Vehicle Emissions Prediction Model: VEPM 7.0 technical report

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Executive summary

The Vehicle Emissions Prediction Model (VEPM) predicts 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 previous version of VEPM (VEPM 6.3) was released in April 2021 (Metcalfe et al 2022). The upgraded VEPM 7.0 is a web-based application which replaces the VEPM 6.3 spreadsheet.

The methodology, assumptions, and emission factors in VEPM 7.0 are identical to VEPM 6.3. However, some changes in functionality have been implemented to simplify the user interface and emission factor calculations.

The purpose of this technical report is to provide technical information for VEPM users, including a description of the detailed assumptions and methodologies for calculating emission factors in VEPM 7.0. Recommendations for future updates are also provided. This VEPM 7.0 technical report supersedes previous technical reports.

Contents

Glossary of terms and abbreviations

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
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 Programme to calculate Emissions from Road Transport
DPF	Diesel particulate filter
EC	Energy consumption
EGR	Exhaust gas recirculation (a type of NOx emission control technology)
EMEP/EEA	European Monitoring and Evaluation Programme/European Environment Agency
Euro	European vehicle emission legislation
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
GDI	Gasoline direct injection (a type of vehicle technology)
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

MoT	Te Manatū Waka: Ministry of Transport
NO_X	Oxides of nitrogen, including nitric oxide nitrogen dioxide and nitrous oxide
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)
PM	Particulate matter
Rigid vehicle	A rigid vehicle has a driver's position, a steering system, motive power and a single rigid chassis.
RUC	Road user charges
SCR	Selective Catalytic Reduction (a type of NOx emissions control technology)
SUV	Sports utility vehicles
VEPM	Vehicle Emissions Prediction Model, developed by Waka Kotahi to predict air emissions and fuel consumption for the New Zealand fleet
VFEM	The Vehicle Fleet Emissions Model developed by MoT to predict the makeup, travel, energy (fuel and electricity) use and greenhouse gas emissions of the New Zealand vehicle fleet for all years from 2001 to 2055
VFEM3	Version 3 of the Vehicle Fleet Emissions Model
VKT	Vehicle kilometres travelled
VOC	Volatile organic compound
YOM	Year of manufacture

1. Introduction

The Waka Kotahi NZ Transport Agency (Waka Kotahi) Vehicle Emissions Prediction Model (VEPM) predicts emissions from vehicles in the New Zealand fleet under typical road, traffic and operating conditions.

This report provides technical information for VEPM users, including a description of the detailed methodology and assumptions for calculation of emission factors in VEPM 7.0. The VEPM User Guide provides instructions for running VEPM[1].

1.1 VEPM

To assess the air quality effects of road projects, or changes in vehicle technology or fleet characteristics it is necessary to estimate emissions from motor vehicles. This can be achieved using emission factors.

Emissions factors are the quantity of pollutants emitted per kilometre driven. Vehicle emissions are primarily dependent on the vehicle type and fuel. Vehicle emissions are also dependent on the driving conditions. For example, emissions are different for any given vehicle under acceleration or deceleration, at different speeds and engine loads.

VEPM is an average speed model which predicts emission factors for the New Zealand fleet under typical road, traffic and operating conditions. Average speed models are based on the fact that the average emissions factor for a pollutant and vehicle type/technology varies as a function of the average speed during a trip.

VEPM calculates New Zealand fleet weighted emission factors for:

- Exhaust emission factors for harmful pollutants:
    - Particulate matter ($PM_{2.5}$[2])
    - Nitrogen oxides (NO_X)
    - Nitrogen dioxide (NO_2)
    - Volatile organic compounds (VOC)
    - Carbon monoxide (CO)
- Exhaust emission factors for greenhouse gases:
    - Carbon dioxide (CO_2)
    - Methane (CH_4)
    - Nitrous oxide (N_2O)
    - Carbon dioxide equivalent, which is calculated from CO_2, CH_4 and N_20 factors (CO_2e)
- Brake and tyre wear factors for particulate matter smaller than 10 µm (PM_{10}) or smaller than 2.5 µm ($PM_{2.5}$)

VEPM also calculates New Zealand fleet weighted fuel consumption.

[1] The model and user guide are available at nzta.govt.nz
[2] Exhaust PM is denoted as $PM_{2.5}$ in VEPM, however almost all PM from vehicle exhaust is less than 1 micron (PM_1), with the majority being in the 10-100 nanometre range.

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

VEPM derives New Zealand-relevant factors based on emissions factors from the European COPERT model (Computer Programme to calculate Emissions from Road Transport). COPERT is a widely used software tool for calculating real world air pollutant and greenhouse gas emissions from the road transport sector. COPERT emission factors are published by the European Monitoring and Evaluation Programme and the European Environment Agency (EMEP/EEA) in a spreadsheet (EEA 2021a). The emission factors are constantly being updated with improved factors for new technologies, emerging issues and real-world effects.

A substantial proportion of the New Zealand fleet is second hand Japanese domestic vehicles, which are manufactured to Japanese vehicle emission standards. VEPM does not include specific Japanese emission factors, because a comprehensive Japanese emissions model is not readily available. An equivalent European emission factor is assumed in VEPM for each Japanese vehicle category, emission standard and pollutant based on a detailed comparison of emission factors from European and Japanese emission models. This approach has been used internationally[3].

1.2 Purpose of VEPM

VEPM has been developed to quantify vehicle emissions and predict how these are likely to change over time. The model can estimate the effect that new technology and improved fuel will have on emissions from New Zealand's vehicle fleet. An important feature of the model is the ability to estimate changes to vehicle emissions in future years (from 2001 to 2050).

VEPM provides estimates that are suitable for air quality assessments, greenhouse gas assessments and emissions inventories. VEPM has been successfully used around New Zealand to estimate vehicle emissions in air quality and greenhouse gas assessments for road projects. The model provides vehicle emission factors, which are used in conjunction with traffic models and air dispersion models to predict air pollutant concentrations downwind of the road.

VEPM emission factors are used in the Air quality screening model[4], which is a simple online tool to assist with undertaking preliminary or screening assessments. VEPM is also used in more detailed assessments. A schematic of the detailed assessment process using VEPM is shown in Figure 1. The Waka Kotahi guide to assessing air quality impacts from state highway projects[5] provides specific guidance for using VEPM to assess potential air quality effects associated with state highway asset improvement projects.

[3] For example, the developers of COPERT used a similar process to develop emission factors for Cyprus where the fleet is dominated by Japanese used imports.
[4] Air quality screening model | Waka Kotahi NZ Transport Agency (nzta.govt.nz)
[5] Air quality assessment guide - October 2019 (nzta.govt.nz)

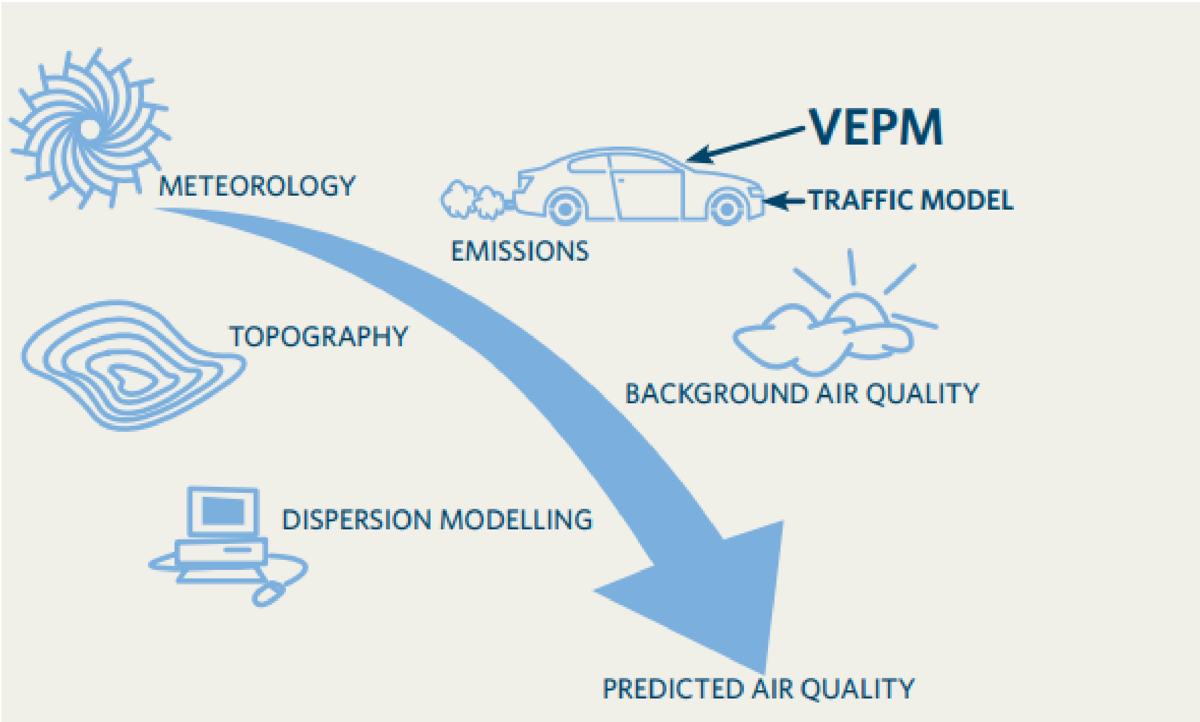

Figure 1: VEPM and the air quality assessment process

1.3 VEPM 7.0

VEPM 7.0 is a web-based application which replaces the spreadsheet version.

The methodology, assumptions and emission factors in VEPM 7.0 are identical to the previous version, VEPM 6.3. However, some changes in functionality have been implemented to simplify the user interface and emission factor calculations as follows:

- Removal of the option to 'remove catalytic converter'.
- Removal of the option to select 'petrol type' and 'diesel type'.
- Removal of the option to specify number of axles on heavy duty vehicles (for calculation of brake and tyre wear).
- Reporting PM_{10} and $PM_{2.5}$ for brake and tyre wear (instead of the user selecting a size fraction which could previously be TSP, PM_{10}, $PM_{2.5}$, PM_1 or $PM_{0.1}$).

1.4 Purpose and scope of this report

The purpose of this report is to provide technical information for VEPM users, including a detailed description of the assumptions and methodologies for calculating emission factors in VEPM 7.0.

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. Each update is typically accompanied by a technical report describing changes to assumptions and methodologies. This VEPM 7.0

report supersedes previous technical reports. However, previous reports are referred to for further detail where appropriate.

1.5 Structure of this report

Chapter 2 of this report provides technical background information for VEPM users, including discussion of the limitations and uncertainty of VEPM. User defined model inputs are also described. Subsequent sections provide information on the methodology and assumptions used to calculate fleet weighted emission factors as follows:

- Chapter 3 provides an overview of the methodology for calculating fleet weighted emissions factors in VEPM.
- Chapter 4 describes the methodology and assumptions to develop default fleet profiles for all years from 2001 to 2050.
- Chapter 5 describes the methodology and assumptions for calculation of fuel consumption and emission factors for each vehicle sub-category.
- Chapter 6 summarises recommendations for future updates.

2. Information for VEPM users

This chapter provides technical background information for VEPM users, including discussion of the limitations and uncertainty of VEPM and a description of user defined model inputs. Additional information about particulate emissions, idle emission rates and the history of VEPM is also provided.

2.1 Limitations of VEPM

VEPM is an average-speed model which is comparatively easy to use, and there is a reasonably close correspondence between the required model inputs and the data generally available to users. However, average speed models do have limitations as described in Appendix 1.

VEPM emission factors are intended to represent:

- typical driving behaviour
- typical congestion levels (at the user defined speed)
- typical road types
- fleet averaged emission characteristics for each vehicle category (for example, the NOx emission factor for EURO I petrol cars is representative of NOx emissions from the average EURO I petrol car, however there may be considerable variation in NOx emissions from individual vehicles).

Emission factors from VEPM will not accurately represent:

- extreme driver behaviour
- emissions from a particular vehicle
- micro events, e.g. emissions over a short time period at a particular location.

VEPM is generally appropriate for assessments of greenhouse gas emissions or air quality effects where average emissions are required over 1 hour or 24-hour assessment periods for the 'average fleet'.

VEPM can account for variation in the fleet composition (e.g. the proportion of heavy duty vehicles), road gradient and heavy vehicle load. Emission estimates are sensitive to these variables, so local data should be used where possible.

VEPM is the only vehicle emissions model available in New Zealand. Other types of models could theoretically provide more detail and accuracy. However, As discussed in Appendix 1, these potential improvements may be offset by a requirement for more detailed input data, the generation of which will also involve some uncertainty.

2.2 Uncertainty of VEPM

All emission models have an inherent uncertainty and evaluating this is a complex task. In the case of VEPM, this is compounded by the fact that the emission factors are based on test data from European vehicles. Research has found that real world emissions from New Zealand vehicles are comparable with real world emissions from European vehicles (Kuschel et al 2019), which supports the continued use of European emission factors in VEPM. However, at a fleet average level, we know that there are differences between the European and New Zealand vehicle fleets (Metcalfe, Kuschel and Gimson, 2020).

Understanding the uncertainty of VEPM emission factors and validating emission estimates with real-world information is an area of ongoing research (Smit et al. 2022).

2.3 Model inputs

Emission factor calculations in VEPM are affected by user defined model inputs, which are briefly described in this section. Instructions for using the model are provided in the VEPM User Guide.

2.3.1 Year

The analysis year, between 2001 and 2050, is selected by users in the VEPM 7.0 Year & Speed tab (as shown in Figure 2). The default fleet profile is based on the user selected year.

