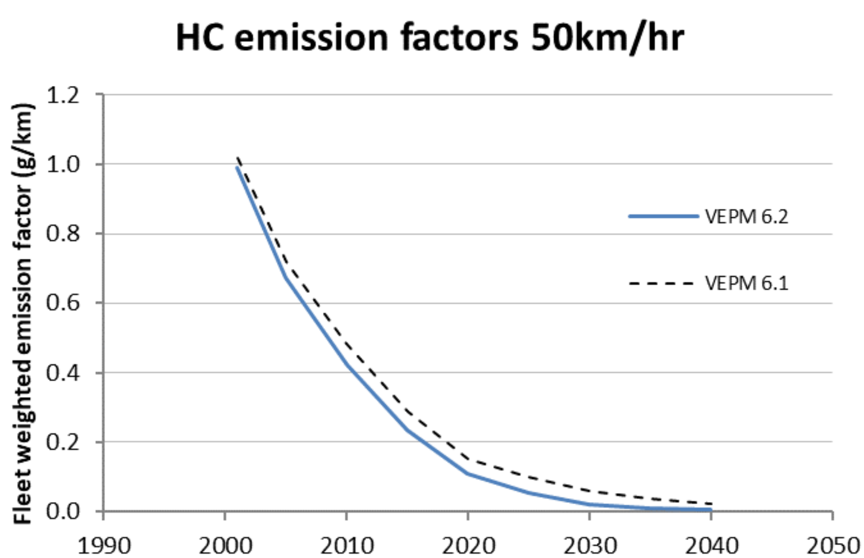

Figure 12: Comparison of HC emission factors from VEPM 6.1 and VEPM 6.2

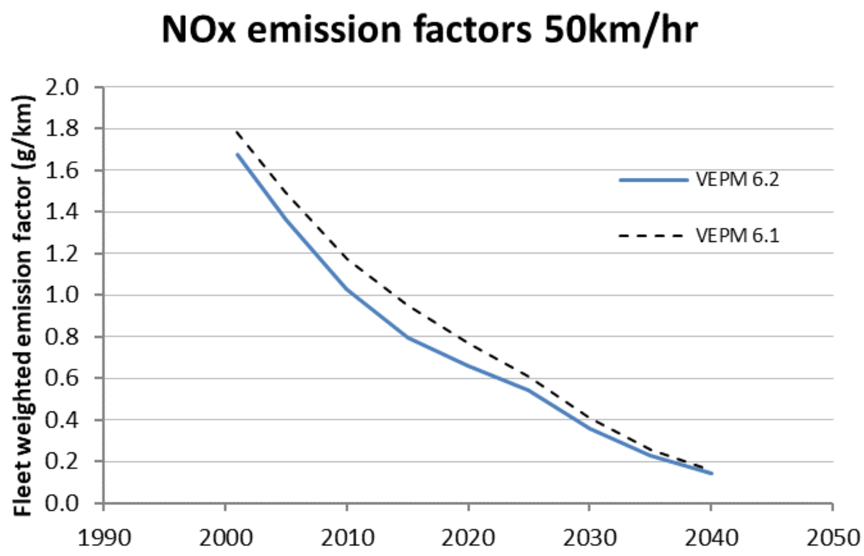

Figure 13: Comparison of NO_X emission factors from VEPM 6.1 and VEPM 6.2

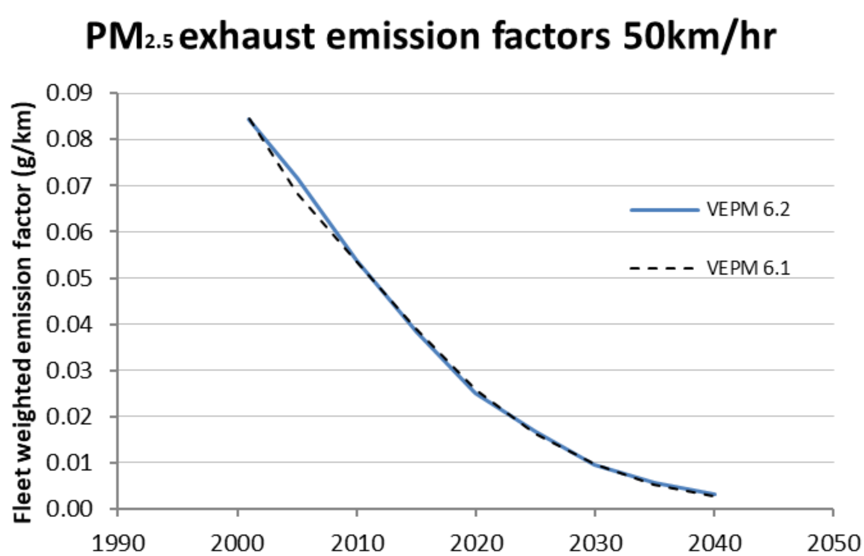

Figure 14: Comparison of $PM_{2.5}$ exhaust emission factors from VEPM 6.1 and VEPM 6.2