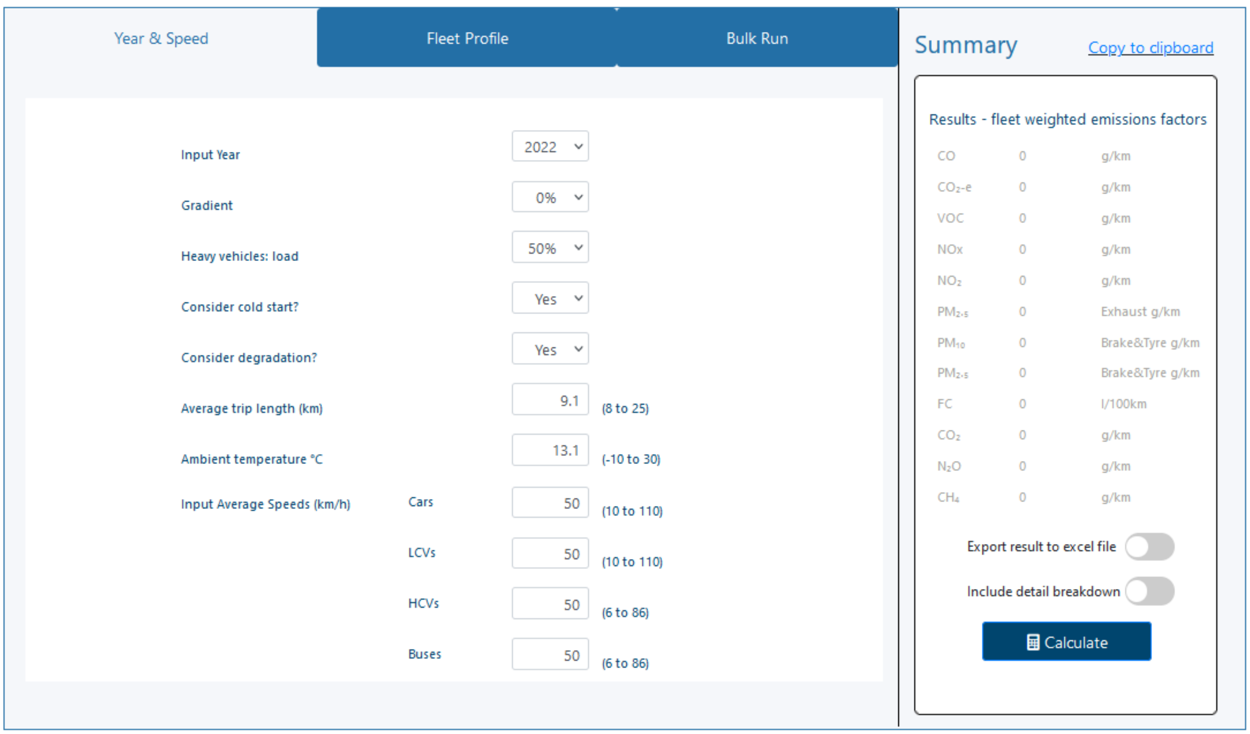

Figure 2: VEPM 7.0 Year & Speed tab

2.3.2 Speed

Average speed is selected by users in the VEPM 7.0 Year and Speed tab (as shown in Figure 2).

For light duty vehicles, average speed must be between 10 and 110km/h. For heavy duty vehicles the valid speed range depends on the vehicle size, the gradient and load.

Average speed emission factors are intended to represent emissions as a function of mean vehicle speed over a complete driving cycle of several kilometres. Average speed data is often derived from traffic models. It is generally appropriate for speed data to be derived from traffic models at a minimum resolution of 1 hour.

2.3.3 Gradient

Gradient is an optional input, which can be selected by users in the VEPM 7.0 Year and Speed tab (as shown in Figure 2). The default gradient is 0%.

Vehicle emissions can be significantly affected by road gradient. Road gradients between -6% and +6% can be selected in 2% increments for both light and heavy-duty vehicles.

Users should be aware that the impact of gradient on emissions is significant. Depending on the gradient and the pollutant being considered, the increase in emissions uphill tends to be significantly greater than the corresponding reduction in emissions going downhill. This means, it cannot be assumed that the increase in emissions due to uphill sections will be cancelled out by the effects of the corresponding downhill sections if the region over which emissions are being assessed has a net zero change in elevation.

2.3.4 Heavy vehicle load

Heavy vehicle emissions are higher when the vehicle is fully loaded. Loading factors for heavy vehicles of 0%, 50% and 100% can be selected. The default load is 50%.

2.3.5 Consider cold start?

When a vehicle is started from cold, emissions are substantially higher, until the engine and catalyst warm up. Cold start effects are included in the emissions calculation by default. This option allows the user to ignore cold start effects, which is appropriate for estimation of emissions from roads outside urban areas.

2.3.6 Consider degradation?

The model includes some allowance for degradation of emissions over time. This option allows the user to ignore degradation effects.

2.3.7 Average trip length

The model allows the user to define average trip lengths. Trip length is used to calculate cold start emissions. So, for example, a shorter average trip length will result in higher average emissions because the proportion of the trip in cold start conditions is higher. The default value in VEPM is 9.1km.

2.3.8 Ambient temperature

Ambient temperature must be between -10 and 30°C. Ambient temperature affects cold start emissions, with higher emissions at lower temperatures. The default is set at 13.1°C to reflect an average winter temperature in Auckland. For specific times, or other locations, this variable should be adjusted.

2.3.9 Fleet profile

Users can adjust the percentage of VKT that is assigned to each vehicle category (shown in Table 2) in the VEPM 7.0 Fleet Profile tab (as shown in Figure 3). If the user defines the fleet profile, the default fleet (percentage of VKT for each vehicle sub-category) is adjusted proportionally.

Fleet weighted emission factors are sensitive to the proportion of heavy commercial vehicles in the fleet, so it is recommended that site-specific or local data should be used wherever possible. Note that:

- The user defined fleet must add up to 100%.
- Users cannot allocate %VKT to vehicle categories that are not included in the default fleet for the analysis year. For example, in 2001 there were no plug-in hybrid vehicles in the fleet so the user cannot include these in the fleet.

Figure 3: VEPM 7.0 Fleet Profile tab

2.4 Particulate

VEPM includes emission factors for particulate matter from vehicle exhaust as well as brake and tyre wear.

In VEPM exhaust particulate is denoted as $PM_{2.5}$. However, almost all particulate matter from both petrol and diesel exhaust is less than 1 micron, with the majority being in the 10-100 nanometre range.

PM from tyre and brake wear are substantially larger with around 40% being above 10 micrometres. VEPM provides estimated brake and tyre wear factors for PM_{10} and $PM_{2.5.}$ These factors are based on the methodology described in the European EMEP/EEA Air pollution emission inventory guidebook (EEA 2019).

VEPM does not include road surface wear emission factors. However, it is recommended that road surface wear emissions should be included in emissions inventories and assessments of air quality impacts. These can be estimated based on Tier 1 emission factors provided in the EMEP/EEA guidebook (EEA 2019).

2.5 Idle emission rates

VEPM does not provide idle emission rates. This means that intersection delays need to be accounted for in average speed calculations.

Alternatively, an approximation of idle emission rates could be obtained from VEPM as follows:

- Calculate emissions rates in grams/hour based on the VEPM emission factor (in g/km) and the corresponding speed at 10km/hour, 15km/hour and 20km/hour
- Extrapolate back to zero km/hour to estimate the emission rate in g/hour

A hypothetical example for carbon monoxide emissions is shown in Table 1.

Table 1: CO emission factors and rates at low speeds for a hypothetical example

Speed (km/hour)	Emission factor (g/km)	Emission rate (g/hour)
25	6.11	153
20	7.01	140
15	8.46	127
10	11.32	113

These emission rates are plotted in Figure 4. Extrapolating the line back to the (zero speed) y axis gives an approximate value for the idle rate of 85g/hour.

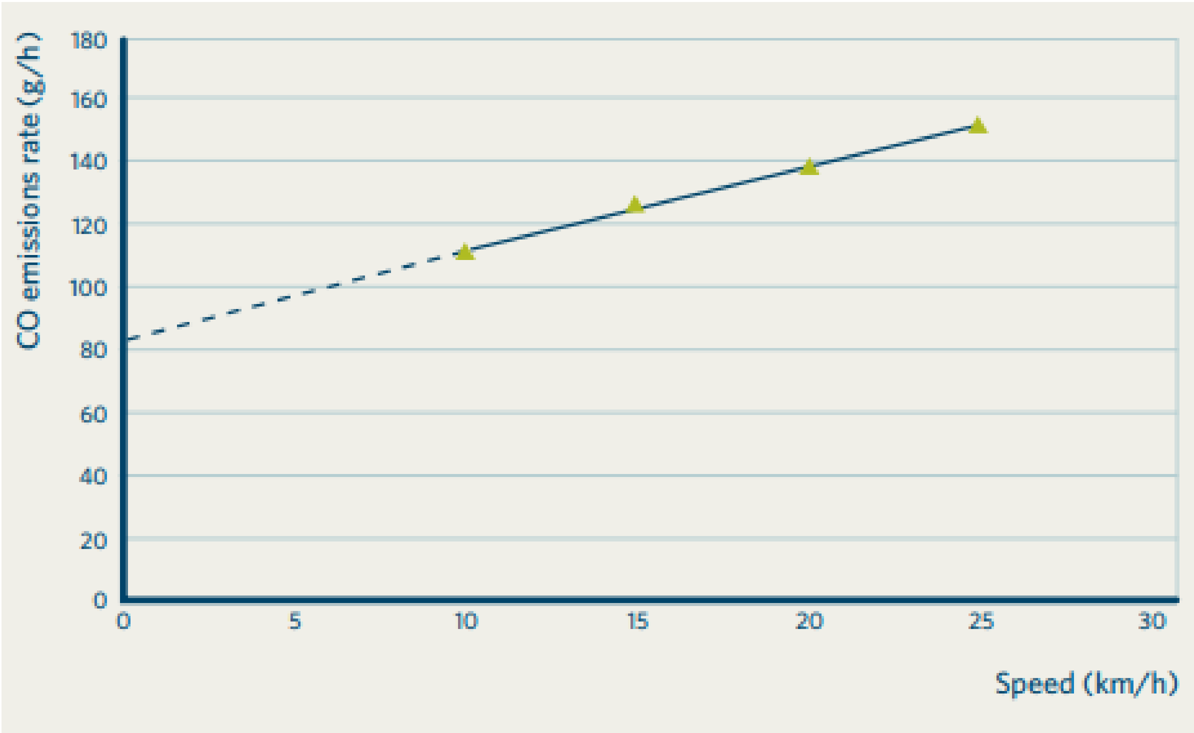

Figure 4: CO emission rates at low speeds for estimation of idle emission rates for a hypothetical example

2.6 Development of VEPM

VEPM was originally developed for the Auckland Council in 2008 (EFRU, 2008). At time of preparation (pre-2008) it was recognised that there was insufficient emissions test data from New Zealand domiciled vehicles to develop VEPM using New Zealand data. The New Zealand fleet includes vehicles that have been manufactured to various emission standards including Japanese, European and Australian. These different jurisdictions have introduced different emission requirements at different times and have used different emission measurement techniques. This inconsistency means that international emission models are not directly applicable to the New Zealand fleet. VEPM was therefore developed using New Zealand fleet data and emissions data from a range of international models. Given the makeup of the New Zealand fleet, and other emissions models in use around the world, emissions data from Japan, USA, Australia and Europe were investigated for the development of VEPM.

The majority of New Zealand new passenger car and light commercial fleet is manufactured to European emission standards. For vehicles manufactured to European emission standards, the UK National Atmospheric Emissions Inventory (NAEI) was selected as the most appropriate source of emission factors for development of VEPM. The NAEI model was supplemented with emissions data from other sources, including the available New Zealand data, where practicable. It also incorporated features from other models, e.g. emission factors for heavy duty vehicles and cold start emissions factors from the European Computer Model to Calculate Emissions from Road Transport (COPERT).

Since the development of VEPM, the NAEI has been updated a number of times and has now been replaced with emissions factors based on the COPERT model. Therefore, emission factors in VEPM have been updated based on emission factors from the COPERT model for all vehicles manufactured to European emission standards.

A substantial proportion of the passenger car and light commercial fleet is second hand Japanese domestic vehicles, which are manufactured to Japanese vehicle emission standards. Japanese vehicle emissions factors would have been ideal for these vehicles. However, a comprehensive Japanese emissions model is not readily available. For these vehicles, detailed comparison was undertaken to assign the closest equivalent European emission factor for each Japanese vehicle class and each pollutant as described in the technical report (EFRU 2008). This approach has also been used internationally[6].

VEPM has been regularly updated since it's release in 2008 to ensure its predictions reflect the changing emissions profile of the New Zealand fleet. Updates have incorporated updated New Zealand fleet data and the latest internationally available emission factors. Key updates to VEPM in each public release are summarised as follows:

- 2008 VEPM 3.0 based on the United Kingdom National Atmospheric Emissions Inventory (UK NAEI) database from the 1990's and early 2000's. To estimate emissions from the Japanese vehicle fleet, a detailed comparison of Japanese and European emission factors was undertaken.
- 2011 VEPM 5.0 based on updated factors from the UK NAEI database (2009) and the European COPERT 4, version 8, 2011 database. Extensive work was undertaken to calibrate VEPM 5.0 against all available emissions data from New Zealand.
- 2012 VEPM 5.1 incorporated emission factors for light duty vehicles at different road gradients from the World Road Association.
- 2017 VPM 5.3 included an updated fleet profile, country of origin and date of emission standard introduction. VEPM 5.3 incorporated emission factors based on COPERT for Euro 5, 6, and V, and the addition of Euro VI and includes emission factors for NO_2.
- 2019 VEPM 6.0 included an updated fleet profile, separate categories for hybrid, plug in hybrid and electric vehicles, including electric buses and trucks. VEPM 6.0 includes updated New Zealand fleet profile data and all emission factors in VEPM 6.0 were aligned and updated with the latest version of COPERT.
- 2020 VEPM 6.1 incorporated emission factors for buses and articulated trucks. Real world fuel consumption factors for light duty diesel vehicles were incorporated. All COPERT emission factors were updated.
- 2021 VEPM 6.2 incorporated an updated fleet profile, added emission factors for methane, nitrous oxide and carbon dioxide equivalent. Light duty vehicle degradation correction factors and gradient correction factors were updated and all COPERT emission factors were updated.
- 2022 VEPM 6.3 incorporated an updated fleet profile, revised assumed emission factors for Japanese used vehicles from 2010 and revised the assumed date of introduction of Euro 6/VI standards in New Zealand.

Details of each update are provided in the corresponding technical report. These are available on the Waka Kotahi website.

[6] The developers of COPERT used a similar process to develop emission factors for Cyprus where the vehicle fleet is also dominated by Japanese used imports.

3. Fleet weighted emission factor calculations in VEPM

This chapter outlines the overall methodology for calculating fleet weighted emissions factors in VEPM.

3.1 Overall methodology: calculation of fleet weighted emission factors

Fleet weighted emissions are calculated in VEPM by multiplying emissions factors in g/km for defined vehicle sub-categories by the proportion of vehicle kilometres travelled (VKT) for those sub-categories. The calculation of fleet weighted emission factors is shown schematically in Figure 5 and is described briefly in the following sections.

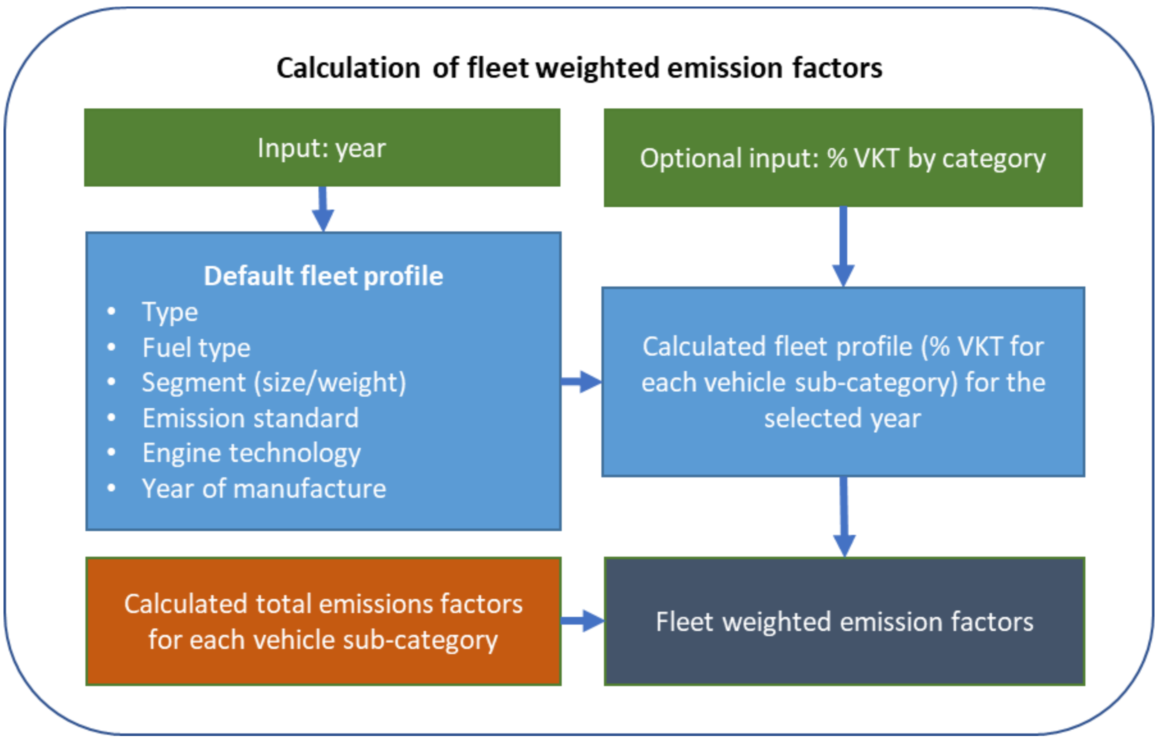

Figure 5: calculation of fleet weighted emission factors in VEPM.

3.1.1 Pollutants

VEPM calculates New Zealand fleet weighted emission factors for:

- Exhaust emission factors for harmful pollutants:
    - Particulate matter ($PM_{2.5}$[7])
    - Nitrogen oxides (NO_X)
    - Nitrogen dioxide (NO_2)
    - Volatile organic compounds (VOC)
    - Carbon monoxide (CO)

[7] Exhaust PM is denoted as $PM_{2.5}$ in VEPM, however almost all PM from vehicle exhaust is less than 1 micron (PM_1), with the majority being in the 10-100 nanometre range.

- Exhaust emission factors for greenhouse gases:
    - Carbon dioxide (CO_2)
    - Methane (CH_4)
    - Nitrous oxide (N_2O)
    - Carbon dioxide equivalent, which is calculated from CO_2, CH_4 and N_20 factors (CO_2e)
- Brake and tyre wear factors for particulate matter smaller than 10 µm (PM_{10}) or smaller than 2.5 µm ($PM_{2.5}$)

VEPM also calculates New Zealand fleet weighted fuel consumption.

3.2 VKT

3.2.1 Vehicle categories

VEPM calculates emission factors for the vehicle categories shown in Table 2.

The vehicle categories in Table 2 are further broken down into sub-categories within VEPM so that specific emission factors can be assigned. Sub-categories include:

- Engine size
    - Petrol cars:
        - <1350
        - ≥1350-1999cc
        - ≥2000cc
    - Diesel cars:
        - <2000cc
        - ≥2000cc
- Emission standard that the vehicle was manufactured to (e.g. Euro 5 or Euro 6), which is assigned based on the vehicle year of manufacture and country of manufacture.
- Some emission standard sub-categories are further broken down by engine technology type (for example, there are different Euro V emission factors for vehicles equipped with EGR or SCR emission control systems).

Table 2: Vehicle categories in VEPM 7.0

Vehicle categories		
Type	**fuel**	**Segment**
Cars	Petrol	<3.5t
	Diesel	<3.5t
	Hybrid	<3.5t
	Plug-in hybrid	<3.5t
	Electric	<3.5t
Light commercial vehicles (LCVs)	Petrol	<3.5t
	Diesel	<3.5t
	Hybrid	<3.5t
	Plug-in hybrid	<3.5t
	Electric	<3.5t
Buses	Diesel	Urban <=12 t Urban 12-18 t Coach 12-18 t
	Electric	>3.5 t
Heavy Commercial Vehicles (HCVs)	Diesel	Rigid <=7.5 t Rigid 7.5 - 10 t Rigid 10 - 20 t Rigid 20 - 25 t Rigid 25 - 30 t Rigid >30 t Articulated 14 - 20 t Articulated 20 - 28 t Articulated 28 - 34 t Articulated 34 - 40 t Articulated 40 - 50 t Articulated 50 - 60 t
	Electric	<10 t >10t

3.2.2 Default fleet profile

Default fleet data (percentage of VKT for each vehicle sub-category) is included in VEPM for all years between 2001 and 2050. The percentage of VKT for each vehicle sub-category is calculated in VEPM based on the user selected analysis year.

Vehicle sub-categories in the New Zealand vehicle fleet data are not consistent with sub-categories in the emission factor database. This means that a series of assumptions are required to derive a default New Zealand fleet for each year. These assumptions are described in chapter 4.

3.3 Emission factors

VEPM is based on emission factors from the European COPERT model, which are published by EMEP/EEA in a spreadsheet (EEA 2021a). The EMEP/EEA spreadsheet provides speed-based exhaust emission factors and energy consumption factors for vehicles broken down by type (passenger car, light commercial vehicle, etc), fuel, segment (size or vehicle weight), the emission legislation with which they are compliant[8] and in some cases, engine technology type.

Emission factors are calculated in VEPM for each vehicle sub-category (defined by type, fuel, size/weight segment and emission legislation/engine technology type) and each pollutant based on user defined speed and a range of optional inputs, which are described in the following section. The emission factors for each vehicle sub-category are combined with fleet data to calculate fleet weighted average emission factors for vehicle categories (shown in Table 2) and for the total fleet.

The methodology and assumptions for calculation of total emission factors for all vehicle sub-categories and pollutants are described in chapter 5.

[8] Some vehicle categories are further broken down by engine technology (for example EGR or SCR specifies the type of NOx emission control system).

4. Default fleet

This Chapter describes the methodology and assumptions to develop default fleet profiles for all years from 2001 to 2050.

4.1 Overall methodology: calculation of default fleet data

Default fleet data (the default percentage of VKT travelled for each vehicle category in VEPM) is included in VEPM for all years between 2001 and 2050.

Default fleet data is based on outputs from version 3 of the Te Manatū Waka: Ministry of Transport (MoT) Vehicle Fleet Emissions Model (VFEM3).

The methodology for deriving default fleet data is shown schematically in Figure 6 and is described in the following sections.

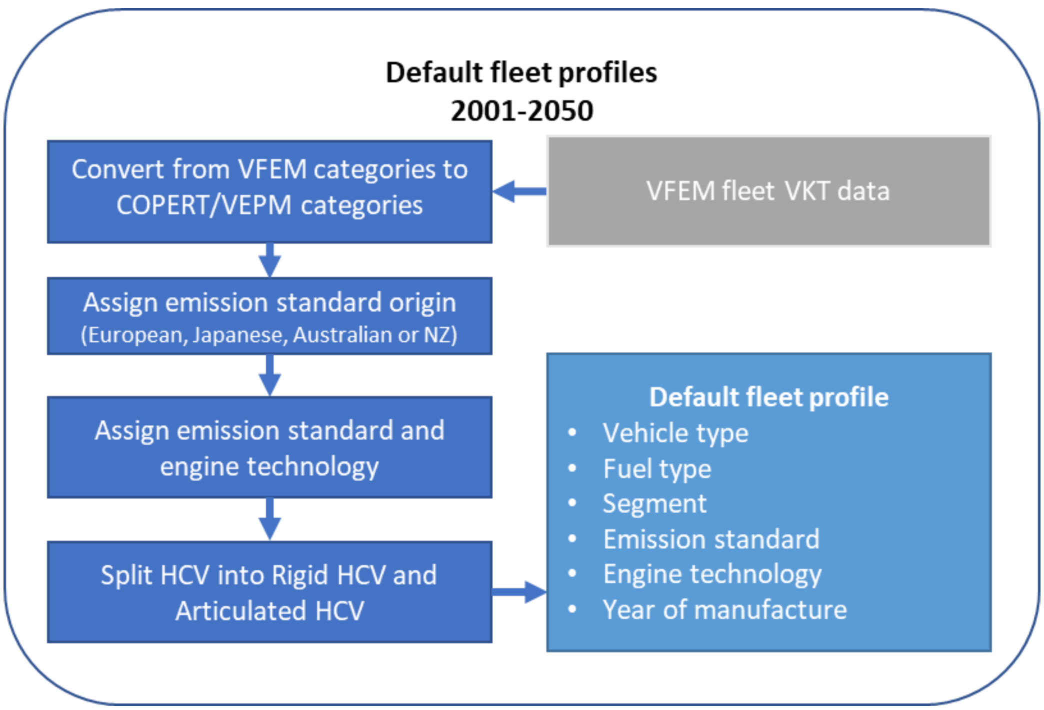

Figure 6: calculation of default fleet data in VEPM.

4.2 VFEM fleet VKT data

VKT data from VFEM3 is provided by MoT for all years from 2001 to 2050 broken down by:

- vehicle type,

- fuel type (petrol, diesel, hybrid, plugin hybrid, electric, etc[9])
- engine capacity (light duty vehicles) or vehicle mass (heavy vehicles)
- year of manufacture,
- and import status (whether the vehicle was sold new in New Zealand or was a used import).

Vehicle types include[10]:

- Light duty vehicles[11]:
  - Cars: passenger cars and sports utility vehicles (SUVs)
  - Light commercial vehicles (LCVs): Utes and vans with gross vehicle mass (GVM) up to 3.5 tonnes
- Heavy duty vehicles:
  - Heavy commercial vehicles (HCVs): Light trucks and heavy trucks with GVM > 3.5 tonnes
  - Buses > 3.5 tonnes

Fleet data in VEPM is regularly updated when VFEM is updated. Details of updated fleet data are provided in VEPM update technical reports.

4.2.1 VFEM fleet data in VEPM 7.0

Fleet data in VEPM 7.0[12] is based on VKT values from VFEM3 for the *high carbon price scenario*. At the time of writing, MoT staff consider this to be the most realistic VFEM3 scenario. The fleet data in VEPM 7.0 includes historical fleet and actual travel data to 2019 with projections to 2050.

Table 3 and Figure 7 show the overall default fleet profile in VEPM 7.0.

Note: the fleet projections in VEPM 7.0 do not account for recently announced policy initiatives including: the Clean Car Package, the biofuels mandate, the March 2024 extension to the road user charge (RUC) exemption for light electric vehicles and the upcoming Waka Kotahi requirement that new public transport buses be zero emission from 2025[13]. It is recommended that updated VFEM data should be incorporated into VEPM when it becomes available.

[9] VFEM includes data for some fuel types that are not currently included in VEPM. These are diesel hybrid, diesel plug-in hybrid, LPG/CNG and hydrogen/other.
[10] Mopeds and motorcycles are included in VFEM data but are not currently included in VEPM.
[11] VFEM includes separate categories for "shared use cars and SUVs" and "shared use vans and utes". These sub-categories are not relevant in VEPM. Shared use VKT are added to "car and SUVs" and "vans and utes" to provide total VKT for cars and SUVs and vans and utes in VEPM.
[12] Fleet data in VEPM 7.0 is unchanged from VEPM 6.3
[13] https://www.nzta.govt.nz/resources/requirements-for-urban-buses/

Table 3: Default fleet (% VKT by vehicle category totals) in VEPM 7.0

	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 hybrid	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	57.8%	7.4%	6.7%	0.6%	1.0%	2.7%	17.0%	0.1%	0.0%	0.1%	5.9%	0.7%	0.0%	0.0%
2030	49.8%	6.6%	12.3%	1.2%	3.3%	2.6%	16.9%	0.2%	0.1%	0.5%	5.7%	0.7%	0.1%	0.1%
2035	41.0%	5.3%	14.9%	2.0%	10.0%	2.4%	15.7%	0.3%	0.1%	1.9%	5.3%	0.7%	0.2%	0.1%
2040	31.2%	3.7%	12.1%	2.7%	23.3%	2.0%	13.2%	0.3%	0.2%	5.0%	4.9%	0.7%	0.5%	0.2%
2045	18.8%	2.2%	7.4%	2.7%	41.5%	1.6%	10.1%	0.3%	0.2%	8.8%	4.5%	0.7%	0.8%	0.3%
2050	10.5%	1.3%	3.9%	2.4%	54.5%	1.3%	7.3%	0.2%	0.2%	12.2%	4.0%	0.6%	1.2%	0.4%

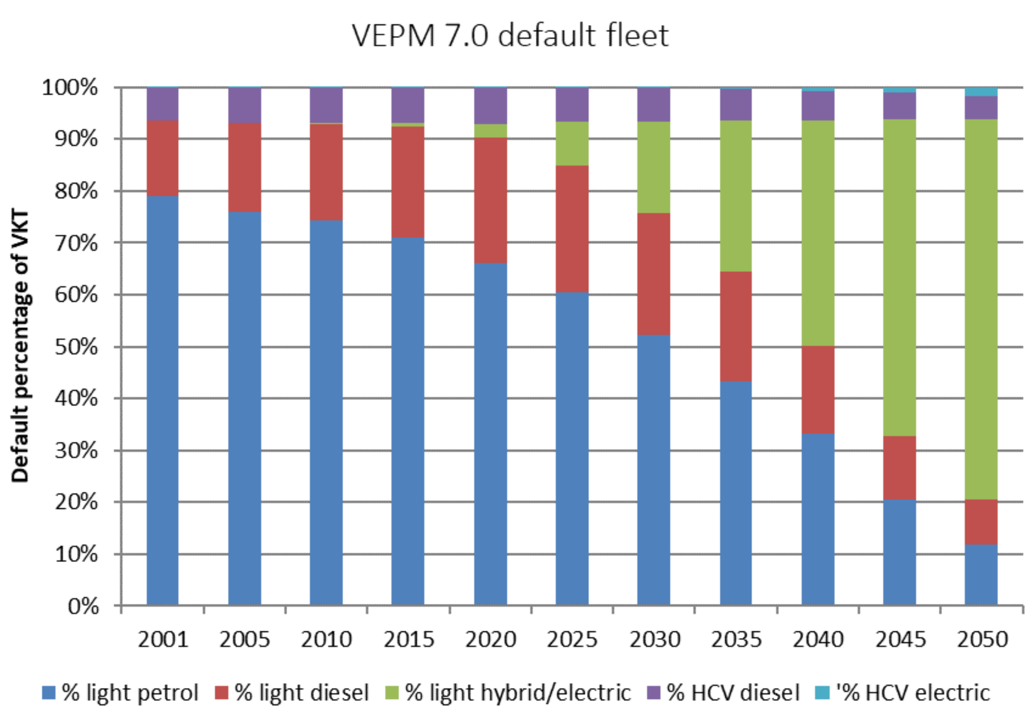

Figure 7: Default fleet (%VKT by vehicle category totals) in VEPM 7.0. Note that HCV includes buses

4.3 Equivalent EMEP/EEA vehicle categories assumed for VFEM vehicle categories

Vehicle classifications in the EMEP/EEA spreadsheet (EEA 2021a) do not match classifications in the New Zealand fleet data from VFEM. This means that a series of assumptions are required as summarised in Table 4. Assumptions for light commercial vehicles, and buses are described in more detail in the following subsections. Assumptions for splitting heavy vehicle VKT between rigid and articulated sub-categories are described in Section 4.8.