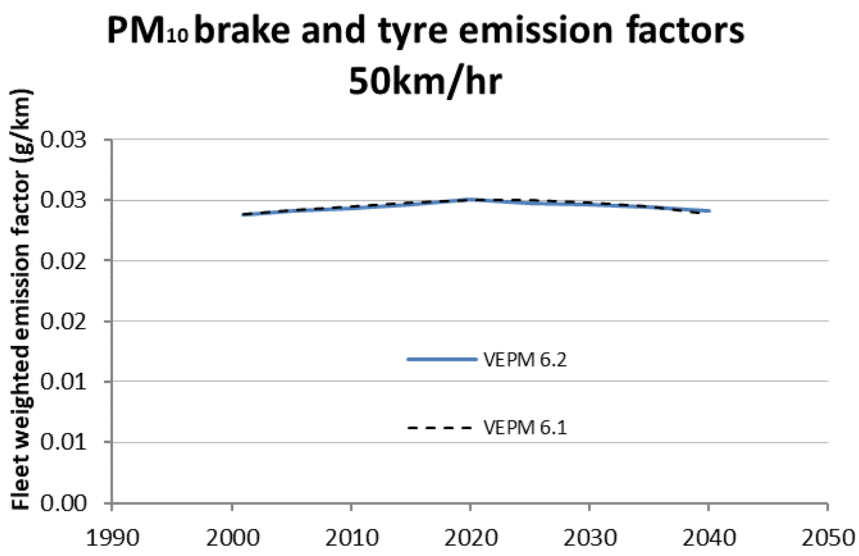

Figure 15: Comparison of PM_{10} brake and tyre emission factors from VEPM 6.1 and VEPM 6.2

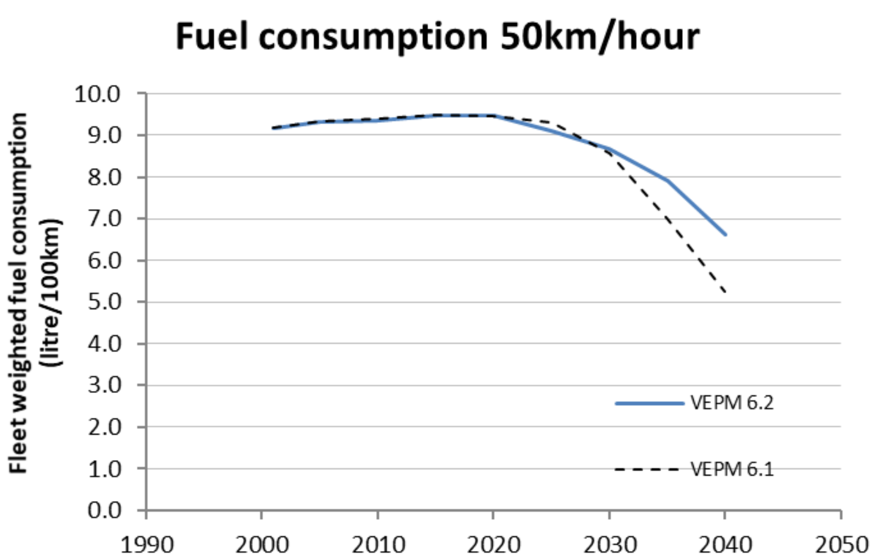

Figure 16: Comparison of fuel consumption factors from VEPM 6.1 and VEPM 6.2

4.1.1 NO_X, CO and HC emission factors

As seen in Figure 11 through to Figure 13, fleet-weighted emissions of CO, HC and NO_X are lower in VEPM 6.2 compared with VEPM 6.1. This is primarily due to:

- light duty degradation factor updates, which increased CO and NO_X emissions from petrol vehicles, and decreased CO and NO_X emissions from diesel vehicles, as discussed in Section 2.5.2, and

- the change to the default assumption for the % of petrol vehicles that do not have functioning catalysts (from 15% in VEPM 6.1 to 0% in VEPM 6.2), which decreased CO, NO_X and HC emissions from light duty petrol vehicles.

For example, the overall effect of these changes on fleet-weighted NO_X emission factors for diesel cars and petrol cars is shown in Figure 17 and Figure 18.

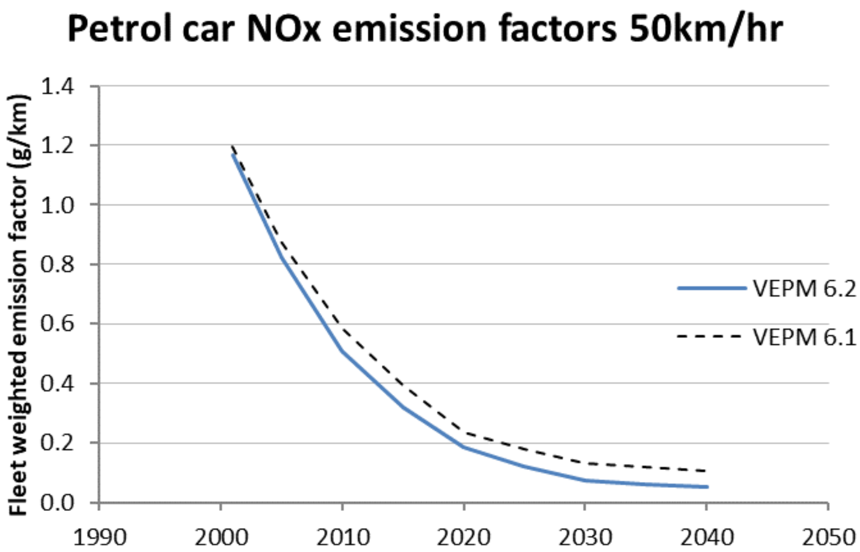

Figure 17: Comparison of petrol car NO_X emission factors from VEPM 6.1 and VEPM 6.2