4.3.1 Light commercial vehicle category

All light commercial vehicles are classified as N1-III in VEPM on the basis that the average light commercial vehicle mass in New Zealand is roughly equivalent to the EMEP/EEA N1-III category (Metcalfe and Sridhar, 2019).

4.3.2 Bus and coach split

For the default fleet breakdown it is assumed that 80% of buses > 12 tonnes are urban buses standard and 20% are coaches. There is no data to support this assumption. Further investigation is recommended to confirm whether the bus and coach split is realistic.

4.3.3 Vehicle categories not included in VEPM

There are vehicle categories in the EMEP/EEA spreadsheet which are not currently included in VEPM (e.g. motorcycles and additional engine size categories for passenger cars). Further work is recommended to consider whether any of these additional categories warrant inclusion in future versions of VEPM.

Table 4: EMEP/EEA vehicle classifications assumed in VEPM7.0

Vehicle fuel and type	NZ VFEM fleet data segment	EMEP/EEA vehicle size segment used
Petrol passenger cars	Petrol cars and SUV’s ○ <1350 ○ 1350-1599cc ○ 1600-1999cc ○ 2000-2999cc ○ >=3000cc	Petrol passenger cars ○ Small ○ Medium ○ Medium ○ Large-SUV-Executive ○ Large-SUV-Executive
Diesel passenger cars	Diesel cars and SUV’s ○ <1350cc ○ 1350-1599cc ○ 1600-1999cc ○ 2000-2999cc ○ >=3000cc	Diesel passenger cars ○ Medium ○ Medium ○ Medium ○ Large-SUV-Executive ○ Large-SUV-Executive
Petrol hybrid	All engine sizes	Petrol hybrid medium, Euro 4
Petrol plug-in hybrid	All engine sizes	Emissions calculated based on emissions for petrol hybrid medium, Euro 4
Light commercial vehicles	Vans and Utes. All engine sizes	Light commercial vehicles N1-III class (reference mass > 1760kg)
Buses	3.5 – 7.5t 7.5 – 12t	Urban buses midi <= 15t
	>12t	Split between urban Buses standard 15-18t & coaches standard <= 18t
Heavy Commercial Vehicles	3.5 – 5.0t (light truck) 5.0 – 7.5t (light truck)	Rigid 3.5 – 7.5t
	7.5 – 10t (light truck)	Split between rigid 7.5 – 12t & articulated
	10 – 20t (heavy truck)	Split between rigid 14 – 20t & articulated
	20 – 25t (heavy truck)	Split between rigid 20 – 26t & articulated
	25 – 30t (heavy truck)	Split between rigid 26 – 28t & articulated
	>30t (heavy truck)	Split between rigid >32t & articulated

4.4 Emission standards

VEPM emission factors for each vehicle category (type, fuel, size segment) are broken down by emission standards (Euro 1, Euro 2 etc).

New Zealand fleet data from VFEM does not include vehicle emissions standards. This means that a series of assumptions are required to further breakdown VKT by emission standards depending on vehicle country of manufacture and year of manufacture. Appendix 2 shows the emission standard that is assigned in VEPM for each vehicle category (type, fuel, segment) by emission standard origin (European, Australian, New Zealand and Japanese) and year of manufacture.

4.5 Assigning country of manufacture and emissions standard origin

The New Zealand fleet includes vehicles that have been manufactured to emission standards from various regions including Europe, Australia and Japan as well as vehicles manufactured in New Zealand before emission standards were introduced.

The country of manufacture is particularly important for estimating emissions from vehicles manufactured from the 70s to the late 90s when there was considerable variation between the emissions standards of vehicles from different parts of the world. For more recent vehicle imports, we know that the vast majority of vehicles entering the fleet are manufactured to European standards (new vehicles) or Japanese standards (used vehicles) (Metcalfe and Sridhar 2017)[14].

VFEM vehicle data does not include a breakdown by country of manufacture or emission standards. This means that assumptions are required to assign emission standards in VEPM. As shown in The detailed methodology and assumptions are described in the following section.

Table 5, VKT is assigned to either European, Japanese, Australian or New Zealand emissions standards in VEPM based on year of manufacture, import status, as well as country of manufacture for older (up to 2009) vehicles. The methodology is summarised as follows:

- For vehicles up to year of manufacture 2009 emission standard origin is based on a detailed country of manufacture and import status breakdown of the fleet was that was developed for VEPM 5.3 based on analysis of fleet data up to 2014[15]. It was assumed that:
  - Vehicles manufactured in Europe, Australia and New Zealand are manufactured to European, Australian and New Zealand emission standards respectively
  - Vehicles manufactured in Japan and first sold in New Zealand (new import status) are manufactured to European standards
  - Used import vehicles from Japan are manufactured to Japanese standards
- For vehicles from year of manufacture 2010 onwards it is assumed that all new vehicles are manufactured to European emission standards and all used vehicles are manufactured to Japanese emission standards.

[14] Statistics on the emission standards of new vehicles are available at: Fleet statistics | Ministry of Transport
[15] This country of origin breakdown was developed in 2016 for incorporation into VEPM 5.3.

The detailed methodology and assumptions are described in the following section.

Table 5: Emissions standard origin assumed in VEPM based on vehicle country of origin and import status

Year of manufacture	Country of manufacture	Import status	Emission standards origin assumed
Up to 2009	Europe	New and used	European
	Australia	New and used	Australian
	New Zealand	N/A	New Zealand
	Japan	New	European
	Japan	Used	Japanese
2010 onwards	All	New	European
2010 onwards	All	Used	Japanese

The breakdown by emission standards origin (European, Australian, New Zealand, Japanese) for vehicles up to year of manufacture 2009 has not been updated since it was developed based on analysis of 2014 fleet data. It is recommended that update of this data should be considered as part of future fleet updates. Investigating whether vehicle import status from VFEM could be used to assign emission standards to vehicles manufactured before 2009 is also recommended.

4.5.1 Detailed emission standard origin methodology in VEPM 7.0

Emission standard origin is assigned using detailed historical data (from VEPM 5.3) for years of manufacture up to 2009 and based on import status (new or used) from VFEM for year of manufacture 2010 onwards.

The detailed methodology depends on the fleet year as described in the following subsections.

VEPM fleets from 2001-2009

For VEPM fleets from 2001 to 2009 detailed emission standard origin breakdown (proportion of VKT) for each vehicle year of manufacture and vehicle category (type, fuel, size segment and import status) is copied from VEPM 5.3 for the corresponding fleet year.

Note that the VEPM 5.3 breakdown was calculated as follows:

- Light duty vehicles:
  - country of manufacture data for the entire fleet was extracted from the motor vehicle register for all years between 2001 and 2014. This data included the vehicle import status.
  - the proportion of vehicles from each country (New Zealand, Australia, Japan and Europe) was calculated for each year of manufacture for each vehicle category (type, fuel, size segment and import status).

  - Emission standard origin (New Zealand, Australian, Japanese and European) was then assigned based on the assumptions shown in Table 5.
- Heavy duty vehicles:
  - country of manufacture data for the entire fleet was extracted from the motor vehicle register for all years between 2001 and 2014. This data **did not** include the vehicle import status which was not available at the time.
  - the proportion of vehicles from each country of manufacture (Europe, Japan, Australia and New Zealand) was calculated for each year of manufacture for each vehicle category (type, fuel, size segment).
  - the country of manufacture proportions were applied to VKT for each year of manufacture for each vehicle category to calculate VKT broken down by country of manufacture, year of manufacture and vehicle category (type, fuel, size segment).
  - Import status (new or used) was not available for heavy duty vehicles. For Japanese manufactured vehicles, VKT were split between new and used vehicles based on 2015 fleet data as follows:
    - For years of manufacture up to 2007, heavy duty VKT was split between new and used based on the total percentage of used heavy duty vehicles, by year of manufacture, in the 2015 fleet[16]. It was assumed that all used vehicles were Japanese country of origin.
    - For years of manufacture from 2008 onwards, it was assumed that the proportion of Japanese country of origin vehicles that are used stayed constant at 50% (compared to 48% in 2007).
    - The split between new and used heavy duty Japanese vehicles for years of manufacture up to 2010 was assumed to be the same for all fleet years.
  - Emission standard origin (New Zealand, Australian, Japanese and European) was then assigned based on the assumptions shown in Table 5.

VEPM fleets from 2001-2009

For VEPM fleets from 2010 to 2014 emission standard origin is assigned as follows in VEPM 7.0:

- For years of manufacture 1968-2009 the detailed emission standard origin breakdown is assumed to be the same as VEPM 5.3 for the corresponding fleet year.
- For years of manufacture 2010 onwards, the emission standard origin is based on import status (new or used) from VFEM. It is assumed that all NZ New vehicles are manufactured to European emission standards and all used imports are manufactured to Japanese emission standards.

VEPM fleets from 2015 onwards

For VEPM fleets from 2015 onwards emission standard origin is assigned as follows in VEPM 7.0:

- For years of manufacture 1968-2009, the detailed emission standard origin breakdown is assumed to be the same as VEPM 5.3 fleet 2014.
- For years of manufacture 2010 onwards, the assumption is the same as for VEPM fleets from 2010 to 2014. The emission standard origin is based on import status (new or used) from VFEM.

[16] This data was obtained from Ministry of Transport 2015 annual fleet statistics spreadsheet (sheet 2.5a to 2.8a)

It is assumed that all NZ New vehicles are manufactured to European emission standards and all used imports are manufactured to Japanese emission standards.

4.6 Assigning emission standards by emission standard origin and year of manufacture

Appendix 2 shows the emission standard that is assigned in VEPM for each vehicle category (type, fuel, segment) by emission standard origin (European, Australian, New Zealand or Japanese) and year of manufacture.

4.6.1 European

It is assumed that vehicles assigned European emission standard origin are manufactured to European emission standards.

However, there is a delay between implementation of standards in Europe and the introduction of these standards in New Zealand. As shown in Table 6 and Table 7 there was a three-to-five-year delay between introduction of Euro 4/5/IV/V emission standards in Europe and the introduction of these standards in New Zealand. At the time of writing, time frames for the introduction of Euro 6/VI standards are not confirmed.

Table 6: Light duty emission standard introduction dates for Europe and New Zealand

	Europe[17]		New Zealand[18]			
	Light duty		Light duty petrol		Light duty diesel	
	New models	All models	New models	All models	New models	All models
Euro 1	Jul-92	Jan-93				
Euro 2	Jan-96	Jan-97				
Euro 3	Jan-00	Jan-01				
Euro 4	Jan-05	Jan-06	Jan-08	Jan-09	Jan-08	Jan-08
Euro 5	Sep-09	Jan-11	Nov-13	Nov-16	Jan-14	Nov-16
Euro 6	Sep-14	Sep-15				

[17] TransportPolicy.net, available at http://transportpolicy.net/index.php?title=EU:_Light-duty:_Emissions

[18] NZ Transport Agency available at https://www.nzta.govt.nz/vehicles/vehicle-types/vehicle-classes-and-standards/environmental-standards/

Table 7: Heavy duty diesel emission standard introduction dates for Europe and New Zealand

	Europe[19]	New Zealand[4]	New Zealand[4]
	New models	New models	All models
Euro I	92		
Euro II	Oct-96		
Euro III	Jan-00		
Euro IV	Oct-05	Jan-08	Jan-09
Euro V	Oct-08	Jan-12	Jan-12
Euro VI	Jan-13		

The date of introduction of European emission standards in VEPM 7.0 is based on the following assumptions:

- For emission standards that are specified in New Zealand legislation, it is assumed that 100% of new vehicles comply with the European emission standard required by New Zealand legislation at the year of manufacture. This is a conservative assumption because some vehicles being imported into New Zealand will comply with European standards before they are required in New Zealand.
- For historical emission standards which are not specified in New Zealand legislation, a four to five year delay is assumed for compliance with European emission standards in New Zealand.
- It is assumed that Euro 6d and Euro VI D/E standards will be implemented in 2030

The emission standards assumed for European (New Zealand new) vehicles based on year of manufacture are shown in Table 31, Appendix 2.

It is recommended that the implementation date for Euro 6 and Euro VI standards should be updated when the implementation date is confirmed.

4.6.2 Australian

Australian Design rules are generally based on European standards with delayed implementation. Australian vehicles are assigned to the equivalent European standard adopted in Australia based on year of manufacture as shown in Table 32, Appendix 2.

[19] TransportPolicy.net, available at http://transportpolicy.net/index.php?title=EU:_Heavy-duty:_Emissions

4.6.3 New Zealand Manufactured

There has been no significant manufacture of vehicles in New Zealand since the 1990s, so there are very few New Zealand manufactured vehicles in today's fleet. However, VEPM calculates emission factors from 2001, so emission factors for these vehicles are still required in the database.

New Zealand manufactured light duty vehicles are assigned to emission factors for New Zealand manufactured vehicles based on year of manufacture as shown in Table 33, Appendix 2. The emission factors are described in Section 5.12.

Any heavy commercial vehicles manufactured in New Zealand are assumed to be equivalent to Australian manufactured vehicles for the same year of manufacture.

4.6.4 Japanese

A substantial proportion of the New Zealand fleet is second hand Japanese domestic vehicles, which are manufactured to Japanese emission standards.

Japanese used vehicles are assumed to comply with the Japanese emission standard required by Japanese legislation at the year of manufacture. Emission standards assumed by year of manufacture are summarised in Table 34, Appendix 2. Emissions are estimated based on the closest equivalent European emission standard for each vehicle sub-category and pollutant, as described in chapter 5.

4.7 Engine technology type sub-categories

Emission factors are assigned in COPERT according to the emission standard that vehicles are manufactured to. Some emission factors are further broken down by engine technology type. For example, there are different Euro V emission factors for vehicles equipped with EGR or SCR emission control systems.

4.7.1 Heavy commercial vehicle engine technology splits

The EMEP/EEA spreadsheet (EEA 2021a) provides separate emission factors for exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) heavy commercial Euro V vehicles. For European member states it is estimated that approximately 75% of Euro V vehicles are equipped with SCR, with the rest being equipped with EGR (EEA 2021). There is no specific data for New Zealand (Metcalfe and Sridhar, 2017) therefore the same assumption has been made for VEPM.

The EMEP/EEA spreadsheet also provides separate EGR and SCR factors for Euro IV vehicles. However, the emission factors are identical so a nominal choice of SCR technology is made in VEPM.

4.7.2 Light duty engine technology splits

The EMEP/EEA spreadsheet specifies emission control technology (in addition to emission standard) for some light duty vehicle categories as follows:

- Gasoline direct injection (GDI) or port fuel injection (PFI) engine technology for some petrol vehicle emission standards. Euro 6 standards also include a gasoline particulate filter option (GPF). However, the emission factors are identical for different technologies.
- Diesel particulate filter (DPF) is specified for Euro 3 to Euro 5 light duty diesel, however no alternative option is provided.
- In addition to DPF, Euro 6 diesel options include DPF combined with selective catalytic reduction (SCR) and DPF combined with a lean NOx trap (LNT). However, the emission factors are identical for different combinations of technologies. At this stage a nominal default choice of DPF technology has been adopted in VEPM.

All light duty emission factors are identical for different vehicle technologies. So, at this stage a nominal choice of technology has been adopted in VEPM (PFI for petrol vehicles, GDI for hybrid vehicles and DPF for diesel vehicles).

Emission factors for different technologies may change as more emission test data becomes available. It is recommended that updated emission factors should be checked whenever emission factors are updated in VEPM to confirm whether emission factors are still identical for different technologies, in which case technology choices and splits should be reviewed and confirmed.

4.8 Splitting rigid and articulated truck VKT

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 the EMEP/EEA spreadsheet 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, VKT undertaken by trucks towing a trailer is estimated based on road user charges (RUC) data (Metcalfe et al 2021). All VKT undertaken by trucks towing a trailer is 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 is assigned to the rigid truck category in VEPM based on the GVM in VFEM.

Table 8 to Table 11 provide estimates for:

1. The overall proportion of heavy duty 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.

The assumptions and methodology for deriving these estimates are described in (Metcalfe et al 2021). The estimates are based on data available in 2021. It is recommended that the articulated truck splits should be updated periodically.

This following section describes how these data are applied in VEPM to split VKT between rigid and articulated truck categories.

Table 8: 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	1,042	44%
2003	2,436	1,078	0	1,078	44%
2004	2,601	1,148	0	1,148	44%
2005	2,652	1,146	0	1,146	43%
2006	2,652	1,149	0	1,149	43%
2007	2,753	1,185	0	1,185	43%
2008	2,734	1,194	0	1,194	44%
2009	2,591	1,098	0	1,098	42%
2010	2,653	1,175	0	1,175	44%
2011	2,675	1,222	0	1,222	46%
2012	2,738	1,247	38	1,209	44%
2013	2,665	1,238	94	1,144	43%
2014	2,831	1,309	99	1,210	43%
2015	2,787	1,275	100	1,175	42%
2016	2,809	1,284	104	1,180	42%
2017	2,982	1,383	119	1,264	42%
2018	3,079	1,384	119	1,265	41%

Table 9: 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%
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%

Table 10: 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
07.5-10.0t	100%	0%	0%	0%	0%	0%	100%
10.0-20.0t	0%	10%	58%	21%	9%	2%	100%
20.0-25.0t	0%	0%	0%	29%	60%	12%	100%
25.0-30.0t	0%	0%	0%	1%	66%	34%	100%
30.0-99.0t	0%	0%	0%	0%	50%	50%	100%

Table 11: 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
07.5-10.0t	100%	0%	0%	0%	0%	0%	100%
10.0-20.0t	0%	10%	58%	21%	11%	0%	100%
20.0-25.0t	0%	0%	0%	29%	72%	0%	100%
25.0-30.0t	0%	0%	0%	1%	99%	0%	100%
30.0-99.0t	0%	0%	0%	0%	100%	0%	100%

4.8.1 Detailed methodology to split rigid and articulated truck VKT in VEPM

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 Table 8) as follows:

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

Where:

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

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

P_{TTT} = the proportion of heavy duty vehicle travel that is undertaken by trucks towing a trailer (shown in Table 8).

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 Table 9 as follows:

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

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)

PTTT,GVM is the proportion of VKT for trucks towing trailers that is taken from each GVM category (shown in Table 9)

VKT is then assigned to articulated truck categories in VEPM based on the estimated gross combined mass of the truck and trailer(s) based on the proportions shown in Table 10 and Table 11 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 (The proportion is shown in Table 10 for all years from 2019 and in Table 11 for all years up to 2012. Between 2012 and 2019 the values are interpolated).

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)

5. Calculation of emission factors

This Chapter describes the methodology and assumptions to calculate emission factors for each vehicle category and emission standard for each pollutant.

5.1 Overall methodology: exhaust emission factors and energy consumption

The calculations are described for vehicles manufactured to European and Japanese emission standards. The proportion of vehicles manufactured to these emission standards is estimated based on the methodology outlined in Chapter 4.

The overall methodology for calculation of total emission factors is shown schematically in Figure 8.

Exhaust emissions are calculated according to Equation 5 as the sum of hot emissions (when the engine is at its 'hot' stabilised operating temperature) and emissions during the transient warming up phase (cold start). Emission factors are adjusted to account for vehicle degradation, fuel and gradient effects.

$$E_{TOTAL} = E_{HOT} \times s(m) \times g \times f + E_{COLD} \times f \qquad \text{Equation 5}$$

Where:

E_{TOTAL} = Total emission factor

E_{HOT} = Hot emission factor

s(m) = Degradation correction factor for a given accumulated vehicle mileage (m)

g = gradient correction factor[20]

f = fuel correction factor

E_{COLD} = Cold emission contribution (function of trip length and ambient temperature)

Exhaust emission factors and correction factors are calculated generally in accordance with the Tier 3 methodology described in the EMEP/EEA air pollutant emission inventory guidebook (EEA 2021). However, some additional information and data sources are used, including a real-world fuel consumption adjustment factor, which is applied to light duty diesel vehicles as described in Section 4.7.

The calculation of energy consumption factors follows the same methodology.

The information and data sources for calculation of emission factors in VEPM 7.0 are summarised in Appendix 4.

The calculations and assumptions are described in detail in the following sections.

[20] Note that heavy duty hot emission factors are adjusted for load as well as gradient.

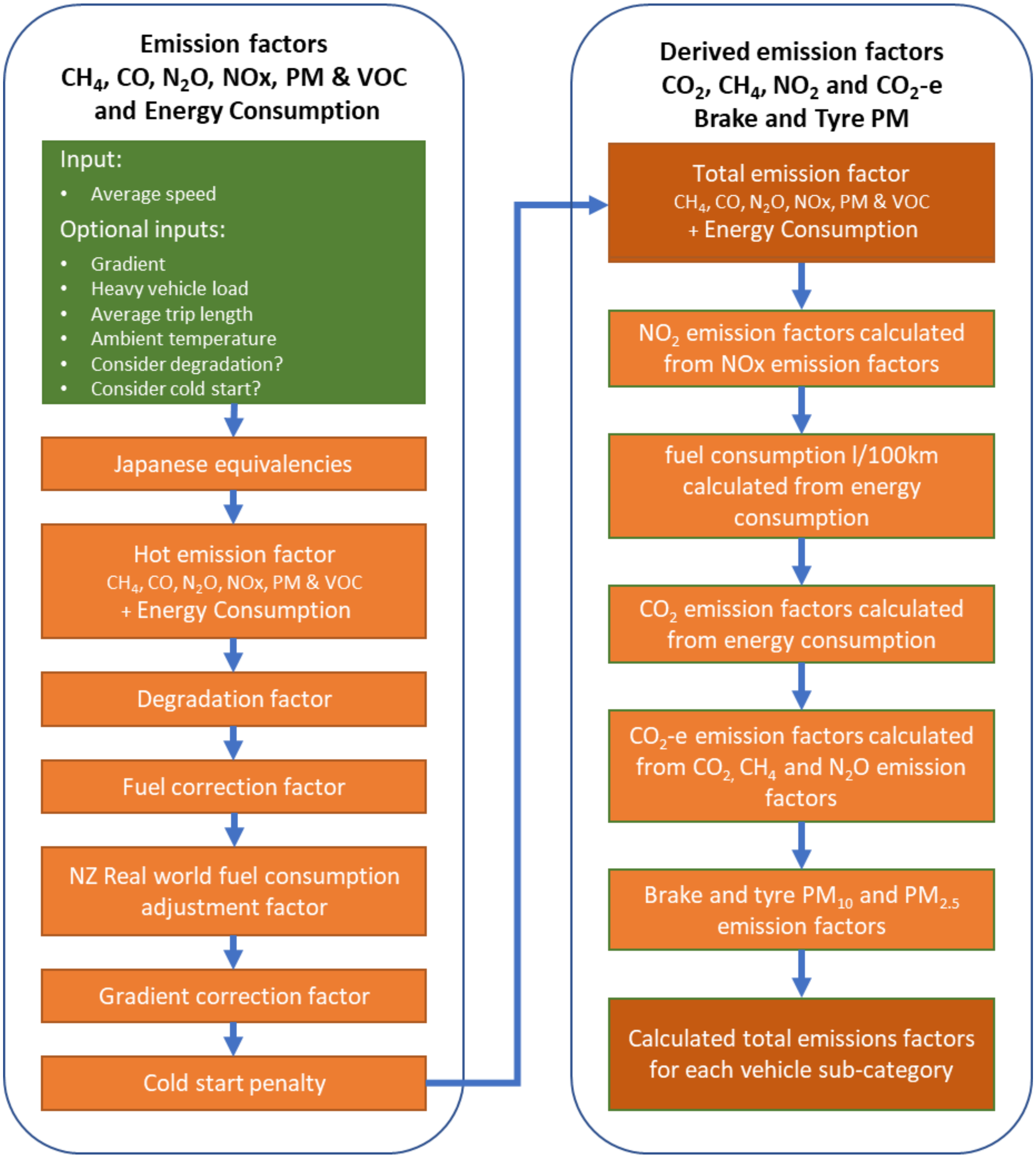

Figure 8: calculation of total emissions factors by vehicle category in VEPM.

5.2 Hot emission factors

5.2.1 Hot emission factors: CO, NOx, VOC, CH_4, N_2O and energy consumption

All hot emission factors (for CO, NOx, VOC, CH_4, N_2O and energy consumption) are the latest available COPERT emission factors from the EMEP/EEA spreadsheet (EEA 2021a), except PM exhaust factors which are based on the previous version EEA (2020).

5.2.2 Hot emission factors: PM exhaust

PM exhaust emission factors for Euro 5/6 and Euro V/VI have not been updated in VEPM 7.0, although updated emission factors are available in the EMEP/EEA spreadsheet (EEA 2021a). The updated EMEP/EEA factors are not straightforward replacements for previous factors in VEPM because:

- For light duty vehicles, PM emission factors are provided for hot and cold modes. In previous versions hot emission factors (only) were provided and cold emission factors were calculated from these (consistent with the method for other pollutants). This is a methodological change, which will require changes to the emission factor calculation method in VEPM.
- For heavy duty vehicles, PM emission factors are provided in g/kWh. In previous versions emission factors were provided in g/km. This is a substantial change, which would require a new methodology for estimating heavy vehicle activity data (kWh as opposed to VKT).

Further work is required to develop a methodology for implementation of these new PM emission factors in VEPM. At the time of writing, the EMEP/EEA guidebook (EEA 2021) does not provide specific guidance on how to implement the new factors.

5.2.3 Assumed driving mode for assigning hot emission factors: CH_4 and N_2O and PM from some petrol vehicles

The EMEP/EEA spreadsheet (EEA 2021a) provides emission factors for urban, rural and highway driving modes (unlike other emission factors, which are calculated based on average speed) for the following pollutants:

- CH_4
- N_2O
- Exhaust PM for pre-Euro 5 petrol cars and LCVs

Hot emission factors are assigned in VEPM based on the speeds that are considered representative for each EMEP/EEA driving mode as shown in Table 12.

Table 12: Assumed driving mode for assigning CH_4, N_2O and PM emission factors based on speed

Min Speed (km/h)	Max Speed (km/h)	Driving mode	
		PM, CH_4 & N_2O HCV	N_2O light vehicle
0	34	Urban peak	Urban hot
35	54	Urban off peak	Urban hot
55	79	Rural	Rural
80	140	Highway	Highway

5.2.4 Calculation of N_2O hot emission factors

N_2O emissions are particularly important for light 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:

$$EF_{N2O} = [a \times Mileage + b] \times EF_{base} \qquad \text{Equation 6}$$

Where:

EF_{N2O} is the N_2O emission factor

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

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

Mileage is the mean mileage of the vehicle category

Equation 6 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 category at the assessment year[21] and the fuel sulphur content at the assessment year.

5.2.5 Hybrid and plug-in hybrid vehicles

Petrol hybrid vehicles are assigned the EMEP/EEA hot emission factor for Euro 4 medium petrol hybrid (GDI) vehicles (EEA 2021). The EMEP/EEA emission factors for petrol hybrid vehicles of different sizes and Euro standards are currently identical so this assumption is not significant.

For plug-in hybrid vehicles, it is assumed that all tail pipe emission factors are 48% of hybrid vehicle emission factors in VEPM 7.0. This is based on an estimate of the typical proportion of driving in electric mode undertaken for Ministry of Transport energy use estimates (Metcalfe and Sridhar, 2016). Plug-in

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

hybrid emission factors are now available in the EMEP/EEA spreadsheet so it is recommended that these should be incorporated into VEPM in future updates.

5.2.6 Japanese vehicles: CO, VOC, NOx and PM and energy consumption

VEPM does not include specific Japanese emission factors, because a comprehensive Japanese emissions model is not readily available. An equivalent European emission factor is assumed in VEPM for each Japanese vehicle category, emission standard and pollutant.

The equivalent European emission factor that is assumed for each Japanese vehicle category, emission standard and pollutant is provided in Appendix 3.

For vehicles manufactured up to 2010, a detailed comparison of emission factors from European and Japanese emission models was undertaken to assign the closest equivalent European emission factor for each Japanese vehicle category and each pollutant. The detailed comparison is described in the technical report (EFRU 2008). This approach has been used internationally[22].