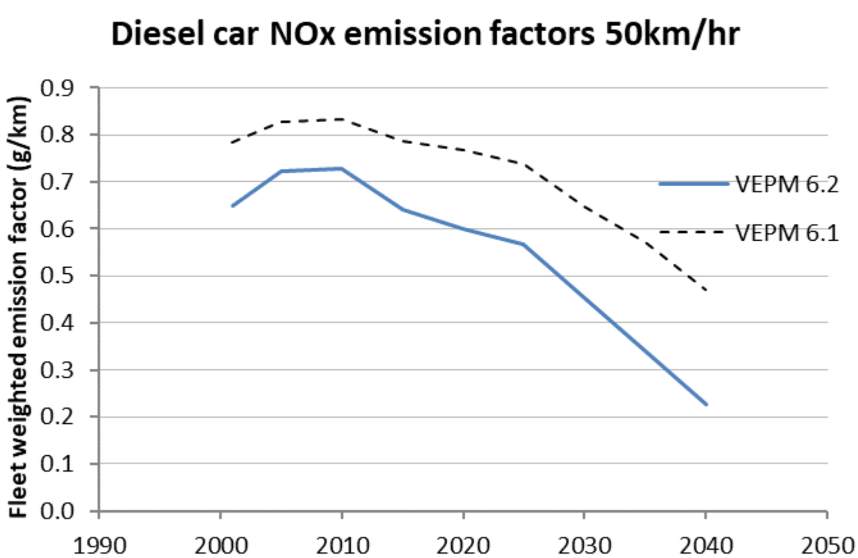

Figure 18: Comparison of diesel car NO_X emission factors from VEPM 6.1 and VEPM 6.2

4.1.2 PM emission factors

As seen in Figure 14 and Figure 15, fleet-weighted emissions of PM from exhaust and brake/tyre wear are essentially the same in VEPM 6.2 compared with VEPM 6.1.

4.1.3 Fuel consumption

As shown in Figure 16, fleet-weighted average fuel consumption is higher in VEPM 6.2 compared with VEPM 6.1 from 2030 onwards. This is due to a lower proportion of electric vehicles in the projected fleet, as discussed in Section 2.2.

5. Recommendations for future updates

Improvement of VEPM is an area of ongoing research, and recommendations from previous reports are not repeated here. Specific recommendations relating to this update of VEPM are as follows:

- VEPM assumes that the **same emission standards apply to Japanese and European** vehicles for the same year of manufacture for all years from 2010 onwards. Further work is recommended to investigate whether this assumption is still valid.
- The impact on predicted emissions factors of using **actual fuel quality** monitoring data to develop the fuel correction factors warrants further investigation.
- The **application of fuel correction** factors should be updated to reflect EMEP/EEA guidance in future updates.
- The inclusion of capability to assess **biofuel impacts** into VEPM warrants further investigation.
- Given the importance of emission control equipment to address ongoing concerns with health effects associated with PM and NO_X, improved capability in VEPM to assess **tampering scenarios** warrants further investigation.
- All **emission degradation** factors in VEPM should be reviewed and updated when COPERT is updated. The relevance of any updates to COPERT Australia should also be considered.
- Further work is recommended to investigate whether New Zealand remote sensing data and emission test results could be used to:
    - compare with international degradation factors
    - develop New Zealand specific degradation factors for CO, NO_X, HC and PM, and
    - investigate the effects of tampering.
- VEPM could be modified to allow the user to select different sets of degradation factors, and to undertake sensitivity analyses. We recommend that this is considered for future updates.
- Proposed **real-world fuel consumption adjustment factors** have been developed for light duty vehicles in VEPM. These have not been implemented in VEPM 6.2 at this stage. Further work is recommended to investigate whether VEPM 6.2 incorporating the proposed adjustment factors produces reasonable estimates of fuel consumption:
    - At a national level from the Waka Kotahi VEMT, which is based on average speed data
    - At a local or regional level using a more detailed traffic model which includes speed data for peak traffic periods.
- Real world fuel consumption of heavy duty vehicles was investigated for the VEPM 6.1 update (Metcalfe *et al* 2020) and resulted in the incorporation of factors for articulated trucks. This VEPM 6.2 update has improved the split between rigid and articulated trucks. Further work is now recommended to investigate estimated **fuel consumption for heavy duty vehicles** in VEPM.

In general, we recommend updating VEPM whenever COPERT is updated. The default fleet profile should also be updated whenever VFEM is updated.

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Appendix 1: Emission factor data sources in VEPM 6.1 and VEPM 6.2

Factor	Vehicle Class	VEPM 6.1	VEPM 6.2	Comments
Hot running	All vehicle categories	EEA 2019	EEA 2020	All hot emission factors updated to the latest version from EMEP/EEA (EEA, 2020)
Hot running	Japanese domestic imports (light duty) up to YOM 2010	EEA 2019 based on EURO/JCAP equivalent emissions factors as described in EFRU (2008)	EEA 2020 with no change to equivalencies	Note that all Japanese and European vehicles were assumed to be equivalent from YOM of 2010 onwards because increased harmonisation means vehicle emission standards are similar. This means that no changes/updates to the equivalencies are considered necessary going forward.
Cold start	All light duty	EEA 2019. No change		No change in latest version of EMEP/EEA guidebook (EEA, 2019).
Fuel correction	All gasoline and diesel	EPEFE as described in EFRU (2008), and EFRU (2011).	No change	No change to assumptions described in EFRU (2008) and EFRU (2011). However, note that changes are recommended as discussed in Section 3
Degradation	European gasoline	FORS 1996, EEA 2019.	CO and NOx based on Carslaw et al 2019	CO and NOx factors updated, however these should be reviewed when COPERT is updated and further work is recommended as discussed in Section 3.
Degradation	Japanese domestic imports	JCAP (2001) as described in EFRU (2008).	No change	No change to assumptions described in EFRU (2008) for pre 2010 vehicles. Note that all vehicles from YOM 2010 onwards are assumed to be equivalent to European standards – including degradation factors. So no changes/updates are necessary going forward.
Degradation	Light duty diesel	Ubanwa et al 2003 + European Auto-Oil study as described in EFRU (2008), and EFRU (2011).	CO and NOx based on Carslaw et al 2019	CO and NOx factors updated, however these should be reviewed when COPERT is updated and further work is recommended as discussed in Section 3.
Degradation	Heavy duty diesel	Ubanwa et al 2003 + Lindhjem & Jackson 1999 as described in EFRU (2008).	No change	No change to assumptions described in EFRU (2008). EMEP/EEA does not include degradation factors for HDV. Review of degradation factors is recommended (EMM 2020) and will be considered for future updates.
Catalyst removal	Light duty gasoline	EFRU (2008)	Assumes 0% catalyst removal as default	Default assumption for the % of catalysts removed has changed to 0%. No other change to assumptions described in EFRU (2008).
Gradient	Light duty	PIARC (2004) (CO and NOx only for gasoline	PIARC (2019)	Factors updated based on latest PIARC guidance.