Harmonisation of international emissions standards means that emissions from modern European and Japanese vehicles are similar. For vehicles manufactured from 2010 onwards a simplified approach was used to assign equivalence. A comparison of Japanese and European emission standards was undertaken to identify the closest equivalent standard (Metcalfe and Peeters 2022). For vehicles manufactured from 2010 onwards, Japanese vehicles are assigned the emission factors of the closest equivalent European emission standard (for all pollutants) based on the date of introduction of Japanese emissions standards.

Articulated trucks

A simplified approach is taken for assigning emissions standards to Japanese used articulated trucks. For these vehicles the emission standard is assigned based on the emission standard assumed in VEPM for HCVs for carbon monoxide based on year of manufacture for Japanese used vehicles[23]. Further work is recommended to make articulated truck assumptions consistent with rigid trucks in future updates.

5.2.7 Japanese vehicles: CH_4 and N_2O

For all years of manufacture:

- Japanese/European emission factor equivalencies for CH_4 are assumed to be the same as VOC
- Japanese/European emission factor equivalencies for N_2O are assumed to be the same as NOx.

[22] For example, the developers of COPERT used a similar process to develop emission factors for Cyprus where the fleet is dominated by Japanese used imports.
[23] For Japanese used vehicles, the closest equivalent European emission factor is assumed in VEPM based on year of manufacture for each pollutant. In some cases, a different European emission standard is assumed for different pollutants (for the same year of manufacture).

5.3 Cold emissions contribution

Engine emissions are higher during the warming up phase (cold start). Cold start emissions are calculated as an extra emission over the emissions that would be expected if all vehicles were only operated with hot engines and warmed-up catalysts.

Although cold start emissions occur in all vehicle categories, they are most significant in petrol vehicles. Cold start emissions factors are not available for heavy duty vehicles.

5.3.1 Light duty CO, NOx, HC, PM and energy consumption cold start penalty factors

Cold start emissions are estimated for light duty vehicles in VEPM based on the methodology described in the EMEP/EEA guidebook as follows:

$$E_{cold} = \beta \times e_{hot} \times (\rho - 1) \qquad \text{Equation 7}$$

Where:

E_{cold} is the cold start penalty 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})

VEPM uses algorithms from the EMEP/EEA guidebook to calculate the ρ ratio and β fraction for different vehicle categories and pollutants (and energy consumption). The ρ ratio and β fraction depend on the ambient temperature. The β fraction also depends on trip length and the ρ ratio depends on speed.

5.3.2 Light duty CH_4 and N_20 cold start penalty factors

The EMEP/EEA guidebook provides urban hot and urban cold driving mode emission factors for N_20 and CH_4 (unlike other emission factors, where the ρ ratio is provided). Equation 7 is rearranged for calculation of N_20 and CH_4 cold start penalty in VEPM as follows:

$$E_{cold} = \beta \times e_{hot} \times \left(\frac{e_{cold}}{e_{hot}} - 1\right) \qquad \text{Equation 8}$$

So:

$$E_{cold} = \beta \times (e_{cold} - e_{hot}) \qquad \text{Equation 9}$$

5.3.3 Hybrid and plug-in hybrid vehicles

The EMEP/EEA guidebook (EEA 2021) does not provide a methodology for calculating cold start emissions from hybrid or plug-in hybrid vehicles, so it is assumed that there is no cold start penalty.

5.3.4 Heavy duty vehicles

The EMEP/EEA guidebook (EEA 2021) does not provide a methodology for calculating cold start emissions from heavy duty diesel vehicles (including rigid and articulated trucks and buses), so it is assumed that there is no cold start penalty.

5.3.5 Japanese vehicles

The method for estimating cold start emissions for Japanese vehicles in VEPM is the same as the method for European vehicles. Japanese vehicle emission standard equivalencies for cold emissions are assumed to be the same as hot emission factor equivalencies.

5.4 Degradation factors

Degradation factors are applied to hot emission factors in VEPM to account for performance deterioration due to vehicle age. The EMEP/EEA guidebook does not currently include comprehensive degradation factors, so VEPM uses factors from several published literature sources to estimate degradation effects.

Degradation factors are calculated in VEPM based on cumulative mileage. It is assumed that degradation factors increase linearly with mileage, and reach a maximum at a specified stabilisation mileage. The calculation of degradation factors is described in EFRU (2008), as follows:

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

and:

$$s(m \geq n) = s(m = 0) + n \times \left(\frac{\delta s}{\delta n}\right)$$ Equation 11

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) where $0 < s(m=0) <= 1$

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

$\delta s/\delta m$ is the degradation rate

The sources of degradation factors in VEPM 7.0 are summarised in Table 13 and are described in more detail in the following sections.

Degradation factors were reviewed in 2021 (Metcalfe et al 2021) and some factors were updated. However, some of the degradation factors in VEPM are outdated. It is recommended that all degradation factors should be reviewed and updated when new information becomes available.

Table 13: Sources of emission degradation factors in VEPM 7.0

Sources of emission degradation factors in VEPM 7.0				
Vehicle type	**Fuel**	**Region of origin**	**Emission standard/YOM**	**Source VEPM 7.0**
Car	Petrol	Europe	Pre-Euro 1	FORS (1996)*
			Euro 1-2	EEA (2019)**
			Euro 3-6	EEA (2019)** for VOC. 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	Carslaw et al (2019) for CO and NO_X. PM based on Ubanwa et al 2003
		Japan	J86 and later	
LCV	Petrol	Europe	Pre-Euro 1	FORS (1996)*
			Euro 1-2	EEA (2019)**
			Euro 3-6	EEA (2019)** for VOC. Carslaw et al (2019) for CO and NO_X
		Japan	Up to YOM 2010	JCAP (2001)
	Diesel	Europe	All	Carslaw et al (2019) for CO and NO_X. PM based on Ubanwa et al (2003).
		Japan	J77 and later	
HCV	Diesel	Europe	All	Ubanwa et al (2003) for PM; Lindhjem & Jackson (1999) for CO, VOC and NO_X
		Japan	All	

* Stabilised degradation factors at 400,000 km are assumed to be 1.39 for VOC, 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.

5.4.1 Calculation of mileage in VEPM

Average cumulative mileage for vehicles by year of manufacture and by vehicle type was calculated based on VKT estimates from VFEM for 2009. This accounts for the higher annual mileage of newer vehicles.

However, the base data has not been updated since 2009. Further work is recommended to investigate whether VFEM outputs could be used to update average cumulative mileage estimates regularly.

5.4.2 Light duty CO and NOx degradation factors

The EMEP/EEA guidebook includes degradation factors for light duty petrol vehicles built to Euro 1 to Euro 4. As shown in Table 13, EMEP/EEA factors are used to calculate CO and NOx degradation factors for Euro 1 and Euro 2 petrol vehicles

Light duty CO and NOx degradation factors for other light duty vehicles were updated in VEPM 6.2 (Metcalfe et al 2021) based on Carslaw et al (2019) which proposes CO and NO_X degradation factors at 50,000 km, 100,000 km and 200,000 km derived from the results of remote sensing in Europe. The degradation factors applied in VEPM 7.0 are shown in Table 14. 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
- Euro 1 degradation rates apply to Pre-Euro diesel vehicles (i.e. no degradation)

Table 14: CO and NOx degradation factors assumed in VEPM 7.0 for specified vehicle categories

Vehicle type	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	Pre-Euro	1	1	1	1
	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 50,000 km 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 12

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 13

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:

$$\left(\frac{\delta s}{\delta m}\right) = \frac{2.9 - 1}{150{,}000} = 1.27 \times 10^{-5}$$

And the degradation factor at 0 km is calculated as follows

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

5.4.3 Light duty VOC degradation factors

The EMEP/EEA guidebook includes degradation factors for light duty petrol vehicles built to Euro 1 to Euro 4. EMEP/EEA factors are used to calculate VOC degradation factors for Euro 1 and later petrol vehicles. It is assumed that Euro 4 factors apply to Euro 5 and Euro 6 vehicles.

The stabilised degradation factors for all light duty diesel vehicles at 80,000 km is assumed to be 1.3 for VOC (i.e. VOC emissions are assumed to increase by 30% from 0 to 80,000 km and then remain stable). This is unchanged from the original VEPM technical report, which 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.

5.4.4 Light duty PM degradation factors

There are no degradation factors for PM emissions from petrol vehicles in VEPM.

The stabilised degradation factor for diesel vehicle PM in VEPM is unchanged from the original VEPM technical report (EFRU 2008). Degradation is 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 (Metcalfe et al 2021) so PM degradation factors have not been updated.

5.4.5 Light duty N_20 degradation factors

As discussed in Section 5.2.3, the effect of mileage is already accounted for in the calculation of light duty N_2O emission factors. No additional degradation factor is applied to N_2O.

5.4.6 Light duty CH_4 degradation factors

The degradation factor for CH_4 is assumed to be the same as the VOC degradation factor.

5.4.7 Heavy duty degradation factors for PM, CO, VOC and NOx

Heavy duty degradation factors are unchanged from the original VEPM technical report (EFRU 2008). Degradation factors for PM are based on Ubanwa et al (2003), which is relatively old and is based on testing of American vehicles. Factors for CO, VOC and NOx are based on USEPA models (Lindhjem & Jackson 1999) which have since been superseded (Metcalfe et al 2021).

The methodology for calculating degradation factors for heavy duty vehicles is similar to the methodology for light duty vehicles, except that a degradation factor of 1 (i.e. no degradation) is assumed until the end of an assumed vehicle warranty period. Degradation then increases linearly up to an assumed stabilisation mileage. These assumptions are based on the USEPA MOVES model methodology.

It is recommended that heavy duty degradation factors should be reviewed and updated when COPERT degradation factors are updated. If suitable European degradation factors are not available, USEPA factors should be updated in the meantime. Heavy duty degradation factors are currently assumed to be the same for trucks and buses. It is recommended that separate degradation factors should be developed for buses when degradation factors are reviewed and updated.

5.4.8 Heavy duty degradation factors for N_20 and CH_4

Degradation factors for N_2O are assumed to be the same as the NOx degradation factor. Degradation factors for CH_4 are assumed to be the same as the VOC degradation factor.

5.4.9 Japanese vehicles

For light duty vehicles manufactured up to 2010 VEPM uses Japanese degradation factors for CO, VOC and NOx (JCAP 2001) as described in the VEPM development report (EFRU 2008).

For all other vehicle categories, the degradation factors are the same as degradation factors for European vehicles. The Japanese vehicle emission standard equivalencies for degradation are assumed to be the same as hot emission factor equivalencies.

5.4.10 Energy consumption degradation factors

A degradation factor of 1 is assumed for energy consumption for all vehicle categories (i.e. no degradation).

5.5 Gradient and load

5.5.1 Light duty vehicle gradient correction factors for CO, NOx and PM

Light duty vehicle gradient correction factors in VEPM are derived from PIARC guidance because correction factors are not included in the EMEP/EEA spreadsheet (EEA 2021a). Gradient adjustment factors are based on factors from PIARC guidance (PIARC 2019).

Gradient factors for petrol cars, diesel cars, petrol LCVs and diesel LCVs are derived from PIARC emission factors (PIARC 2019[24]) 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 distinction 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 type, fuel type and pollutant. For example, Table 15 shows CO emission factors for Euro 3 petrol cars.

Table 15: 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	1,317	2,399
6%	1	18	103	51	79	65	90	161	271	466	730	1,599	2,742	3,431

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 16 shows the CO emission ratios for Euro 3 petrol cars.

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

Table 16: 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 9 shows the fitted polynomial curve for CO emissions from Euro 3 petrol cars.

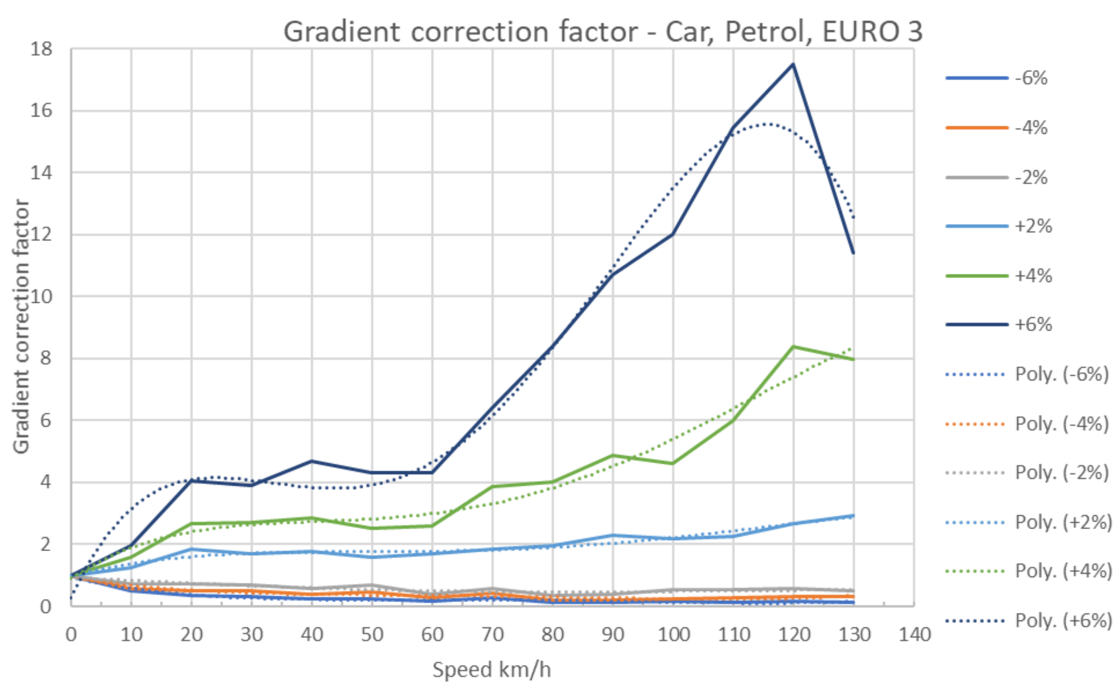

Figure 9: Fitted polynomial curves to derive gradient correction factors for CO from Euro 3 petrol cars

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.

5.5.2 N_2O and CH_4 gradient correction factors

The gradient correction factor for N_2O is assumed to be 1 (i.e. no correction is applied)

The following assumptions are applied for CH_4:

- No gradient correction factor is applied to light duty emission factors (this is consistent with the assumption for VOC).
- 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 category.

5.5.3 Heavy duty gradient and load

Heavy duty vehicle hot emission factors and energy consumption factors are corrected for gradient and load in the EMEP/EEA spreadsheet (EEA 2021a). These factors are adopted in VEPM 7.0.

5.5.4 Japanese vehicles

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

5.6 Fuel properties

VEPM utilises the fuel properties shown in Table 17 and Table 18**Error! Reference source not found.** to calculate fuel correction factors. These are based on the fuel specifications in the regulations at the time.

The fuel type in VEPM is automatically selected for the assessment year based on the type of fuel that was available in New Zealand at the time. The base fuel properties are default values from EMEP/EEA 2021.