Factor	Vehicle Class	VEPM 6.1	VEPM 6.2	Comments
		vehicles and CO, NOx and PM for diesel vehicles)		
f-NO_2	All	EEA 2019.	No change	No change in latest version of EMEP/EEA guidebook (EEA, 2019)
Brake and tyre wear	All	EEA 2019.	No change	
NZ real world fuel consumption	Light duty diesel	New in VEPM 6.1	No change	Correction factors applied in VEPM 6.1 based on methodology and assumptions described in Metcalfe, Kuschel and Gimson (2020). Proposed factors have been developed for VEPM 6.2 however they have not been implemented at this stage.

Appendix 2: VEPM 2021 update advice from EMM (2020)

This provides a brief update to the advice about updating degradation factors in VEPM provided by Paul Boulter for the VEPM 6.1 update (EMM 2020).

New information on degradation factors

I have checked the following sources of information:

- EMEP/EEA air pollutant emission inventory guidebook 2019
  - Relevant section is *1.A.3.b.i-iv Road transport*.
  - The guidebook was updated in October 2020. A version downloaded on 1 June, and compared with the version from April 2020 that was used in the last version of VEPM (6.1).
  - Conclusions:
    - Petrol car and LCV, Euro 1 and Euro 2: no change since VEPM 6.1.
    - Petrol car and LCV, Euro 3 and Euro 4: no change since VEPM 6.1.
    - No new degradation factors for other vehicle categories.
- COPERT version 5.4 (September 2000)
  - Conclusion: No apparent changes to degradation factors since VEPM 6.1.
- Handbook of emission factors
  - Conclusion: No relevant update since VEPM 6.1.

Emission Impossible assumptions

Confirm if reasonable to retain the Carslaw RSD-based degradation factors for light duty

Emisia were contacted in relation to the plans for degradation factors in COPERT and the guidebook. Here is the response:

> "There is a plan to update the degradation factors reasonably soon, hopefully by spring next year. The priority is for latest technology (Euro 5 and 6) passenger cars (petrol + diesel) and possibly light commercial vehicles too. CONOX is one of the sources that we will consult. More data will come from ongoing on-road testing projects (with PEMS). Eventually, the results of this exercise will be transferred to COPERT."

Therefore, if the CONOX degradation factors are implemented in VEPM now, they may have to be updated when the next version of COPERT is issued. However, VEPM could be modified to allow the user to select different sets of degradation factors, and to do sensitivity analyses.

Emission impossible has mentioned that NZ-specific remote sensing results could be used to test the degradation factors from overseas studies. This would be very useful in principle. It would be of most benefit for NO_X, if this is possible with the available data.

Review of HDV degradation approach

Emission Impossible have suggested using the emission degradation factors for HDVs from MOVES3. I would suggest that, although it could be possible to apply a simplified version of the MOVES approach, there are several difficulties. For example:

- As noted in EMM's 2020 report, the approach in MOVES is quite complex, and the effort required to transcribe the MOVES approach into VEPM could be significant.
- The MOVES adjustment factors are defined with respect zero-mile emissions for specific model years (and US vehicles). For a given model year, it is possible that the NZ heavy duty vehicle fleet has a mix of technologies that is rather different from that of the US fleet.
- For recent model years, the degradation effects could well be technology-specific (e.g. after-treatment strategies), and MOVES does not appear to have data that allows for this.
- For COPERT/Guidebook, I'm not sure that it's possible to state an odometer reading that corresponds to the base emission factors for heavy duty vehicles. For example, the emission factors are based on the outputs of PHEM, and the underlying data are from engine tests. The engines will have been taken from a range of vehicles, and the odometer readings for the underlying tests are not available.

Emission Impossible might want to look into the MOVES approach a little further, but I would suggest that consistency with COPERT is simpler and at least internally consistent from a calculation point of view. The approach could be revisited once COPERT has been updated. In addition, as significant amount of effort could be used in the development of an approach based on MOVES, only for it to be replaced by a COPERT approach (should this be available).

Any NZ measurements that become available in the next few years (PEMS or otherwise) can be used to check the validity of the assumptions.

Degradation approach for light-duty diesel PM

The VEPM referencing of degradation for light-duty diesel PM emissions seems to be unclear. I have not been able to find any new information on this to support any changes to VEPM. Robin Smit has confirmed that COPERT Australia currently reflects the COPERT 4 approach (as per EMEP/EEA guidebook, EEA 2019). There are plans to update COPERT Australia, possibly next year, using Australian remote sensing data for updates, if any (including UV Smoke for PM).

Appendix 3: Summary of CONOX study from EMM (2020)

The CONOX project was carried out during 2017 under a contract from the Swiss Federal Office for the Environment. The project involved a joint European and US effort to analyse large datasets from remote sensing measurements in various countries to achieve a better understanding of air pollution from road transport. The analysis yielded new knowledge relating to emission degradation for petrol and diesel cars. Carslaw *et al* (2019) made use of the remote sensing data from the CONOX study, and a more recent subset of UK remote sensing data, to assess the influence of mileage on emissions of CO and NO_x, and to propose new degradation factors. HC emissions were also considered. The project yielded the first on-road degradation factors for Euro 5 and Euro 6 cars, although for the latter there were too few data to propose reliable estimates. The results are summarised in the following sections.

Petrol cars

Table 32 shows the degradation factors for petrol cars determined from the CONOX study ('RS CONOX'), the corresponding factors from HBEFA/COPERT, and the results from earlier work in Switzerland by Borken-Kleefeld & Chen (2015) ('RS-ZH'). Carslaw *et al* proposed revised emission degradation factors for Euro 3 to Euro 5 petrol cars, and these are also shown in the table. A linear rate of increase in emissions is assumed. The durability requirements for emissions for conformity of production are also shown.

Table 32: Illustrative degradation factors for petrol cars

Cumulative mileage	**50,000 km NO_X**	**100,000 km NO_X**	**200,000 km NO_X**	**50,000 km CO**	**100,000 km CO**	**200,000 km CO**
	Euro 1			**Euro 1**		
Durability requirement	-	-	-	-	-	-
HBEFA/COPERT[e]	1.06	1.76	2.04	1.11	1.63	1.85
RS-ZH (2000-2013)[d]	1.35	1.85	3.4	1.25	1.55	2.4
	Euro 2			**Euro 2**		
Durability requirement	-	-	-	-	-	-
HBEFA/COPERT[e]	1.06	1.76	2.04	1.11	1.63	1.85
RS-ZH (2000-2013)[d]	1.35	1.75	3.1	1.15	1.35	1.85
	Euro 3			**Euro 3**		
Durability requirement	-	1.2[a]	-	-	1.2[a]	-
HBEFA/COPERT[e]	1.07	1.17	1.28[b]	1.06	1.2	1.37[b]
RS-ZH (2000-2013)[d]	1.2	1.5	2.15	1.15	1.3	1.65
RS CONOX (2011-18)	1	2	4	1	1	2.2
Proposal	**1**	**1.63**	**2.9**	**1**	**1**	**2**
	Euro 4			**Euro 4**		
Durability requirement	-	1.2	-	-	1.2	-
HBEFA/COPERT[e]	1.07	1.17	1.28[b]	1.25/1.05	1.5/1.1	1.75[b]/1.2[b]
RS-ZH (2000-2013)[d]	1.15	1.4	1.9	1.25	1.5	2.25
RS CONOX (2011-18)	1	1.4	2.1	1	1.25	2
Proposal	**1**	**1.5**	**2**	**1**	**1.5**	**2**
	Euro 5			**Euro 5**		
Durability requirement	-	-	1.6[c]	-	-	1.5[c]
RS CONOX (2011-18)	1	1	2.65	1	1.3	2
Proposal	**1**	**1 to 125k**	**2.5**	**1**	**1.3**	**2**

(a) Requirement up to 80,000 km.
(b) Assumed degradation factor from 160,000 km onwards.
(c) Requirement up to 160,000 km.
(d) Borken-Kleefeld & Chen 2015.
(e) Average over engine size and urban-rural driving.

For NO_X, the proposed degradation rates were clearly higher than the legal durability requirements and the factors used in COPERT/HBEFA. Importantly, an upper mileage threshold for degradation (as applied in the models) was not observed in the remote sensing data.

In the case of CO, Carslaw *et al* derived higher degradation rates than previously assumed for Euro 4 and Euro 6 cars (preliminary), but lower degradation rates for Euro 3 and Euro 5 cars.

HC emissions showed a mixed response, with Euro 3 and Euro 4 vehicles showing some evidence of a decrease with mileage. Carslaw *et al* did not explain why HC emissions decreased but speculated that the composition of HC changes with an ageing catalyst, and that therefore a fixed scaling factor would be inappropriate. They suggested that the degradation results for HC should not be used until further investigations have been made.

Carslaw *et al* (2019) also noted the following with respect to petrol cars:

- There were few records for new or low mileage vehicles in the remote sensing data, as these make up only a small proportion of the fleet. An emission factor for 0 km can therefore not be accurately determined.
- The share of vehicles with mileages above 200,000 km is also small, and it is unlikely that high-mileage vehicles will not have the same characteristics as the 'fleet average car'. Therefore, degradation factors for mileages above 200,000 km were not proposed.

Diesel cars

Table 33 shows the degradation factors for diesel cars determined from the study, and the corresponding factors from the earlier work in Switzerland by Chen & Borken-Kleefeld & Chen (2016). Carslaw *et al* propose revised emission degradation factors for Euro 3 to Euro 5 diesel cars, and these are also shown in the table. A linear rate of increase in emissions is again assumed.

Emissions of NO_X were notable for only a small increase with mileage.

CO emissions exhibited a clear increase with mileage, and much more than has previously been assumed or measured. CO emissions from high-mileage diesel cars can be equivalent to those of petrol cars. The main exception was CO for Euro 3 cars, which generally decreased with mileage; this effect may have been a result of unreliable values for the low-mileage Euro 3 cars, of which few were actually measured.

Emissions of HC increased with mileage for Euro 3 to 5 vehicles. HC emissions for Euro 6 vehicles were rather low and not reliably measured.

As with petrol cars, Carslaw *et al* (2019) also noted that for diesel cars an emission factor for 0 km cannot be accurately determined, and degradation factors for mileages above 200,000 km were not proposed.