Table 17: 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 18: 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)
10	Base fuel	400	840	9	51	350
11	Pre-Sep 2002	3,000	835	11	45	370
12	Sep 2002-Dec 2003	1,561	840	11	47	370
13	Jan 2004-Dec 2005	500	835	11	49	370
14	Jan 2006-Dec 2008	50	835	11	51	360
15	Jan 2009 onwards	10	835	11	51	360

5.7 Fuel correction factors

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 from the EMEP/EEA Guidebook (EEA 2021) to compensate for fuel effects except that the algorithms for PM for pre-2004 diesel are adjusted to account for the high sulphur content of New Zealand diesel.

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 14

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

5.7.1 Fuel correction algorithms for pre 2004 diesel

The sulphur content of New Zealand diesel was significantly higher than the European base fuel up to 2004.

The PM fuel correction algorithms were adjusted Table 3 to take this into account by applying a scaling factor. For light duty vehicles the scaling factor was based on an UK data that a 2.4% reduction in PM was achieved by switching from 2,000ppm to 500ppm sulphur diesel (EFRU 2008). For heavy duty vehicles, the scaling factor was based on UK data that a 13% reduction in PM was achieved by switching from 2,000ppm to 500ppm sulphur fuel. The adjusted algorithms are shown in Table 20 and

Table 21.

5.7.2 Fuel correction algorithms

The fuel correction factors applied to different passenger cars, light commercial vehicles and heavy duty diesel vehicles used in VEPM 7.0 are shown in Table 19, Table 20 and Table 21. These are the same as EMEP/EEA (EEA 2021) algorithms except for the PM correction factors for pre-2004 diesel.

Table 19: 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)]
VOC	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 EC	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 20: 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
VOC	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	Pre 2004 diesel (fuel types 11 and 12): 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 – 500)/100]/[1-2.4% x (S-500)/(2000-500)] Fuel types 13, 14 and 15: 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 EC	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 21: 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
VOC	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	Pre 2004 diesel (fuel types 11 and 12): FCorr = [0.06959 + 0.00006 x DEN + 0.00065 x PAH – 0.00001 x CN] x [1-0.0086 x (450 – 500)/100]/[1-13% x (S-500)/(2000-500)] Fuel types 13, 14 and 15: 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 EC	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 utilises the fuel properties shown in Table 17 and Table 18 to calculate the fuel correction factors.

The base fuels and the available improved fuel qualities assumed in VEPM 7.0 for each vehicle emission standard are shown in Table 22 (for petrol) and Table 23 (for diesel). The fuel correction factors are calculated relative to the applicable base fuel for the vehicle technology.

Fuel correction factors are applied to hot emission factors and the cold emission penalty in VEPM (in accordance with the EMEP/EEA methodology (EEA 2021).

Table 22: Base fuels used to correct petrol fuel quality for each vehicle technology category in VEPM

Vehicle Technology	Base Fuel	Available Improved Fuel Qualities
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 23: Base fuels used to correct diesel fuel quality for each vehicle technology category in VEPM

Vehicle Technology	Base Fuel	Available Improved Fuel Qualities
Pre-Euro 3	Base (diesel type 10)	Diesel types 11-15
Euro 3	Jan 2004 (diesel type 13)	Diesel types 14-15
Euro 4	Jan 2006 (diesel type 14)	Diesel type 15
Euro 5 and later	Jan 2009 (diesel type 15)	-

Smit *et al* (2022) note in their report that actual fuel properties can differ appreciably from the fuel specifications and thereby influence the fuel correction factors. A preliminary assessment of the potential impact of using actual fuel properties found that using actual fuel properties would slightly reduce hot emissions factors for CO, HC and PM and would slightly increase NOx (Metcalfe et al, 2021). Changing fuel corrections from being based on specifications to actual fuel properties warrants further investigation.

5.8 Fuel consumption and greenhouse gas emissions

5.8.1 Fuel consumption

Fuel consumption is estimated in VEPM from estimated total energy consumption factors based on the following fuel properties which were obtained from MBIE data tables for oil, for 2016. These properties are assumed to be the same for all years.

Gross calorific value:

- Petrol 47.01 MJ/kg
- Diesel 45.79 MJ/kg

Density:

- Diesel 0.835 kg/litre
- Petrol 0.747 kg/litre

Gross calorific values are used in VEPM for consistency with the New Zealand Greenhouse Gas Inventory. However, default calorific values provided in the EMEP/EEA guidebook are net calorific values. It is recommended that the assumptions and calculations in VEPM should be reviewed and updated to ensure that fuel consumption estimates are consistent with EMEP/EEA assumptions.

For consistency, it is recommended that fuel properties should be updated regularly. Updating VEPM to calculate fuel consumption based on fuel properties for the user selected assessment year could also be considered.

5.8.2 Exhaust CO_2 and CO_2-e emission factors

In VEPM 7.0 CO_2 emissions are calculated from estimated total energy consumption factors. Gross CO_2 emission factors for regular petrol and diesel from the 2017 New Zealand greenhouse gas inventory (MfE, 2019) are assumed for all years:

- Petrol 66.70 tCO_2/TJ
- Diesel 69.31 tCO_2/TJ

These emission factors are updated annually in the New Zealand greenhouse gas inventory.

As noted in the previous section, gross calorific values are used in VEPM for consistency with the New Zealand Greenhouse Gas Inventory. However, the EMEP/EEA energy consumption factors are based on net calorific values, which is consistent with IPCC guidelines for greenhouse gas inventories. It is recommended that the assumptions and calculations in VEPM should be reviewed and updated to ensure CO_2 emissions are calculated correctly.

For consistency, it is recommended that factors should be updated regularly in future versions of VEPM and should be updated to account for differences between regular and premium petrol. Updating VEPM to calculate CO_2 based on emission factors for the assessment year could also be considered

CO_2-equivalent (CO_2-e) emission factors are calculated in VEPM 7.0 as follows:

$$CO_{2-e} = CO_2 + (298 \times N_2O) + (25 \times CH_4) \quad \text{Equation 15}$$

Equation 15 is based on global warming potentials used by Ministry for the Environment, which are from the IPCC Fourth Assessment Report (MfE 2020).

5.8.3 CO_2 from lubrication and additives

The EMEP/EEA guidebook (EEA, 2021) provides a methodology for estimation of CO_2 emissions from lubricant oil and exhaust additives (urea solutions such as AdBlue). These are not included VEPM 7.0.

Investigation of data requirements, data availability and potential significance of these emissions is recommended.

5.9 New Zealand real world fuel consumption adjustment factors

5.9.1 Light duty real world fuel consumption adjustment factors

New Zealand real world fuel consumption correction factors are applied to light duty diesel vehicles in VEPM 7.0 as shown in Table 24.

The adjustment factors are applied in VEPM 7.0 to adjust fuel consumption predictions (and consequently CO_2 emission predictions) for diesel cars and LCVs for all years of manufacture.

Table 24: New Zealand real world fuel consumption adjustment factors applied in VEPM 7.0

Vehicle type	Engine size category in VEPM	Real world fuel consumption adjustment factor
Diesel car	<2000cc	1.29
	≥2000cc	1.14
Diesel LCV	N/A	1.08

The fuel consumption adjustment factors were estimated based on MoT real world fuel consumption factors. MoT has developed factors for diesel and petrol vehicles in New Zealand using fuel consumption and travel data from a large data set of fuel card transactions (Wang et al 2015). Previous work found that there was good agreement between VEPM and these real-world fuel consumption for light duty petrol vehicles. However, it was found that light duty diesel fuel consumption was underestimated by VEPM (Kuschel et al 2019). New Zealand real world adjustment factors were developed so that light duty diesel fuel consumption estimates from VEPM are more realistic. The methodology and assumptions for derivation of the factors are described in Metcalfe et al (2020).

Real world fuel consumption factors by year of manufacture for petrol and diesel light duty vehicles have been proposed (Metcalfe et al 2021) however these have not yet been implemented in VEPM. Further work is recommended to validate and implement updated real world fuel consumption factors.

5.9.2 Heavy duty real-world fuel consumption

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. The VEPM 6.2 update improved the split between rigid and articulated trucks (Metcalfe et al 2021). Further work is recommended to compare estimated fuel consumption for heavy duty vehicles in VEPM with real world fuel consumption estimates.

5.10 NO_2 emission factors

The EMEP/EEA Air pollutant emission inventory guidebook includes factors for the proportion of NO_2 in NOx (f-NO_2) according to vehicle type, fuel used and the Euro emission standard. Table 25, Table 26, and Table 27 show the factors that are assumed in VEPM 7.0, which are from the EMEP guidebook (EEA,2021).

Table 25: Fraction of NO_2 emissions by petrol cars and LCVs assumed in VEPM 7.0

Emission standard	f-NO_2
Pre-EURO	0.04
Euro 1	0.04
Euro 2	0.04
Euro 3	0.03
Euro 4	0.03
Euro 5	0.03
Euro 6	0.02

Table 26: Fraction of NO_2 emissions by diesel cars and LCVs assumed in VEPM 7.0

Emission standard	f-NO_2
Pre-EURO	0.15
Euro 1	0.13
Euro 2	0.13
Euro 3	0.27
Euro 4	0.46
Euro 5 car	0.40
Euro 5 LCV	0.33
Euro 6 a/b/c	0.30
Euro 6d	0.20

Table 27: Fraction of NO_2 emissions by diesel heavy vehicles assumed in VEPM 7.0

Emission standard	f-NO_2
Pre-EURO	0.11
Euro I	0.11
Euro II	0.11
Euro III	0.14
Euro IV	0.14
Euro V	0.10
Euro VI	0.10

5.11 Brake and tyre wear emission factors

Brake and tyre wear emission factors in VEPM 7.0 are calculated in accordance with the Tier 2 methodology described in the EMEP/EEA guidebook (EEA, 2019).

Brake and tyre wear factors are calculated based on the same methodology for electric vehicles and conventional vehicles.

The emission factor calculation takes speed into account. For heavy-duty vehicles, the load and vehicle size (based on the number of axles) are also taken into account.

The default number of axles for heavy-duty vehicles in VEPM 7.0 is shown in Table 28. These were derived from information provided by Waka Kotahi on the requirements of the Vehicle Dimensions and Mass Rule (as reported in Metcalfe & Sridhar 2019).

Table 28: Default number of axles assumed in VEPM 7.0 for calculation of tyre wear emission factors

Vehicle type	Vehicle category	Default number of axles
Light vehicles		2 axles
Rigid HCV Diesel	3.5 – 7 t	2 axles
	7.5 – 10 t	2 axles
	10 – 20t	3 axles
	20 – 25t	4 axles
	25 – 30t	5 axles
	>30t	6 axles
Articulated HCV Diesel	14 – 20 t	5 axles
	20 – 28 t	6 axles
	28 – 34t	6 axles
	34 – 40t	7 axles
	40 – 50t	8 axles
	>50t	9 axles
Electric HCV	<10t	2 axles
	>10t	3 axles
Bus Diesel	<12t	2 axles
	>12t	3 axles
Bus Electric		2 axles

At the time of writing, new electric buses are commonly 3 axle. It is recommended the default number of axles for electric buses should be updated in the next version of VEPM.

5.12 New Zealand manufactured vehicle emission factors

New Zealand vehicles were not built to meet any emission standard until an emissions rule was implemented in 2005. Emission factors for New Zealand manufactured light duty vehicles were derived based on testing of New Zealand vehicles undertaken for Ministry of Transport in 2005. The VEPM development report shows that petrol cars manufactured in New Zealand were broadly equivalent to vehicles manufactured to pre-Euro (ECE 15/02) and Euro 1 standards. The proportion of New Zealand manufactured vehicles manufactured to these standards was estimated as shown in Table 29.

In VEPM 7.0 emission factors for New Zealand manufactured vehicles are calculated from total emission factors for ECE 15/02 and Euro 1 emission factors, based on the proportions shown in Table 29.

Table 29: New Zealand manufactured passenger car equivalent emissions standards assumed in VEPM 7.0 based on year of manufacture

Year of manufacture	% of ECE 15/02 cars in the fleet	% of Euro 1 cars in the fleet
<=1987	100%	0%
1988-1992	80%	20%
1993-1997	40%	60%
1998-2002	10%	90%
>=2003	0%	100%

6. Recommendations

Improvement of VEPM is an area of ongoing research. Recommendations from research reports are not repeated here.

Specific recommendations relating to future updates are summarised from previous sections of this report as follows:

- **Fleet projections** in VEPM 7.0 do not account for recently announced policies. It is recommended that updated VFEM data should be incorporated into VEPM when it becomes available.
- Further investigation is recommended to confirm whether the percentage split of bus VKT between **bus and coach** is realistic.
- The **emission standards split for vehicles up to year of manufacture 2009** has not been updated since it was developed based on analysis of 2014 fleet data. It is recommended that update of this data should be considered as part of future fleet updates, including investigation of whether vehicle import status data from VFEM could be used.
- There are vehicle categories in the EMEP/EEA spreadsheet which are not currently included in VEPM (e.g. motorcycles and additional engine size categories for passenger cars). Further work is recommended to consider whether any of these **additional vehicle categories** warrant inclusion in future versions of VEPM.
- The assumptions and for splitting articulated and rigid truck VKT are based on data available in 2021. It is recommended that the **articulated truck VKT splits** should be updated periodically.
- At the time of writing, MoT have Cabinet approval to propose regulations for the implementation of **Euro 6 and Euro VI emission standards**. Implementation dates for Euro 6 and Euro VI requirements for new vehicles should be update in VEPM when time frames are confirmed.
- For some vehicle categories and emission standards, EMEP/EEA emission factors are further broken down by emission control **technology**. It is recommended that technology choices and splits should be reviewed and confirmed whenever emission factors are updated in VEPM.
- Investigate the implications and develop a methodology to incorporate **updated PM emission factors** from the EMEP/EEA spreadsheet (EEA 2021a)
- It is recommended the emission factors for **plug-in hybrid** vehicles should be updated with emission factors from the EMEP/EEA spreadsheet.
- Further work is recommended to make assumptions for assigning **Japanese equivalencies for articulated trucks** equivalent with assumptions for rigid trucks.
- All emission **degradation factors** in VEPM should be reviewed and updated when COPERT is updated.
- **Heavy duty degradation factors** are especially out of date. If suitable European degradation factors are not available, it is recommended that the USEPA degradation factors should be updated in the meantime.