Table 33: Illustrative degradation factors for diesel cars

Cumulative mileage	**50,000 km NO_X**	**100,000 km NO_X**	**200,000 km NO_X**	**50,000 km CO**	**100,000 km CO**	**200,000 km CO**
	Euro 1			**Euro 1**		
Durability requirement	-	1[a][d]	-	-	1.1[a]	-
RS-ZH (2000-2013)[c]	1	1	1	1	1	1
	Euro 2			**Euro 2**		
Durability requirement	-	-	-	-	-	-
RS-ZH (2000-2013)[c]	1	1	1.25	1	1	1
	Euro 3			**Euro 3**		
Durability requirement	-	1[a][d]	-	-	1.1[a]	-
RS-ZH (2000-2013)[c]	1.06	1.125	1.25	-	-	-
RS CONOX (2011-18)	1	1.07	1.2	-	-	-
Proposal	**1**	**1.05**	**1.2**	**1**	**1**	**1**
	Euro 4			**Euro 4**		
Durability requirement	-	1[d]	-	-	1.1	-
RS-ZH (2000-2013)[c]	1	1	1	1	1	1
RS CONOX (2011-18)	1	1.04	1.09	1	1.1	1.9
Proposal	**1**	**1.03**	**1.06**	**1**	**1**	**1.3**
	Euro 5			**Euro 5**		
Durability requirement	-	-	1.1[b][d]	-	-	1.5[b]
RS CONOX (2011-18)	1	1	1	1	1.2	1.6
Proposal	**1**	**1**	**1.03**	**1**	**1**	**1.3**

(a) Requirement up to 80,000 km.
(b) Requirement up to 160,000 km.
(c) Chen & Borken-Kleefeld 2016.
(d) For NO_X alone and NO_X+HC.

Appendix 4: Proposed improved real-world fuel consumption adjustment factors

Table 34 shows the proposed improved real-world fuel consumption adjustment factors for European and New Zealand new light vehicles to get VEPM predictions (at 48 km/hr) to match VFEM estimates.

Table 34: Proposed improved real-world fuel consumption adjustment factors for European and New Zealand new light vehicles from this update

Standard	Segment	VEPM Engine size (l)	VEPM YoM	VEPM Unadj FC (l/100km)	VFEM Engine size/s (cc)	VFEM YoM	VFEM RW FC (l/100km)	Proposed Adjustment Factor
<u>1.1</u>	**<u>Petrol Cars</u>**							
PRE ECE	Small	<1.4 l	<= '71	8.453	<1350	70-71	8.555	1.012
	Medium	1.4 - 2.0 l	<= '71	9.869	<1600, <2000	70-71	9.411	0.954
	Large-SUV-Executive	> 2.0 l	<= '71	11.915	<3000, >3000	70-71	12.159	1.021
ECE 15/00-01	Small	< 1.4 l	72-77	7.232	<1350	72-77	8.541	1.181
(ECE 15/00)	Medium	1.4 - 2.0 l	72-77	8.239	<1600, <2000	72-77	9.396	1.140
	Large-SUV-Executive	> 2.0 l	72-77	8.914	<3000, >3000	72-77	12.139	1.362
ECE 15/00-01	Small	< 1.4 l	72-77	7.232	<1350	72-77	8.541	1.181
(ECE 15/01)	Medium	1.4 - 2.0 l	72-77	8.239	<1600, <2000	72-77	9.396	1.140
	Large-SUV-Executive	> 2.0 l	72-77	8.914	<3000, >3000	72-77	12.139	1.362
ECE 15/02	Small	< 1.4 l	78-80	6.844	<1350	78-80	8.525	1.246
	Medium	1.4 - 2.0 l	78-80	7.620	<1600, <2000	78-80	9.379	1.231
	Large-SUV-Executive	> 2.0 l	78-80	9.595	<3000, >3000	78-80	12.118	1.263
ECE 15/03	Small	< 1.4 l	81-84	6.844	<1350	81-84	8.513	1.244
	Medium	1.4 - 2.0 l	81-84	7.620	<1600, <2000	81-84	9.366	1.229
	Large-SUV-Executive	> 2.0 l	81-84	9.595	<3000, >3000	81-84	12.100	1.261
ECE 15/04	Small	< 1.4 l	85-95	6.558	<1350	85-95	8.488	1.294
	Medium	1.4 - 2.0 l	85-95	7.845	<1600, <2000	85-95	9.338	1.190
	Large-SUV-Executive	> 2.0 l	85-95	8.695	<3000, >3000	85-95	12.064	1.388

Standard	Segment	VEPM Engine size (l)	VEPM YoM	VEPM Unadj FC (l/100km)	VFEM Engine size/s (cc)	VFEM YoM	VFEM RW FC (l/100km)	Proposed Adjustment Factor
Euro 1	Small	< 1.4 l	96-99	6.215	<1350	96-99	8.319	1.339
	Medium	1.4 - 2.0 l	96-99	7.451	<1600, <2000	96-99	9.152	1.228
	Large-SUV-Executive	> 2.0 l	96-99	9.618	<3000, >3000	96-99	11.824	1.229
Euro 2	Small	< 1.4 l	00-03	5.981	<1350	00-03	8.077	1.350
	Medium	1.4 - 2.0 l	00-03	7.299	<1600, <2000	00-03	8.885	1.217
	Large-SUV-Executive	> 2.0 l	00-03	9.958	<3000, >3000	00-03	11.480	1.153
Euro 3	Small	< 1.4 l	04-08	6.352	<1350	04-08	7.804	1.229
	Medium	1.4 - 2.0 l	04-08	7.555	<1600, <2000	04-08	8.585	1.136
	Large-SUV-Executive	> 2.0 l	04-08	9.095	<3000, >3000	04-08	11.092	1.220
Euro 4	Small	< 1.4 l	09-15	6.485	<1350	09-15	7.410	1.143
	Medium	1.4 - 2.0 l	09-15	7.921	<1600, <2000	09-15	8.152	1.029
	Large-SUV-Executive	> 2.0 l	09-15	10.974	<3000, >3000	09-15	10.532	0.960
Euro 5	Small	< 1.4 l	16-24	6.485	<1350	16-24	6.694	1.032
	Medium	1.4 - 2.0 l	16-24	7.921	<1600, <2000	16-24	7.365	0.930
	Large-SUV-Executive	> 2.0 l	16-24	10.974	<3000, >3000	16-24	9.515	0.867
Euro 6 d-temp	Small	< 1.4 l	25-25	6.485	<1350	25	6.232	0.961
	Medium	1.4 - 2.0 l	25-25	7.921	<1600, <2000	25	6.856	0.866
	Large-SUV-Executive	> 2.0 l	25-25	10.974	<3000, >3000	25	8.858	0.807
Euro 6 d	Small	< 1.4 l	>=2026	6.485	<1350	26-31	5.927	0.914
	Medium	1.4 - 2.0 l	>=2026	7.921	<1600, <2000	26-31	6.520	0.823
	Large-SUV-Executive	> 2.0 l	>=2026	10.974	<3000, >3000	26-31	8.424	0.768
NZ new	Small	< 1.4 l	<= '87	6.844	<1350	70-87	8.527	1.246
	Medium	1.4 - 2.0 l	<= '87	7.620	<1600, <2000	70-87	9.381	1.231
	Large-SUV-Executive	> 2.0 l	<= '87	9.595	<3000, >3000	70-87	12.120	1.263

Standard	Segment	VEPM Engine size (l)	VEPM YoM	VEPM Unadj FC (l/100km)	VFEM Engine size/s (cc)	VFEM YoM	VFEM RW FC (l/100km)	Proposed Adjustment Factor
NZ new	Small	< 1.4 l	88-92	6.718	<1350	88-92	8.488	1.263
	Medium	1.4 - 2.0 l	88-92	7.586	<1600, <2000	88-92	9.338	1.231
	Large	> 2.0 l	88-92	9.600	<3000, >3000	88-92	12.064	1.257
NZ new	Small	< 1.4 l	93-97	6.467	<1350	93-97	8.436	1.305
	Medium	1.4 - 2.0 l	93-97	7.518	<1600, <2000	93-97	9.281	1.234
	Large	> 2.0 l	93-97	9.609	<3000, >3000	93-97	11.991	1.248
NZ new	Small	< 1.4 l	98-02	6.278	<1350	98-02	8.167	1.301
	Medium	1.4 - 2.0 l	98-02	7.468	<1600, <2000	98-02	8.985	1.203
	Large	> 2.0 l	98-02	9.615	<3000, >3000	98-02	11.609	1.207
NZ new	Small	< 1.4 l	>= '03	6.215	<1350	03	7.956	1.280
	Medium	1.4 - 2.0 l	>= '03	7.451	<1600, <2000	03	8.752	1.175
	Large	> 2.0 l	>= '03	9.618	<3000, >3000	03	11.308	1.176
1.2	**Diesel Cars**							
Conventional	Medium	< 2.0 l	<= '95	6.107	<1350, <1600, <2000	70-95	8.136	1.332
	Large-SUV-Executive	> 2.0 l	<= '95	6.107	<3000, >3000	70-95	10.823	1.772
Euro 1	Medium	< 2.0 l	96-99	5.418	<1350, <1600, <2000	96-99	7.742	1.429
	Large-SUV-Executive	> 2.0 l	96-99	7.412	<3000, >3000	96-99	10.299	1.389
Euro 2	Medium	< 2.0 l	00-03	5.675	<1350, <1600, <2000	00-03	7.637	1.346
	Large-SUV-Executive	> 2.0 l	00-03	7.412	<3000, >3000	00-03	10.159	1.371
Euro 3	Medium	< 2.0 l	04-07	5.586	<1350, <1600, <2000	04-07	7.532	1.348
	Large-SUV-Executive	> 2.0 l	04-07	7.412	<3000, >3000	04-07	10.019	1.352
Euro 4	Medium	< 2.0 l	08-15	5.586	<1350, <1600, <2000	08-15	7.333	1.313
	Large-SUV-Executive	> 2.0 l	08-15	7.412	<3000, >3000	08-15	9.755	1.316
Euro 5	Medium	< 2.0 l	16-24	5.586	<1350, <1600, <2000	16-24	6.739	1.206
	Large-SUV-Executive	> 2.0 l	16-24	7.412	<3000, >3000	16-24	8.958	1.209

Standard	Segment	VEPM Engine size (l)	VEPM YoM	VEPM Unadj FC (l/100km)	VFEM Engine size/s (cc)	VFEM YoM	VFEM RW FC (l/100km)	Proposed Adjustment Factor
Euro 6 d-temp	Medium	< 2.0 l	25-25	5.586	<1350, <1600, <2000	25	6.368	1.140
	Large-SUV-Executive	> 2.0 l	25-25	7.412	<3000, >3000	25	8.465	1.142
Euro 6 d	Medium	< 2.0 l	>=2026	5.586	<1350, <1600, <2000	26-31	6.124	1.096
	Large-SUV-Executive	> 2.0 l	>=2026	7.412	<3000, >3000	26-31	8.139	1.098
1.3	**Hybrid and Electric**							
Petrol Hybrid	Medium		All Years	3.831	All sizes	01-31	6.621	1.728
Plug-in hybrid			All Years	1.839	All sizes	01-31	3.465	1.884
2.1	**Petrol LCVs**							
Conventional	N1-III		<= '95	10.150	All sizes	70-95	11.653	1.148
Euro 1	N1-III		96-99	11.909	All sizes	96-99	11.264	0.946
Euro 2	N1-III		00-03	11.909	All sizes	00-03	11.160	0.937
Euro 3	N1-III		04-08	11.909	All sizes	04-08	11.057	0.928
Euro 4	N1-III		09-15	11.909	All sizes	09-15	10.811	0.908
Euro 5	N1-III		16-24	6.980	All sizes	16-24	9.764	1.399
Euro 6 d-temp	N1-III		25-26	6.980	All sizes	25-26	9.023	1.293
Euro 6 d	N1-III		>=2027	6.980	All sizes	27-32	8.527	1.222
2.2	**Diesel LCVs**							
Conventional	N1-III		<= '95	8.477	All sizes	70-95	9.834	1.160
Euro 1	N1-III		96-99	7.557	All sizes	96-99	9.358	1.238
Euro 2	N1-III		00-03	7.557	All sizes	00-03	9.231	1.221
Euro 3	N1-III		04-07	7.557	All sizes	04-08	9.104	1.205
Euro 4	N1-III		08-15	7.557	All sizes	09-15	8.863	1.173
Euro 5	N1-III		16-24	7.816	All sizes	16-24	8.137	1.041
Euro 6 d-temp	N1-III		25-26	7.816	All sizes	25-26	7.645	0.978
Euro 6 d	N1-III		>=2027	7.816	All sizes	27-32	7.310	0.935

Table 35 shows the proposed improved real-world fuel consumption adjustment factors for Japanese used imported light vehicles to get VEPM predictions (at 48 km/hr) to match VFEM estimates.

Table 35: Proposed improved real-world fuel consumption adjustment factors for Japanese used imported light vehicles from this update

Standard	VEPM Engine size (l)	VEPM YoM	VEPM Unadj FC (l/100km)	VFEM Engine size/s (cc)	VFEM YoM	VFEM RW FC (l/100km)	Proposed Adjustment Factor
1.1	**Petrol Cars**						
Pre 1973, J73	< 1.4 l	50-74	8.453	<1350	70-74	8.549	1.011
	1.4 - 2.0 l	50-74	9.869	<1600, <2000	70-74	9.405	0.953
	> 2.0 l	50-74	11.915	<3000, >3000	70-74	12.152	1.020
J75, J76	< 1.4 l	75-77	6.215	<1350	75-77	8.535	1.373
	1.4 - 2.0 l	75-77	7.451	<1600, <2000	75-77	9.390	1.260
	> 2.0 l	75-77	9.618	<3000, >3000	75-77	12.132	1.261
J78	< 1.4 l	78-85	6.215	<1350	78-85	8.517	1.370
	1.4 - 2.0 l	78-85	7.451	<1600, <2000	78-85	9.370	1.258
	> 2.0 l	78-85	9.618	<3000, >3000	78-85	12.105	1.259
J78	< 1.4 l	78-85	6.215	<1350	78-85	8.517	1.370
	1.4 - 2.0 l	78-85	7.451	<1600, <2000	78-85	9.370	1.258
	> 2.0 l	78-85	9.618	<3000, >3000	78-85	12.105	1.259
J00	< 1.4 l	00-04	6.352	<1350	00-04	8.046	1.267
	1.4 - 2.0 l	00-04	7.555	<1600, <2000	00-04	8.852	1.172
	> 2.0 l	00-04	9.095	<3000, >3000	00-04	11.437	1.257
J05	< 1.4 l	> '05	6.485	<1350	05-10	7.713	1.189
	1.4 - 2.0 l	> '05	7.921	<1600, <2000	05-10	8.485	1.071
	> 2.0 l	> '05	10.974	<3000, >3000	05-10	10.963	0.999
1.2	**Diesel Cars**						
Pre 1986	< 2.0 l	50-85	6.107	<1350, <1600, <2000	70-85	8.268	1.354
	> 2.0 l	50-85	6.107	<3000, >3000	70-85	10.998	1.801

Standard	VEPM Engine size (l)	VEPM YoM	VEPM Unadj FC (l/100km)	VFEM Engine size/s (cc)	VFEM YoM	VFEM RW FC (l/100km)	Proposed Adjustment Factor
J86	< 2.0 l	86-91	5.418	<1350, <1600, <2000	86-91	7.979	1.473
	> 2.0 l	86-91	7.412	<3000, >3000	86-91	10.614	1.432
J92, J94	< 2.0 l	92-97	5.418	<1350, <1600, <2000	92-97	7.821	1.443
	> 2.0 l	92-97	7.412	<3000, >3000	92-97	10.404	1.404
J98	< 2.0 l	98-01	5.418	<1350, <1600, <2000	98-01	7.689	1.419
	> 2.0 l	98-01	7.412	<3000, >3000	98-01	10.229	1.380
J02	< 2.0 l	02-04	5.418	<1350, <1600, <2000	02-04	7.597	1.402
	> 2.0 l	02-04	7.412	<3000, >3000	02-04	10.107	1.363
J05	< 2.0 l	> '05	5.586	<1350, <1600, <2000	05-10	7.479	1.339
	> 2.0 l	> '05	7.412	<3000, >3000	05-10	9.949	1.342
2.1	**Petrol LCVs**						
J73, J75, J79		50-79	10.150	All sizes	70-79	11.860	1.169
J79, J81		80-87	10.150	All sizes	80-87	11.627	1.146
J88		88-00	11.909	All sizes	88-00	11.355	0.953
J01		01-04	11.909	All sizes	01-04	11.134	0.935
J05		> '05	11.909	All sizes	05-10	11.005	0.924
2.2	**Diesel LCVs**						
Pre 1974, J74		50-76	8.477	All sizes	70-76	10.136	1.196
J77, J79		77-81	8.477	All sizes	77-81	9.946	1.173
J82, J83, J87		82-87	8.477	All sizes	82-87	9.771	1.153
J88		88-92	7.557	All sizes	88-92	9.596	1.270
J93		93-96	7.557	All sizes	93-96	9.453	1.251
J97, J03		97-04	7.557	All sizes	97-04	9.263	1.226
J05		> '05	7.557	All sizes	05-10	9.040	1.196