- Heavy duty degradation factors are currently assumed to be the same for trucks and buses. It is recommended that **separate degradation factors should be developed for buses**, when degradation factors are reviewed and updated
- The base data used to calculate **cumulative VKT**, which is used to estimate degradation, has not been updated since 2009. We recommend investigating whether VFEM outputs could be used to update this data regularly.
- Changing **fuel correction factors** from being based on specifications to actual fuel properties warrants further investigation.
- Emission factors based on gross **calorific values** of fuels are used in VEPM for consistency with the New Zealand Greenhouse Gas Inventory. However, default calorific values provided in the EMEP/EEA guidebook are net calorific values. It is recommended that the assumptions and calculations in VEPM should be reviewed and updated to ensure that fuel consumption estimates are consistent with EMEP/EEA assumptions, and that reported CO_2 emissions are consistent with the New Zealand Greenhouse Gas Inventory.
- It is recommended that fuel properties (gross calorific value and density) and **gross CO_2** emission factors for petrol and diesel should be updated regularly in future versions of VEPM. Updating VEPM to calculate fuel consumption based on fuel properties and CO_2 emission factors for the assessment year could also be considered
- Investigation of data requirements, data availability and potential significance of **CO_2 emissions from lubricants and additives** is recommended.
- **Real world fuel consumption factors** by year of manufacture for petrol and diesel light duty vehicles have been proposed (Metcalfe et al 2021) however these have not yet been implemented in VEPM. Further work is recommended to validate and implement updated real world fuel consumption factors.
- Further work is recommended to investigate how real world **fuel consumption of heavy duty vehicles** compares with VEPM estimates.
- It is recommended the default number of **axles for electric buses** (for calculation of brake and tyre wear) should be updated in the next version of VEPM.

In general, we recommend updating VEPM whenever the EMEP/EEA spreadsheet is updated. The default fleet profile should also be updated whenever VFEM is updated.

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Appendix 1: Average speed models

This Appendix provides background information on the principles of average speed models, their limitations, and alternatives. This appendix is adapted from Metcalfe and Boulter (2022).

Average speed models – principle of operation

VEPM derives New Zealand-relevant factors from the European COPERT model[25], which is an example of a well-established average-speed model. These models are usually based on the results of laboratory tests in which a sample of vehicles is driven over several well-defined speed profiles (driving cycles) on a chassis dynamometer[26]. The laboratory tests use driving cycles that represent a wide range of real-world operating conditions, including different ranges of speed, acceleration, periods of idling, etc.

Figure 10, copied from Barlow & Boulter, (2009), shows an example of the average-speed approach for NOx emissions. This shows how a continuous average-speed emission function is fitted to the emission factors measured for several vehicles over a range of driving cycles, with each cycle representing a specific type of driving, including stops, starts, accelerations and decelerations. The red line shows the fitted function and the blue points the underlying emission measurements.

Emission factor curves tend to be developed for a sample of vehicles that are taken to have similar charactistics (e.g. type, size, emission standard). There would tend to be some scatter in the resulting emission factors due to differences in the characteristics of driving cycles, as well as differences in vehicle emissions behaviour. The test results may also be taken from different laboratories, which adds further variability. The upshot is that driving cycles with similar average speeds can have quite different emission factors.

[25] https://www.emisia.com/utilities/copert/
[26] In some cases, the underlying emissions data may be generated using another model.

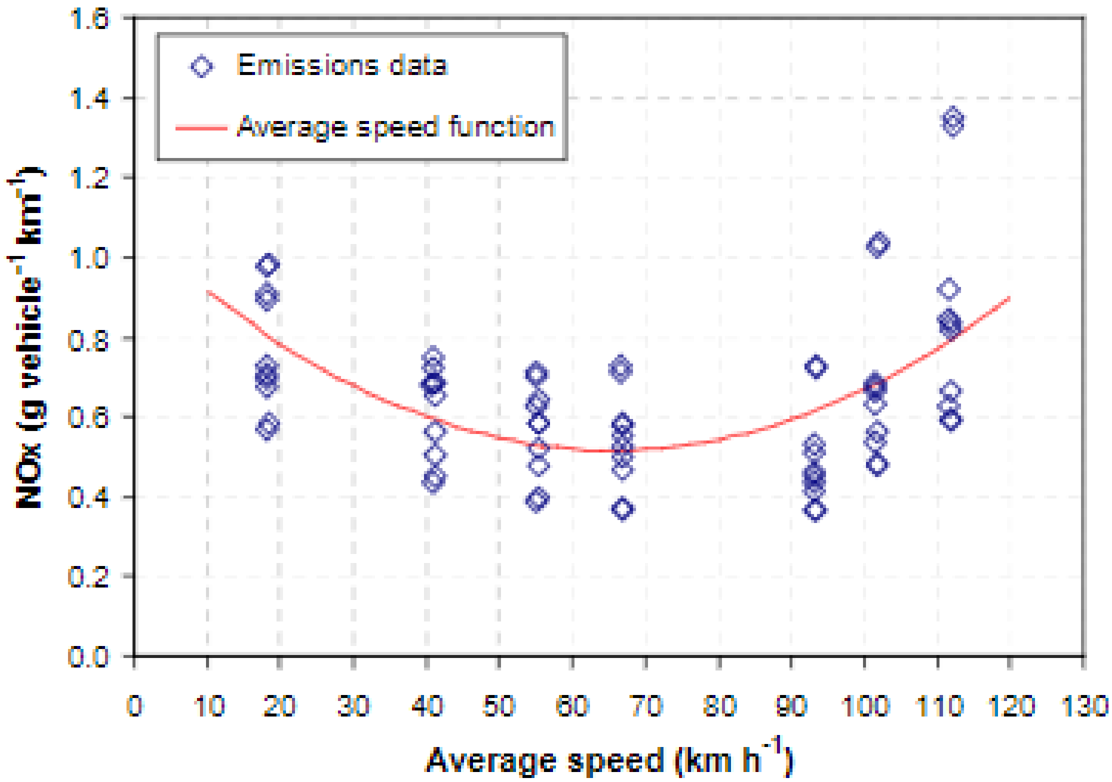

Figure 10: NOx emission factors vs average speed for individual driving cycles, and a corresponding average speed emission function for Euro 3 cars <2.0 litres.

Fitting a line to the data points results in a typical parabolic (often termed 'U-shaped') emissions-speed curve. Very low average speeds generally represent stop-and-go driving, with high fuel use and emission factors. Reducing the speed will also tend to increase the proportion of time spent in lower gears, which in turn will tend to increase fuel consumption per unit distance. Conversely, when vehicles travel at high speeds, they demand high engine loads, and are faced with high aerodynamic resistance, which require more fuel. As a result, the emissions-speed curve has its distinctive shape, with high emission factors at both ends of the speed range, and lower emission rates in the middle of the speed range.

The average-speed modelling approach therefore involves averaging for at least three levels; each measurement point (see Figure 10) is an average for a given driving cycle, and the average-speed function is fitted across multiple driving cycles and vehicles.

Given enough data, different curves can be established for multiple vehicle types, and in some cases for different road types. In COPERT, emission factors are defined as a function of speed for vehicles typically represented in the European fleet. Vehicles are classified by category (passenger car, Light Commercial etc), type (petrol, diesel, hybrid, etc), emission standard and vehicle size.

Limitations of average speed models

Average speed models have some limitations, including the following (Barlow & Boulter, 2009):

(i) Trips having different operational[27] characteristics (and different emission levels) can have the same average speed. All the types of operation associated with a given average speed cannot be accounted for using a single emission factor. This is a particular problem at low-medium average speeds, for which the range of possible operational conditions is great. This has always been a shortcoming of average-speed models and has been one of the main reasons for the development of other types of model.

(ii) For modern catalyst equipped vehicles a large proportion of the total emission during a trip can be emitted as very short, sharp peaks, often occurring during gear changes and periods of high acceleration. Average speed has therefore become a less reliable indicator for the estimation of emissions for modern vehicles.

(iii) The shape of an average-speed function is not *fundamental*, but depends on, amongst other factors, the types of cycle and specific vehicles used in development of the functions, and the regression method. For example, each cycle used in the development of the functions typically represents a given real-world driving condition, but the actual distribution of these driving conditions in the real world will vary by time and location.

(iv) Average-speed models do not allow (in principle) for detailed spatial resolution in emission predictions.

By their nature, average-speed models are therefore not best suited to the estimation of emissions from individual vehicles, or where an investigation of detailed vehicle operation is required. They are better suited to ‘bulk’, large-scale and generalised analyses.

This is illustrated further by the results of a real-world emissions study undertaken in New Zealand (Kuschel et al. 2019). The study found that measured CO_2 emissions from individual vehicles compared reasonably well, on average, with the VEPM emission factor for the corresponding vehicle category. However, at any specific part of a real-world trip, emissions can be significantly different to the VEPM emission factor, as shown in Figure 11. This shows CO_2 emission test results at a 1-minute resolution compared with VEPM emission factors for two example vehicles.

[27] In this report the term ‘vehicle operation’ refers to a wide range of parameters which describe the way in which a driver controls a vehicle (e.g. average speed, maximum speed, acceleration pattern, gear-change pattern), as well as the way in which the vehicle responds (e.g. engine speed, engine load).

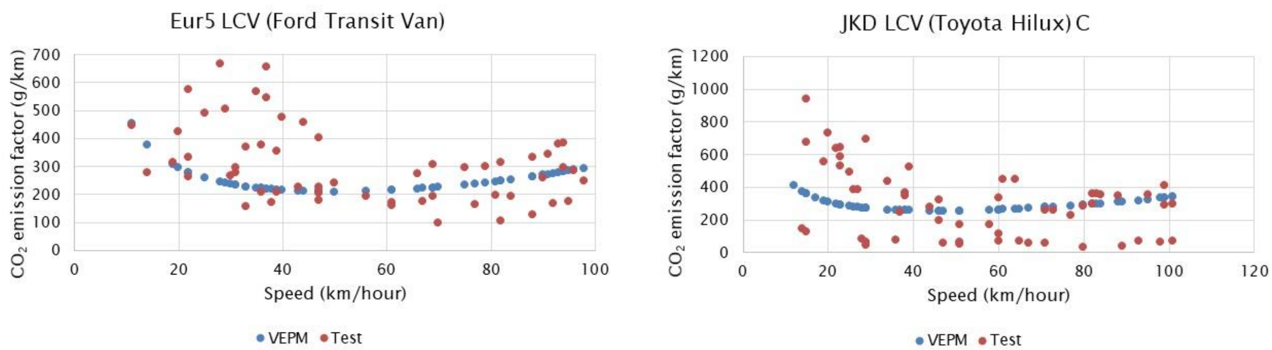

Figure 11: Real world emission test results graphed at 1 minute resolution compared against VEPM predictions for CO_2 for two example vehicles (Kuschel et al. 2019).

Alternatives to average speed models

Various vehicle emissions models have been developed internationally with different levels of complexity for different uses. These can be classified by generic model type. The most common model types are shown in Table 30, together with their applications:

Table 30: The most common types of emission models and their applications

Type	Input data required to define vehicle operation	Characteristic	Typical application	Example
Aggregate	Area or road type	Simplest level, no speed or vehicle specific dependency	National inventories	COPERT (Europe and international)
Average speed	Average trip speed	Speed and vehicle type/ technology	National and regional inventories	COPERT (Europe) VEPM (New Zealand)
Traffic situation	Road type, speed limits, level of congestion	Driving pattern (speed, acceleration etc) and vehicle type/technology specific	Environmental impact assessment, area-wide urban traffic management assessment	HBEFA (Germany, Switzerland, Austria, Sweden, Norway, France)
Modal	Driving pattern, vehicle specific data – power, speed, emissions	Micro-scale modelling, typically 1 second intervals, individual vehicle specific	Urban traffic management assessment	PHEM (EUROPE)

Traffic situation models provide emission factors for a combination of traffic descriptors instead of average speed. For example, the Handbook of Emission Factors (HBEFA) is a traffic situation model that is used in several European countries. The HBEFA model provides factors for different road types (motorway, distributor, etc), levels of service, and speed limits.

The most detailed 'modal' models (also known as 'instantaneous' and 'micro-scale' models) estimate vehicle emissions via engine or vehicle operating models at a resolution of one to several seconds. These models typically require detailed information on vehicle characteristics and vehicle movements (Smit et al. 2010). One application of these models is to provide emission factors for other types of model. For example, in Europe PHEM has been used to develop emission factors for both COPERT and HBEFA.

A review of emission model validation studies found no evidence that more complex models perform systematically better in terms of prediction errors than simpler ones (Smit et al. 2010). The review concludes that more complex models have the potential to provide more accurate predictions as they take into account more variables. However, they also require more detailed input data which may not be readily available to the model user (so simplifying assumptions need to be made) or may be available but with unknown quality (e.g. simulated driving patterns from traffic models). The authors conclude that the larger appetite for input data (and their associated errors) offsets the potential accuracy gains of more complex models.

Appendix 2: emission standards assumed by year of manufacture

Vehicles are assigned to an emission standard origin (European, Australian, New Zealand, Japanese) based on the assumptions outlined in section 3.4. Note that from 2010 all used vehicle imports are assigned to Japanese and all new vehicle imports are assigned to European.

European

Table 31: Emission standards assumed by year of manufacture for vehicles assigned **European emission standard origin** (includes New Zealand new European and Japanese vehicles up to year of manufacture 2009 and all New Zealand new vehicles from 2010 onwards)

Category	Fuel Type	Year of Manufacture	EMEP Standard	EMEP Technology
Passenger Cars	Petrol	<1972	PRE ECE	-
Passenger Cars	Petrol	1972-1977	ECE 15/00-01	-
Passenger Cars	Petrol	1978-1980	ECE 15/02	-
Passenger Cars	Petrol	1981-1984	ECE 15/03	-
Passenger Cars	Petrol	1985-1995	ECE 15/04	-
Passenger Cars	Petrol	1996-1999	Euro 1	-
Passenger Cars	Petrol	2000-2003	Euro 2	-
Passenger Cars	Petrol	2004-2008	Euro 3	PFI
Passenger Cars	Petrol	2009-2015	Euro 4	PFI
Passenger Cars	Petrol	2016-2029	Euro 5	PFI
Passenger Cars	Petrol	>=2030	Euro 6 d	PFI
Passenger Cars	Diesel	<1996	Conventional	-
Passenger Cars	Diesel	1996-1999	Euro 1	-
Passenger Cars	Diesel	2000-2003	Euro 2	-
Passenger Cars	Diesel	2004-2007	Euro 3	DPF
Passenger Cars	Diesel	2008-2015	Euro 4	DPF
Passenger Cars	Diesel	2016-2029	Euro 5	DPF
Passenger Cars	Diesel	>=2030	Euro 6 d	DPF
Light Commercial Vehicles	Petrol	<1996	Conventional	-
Light Commercial Vehicles	Petrol	1996-1999	Euro 1	-
Light Commercial Vehicles	Petrol	2000-2003	Euro 2	-
Light Commercial Vehicles	Petrol	2004-2008	Euro 3	PFI
Light Commercial Vehicles	Petrol	2009-2015	Euro 4	PFI
Light Commercial Vehicles	Petrol	2016-2029	Euro 5	PFI
Light Commercial Vehicles	Petrol	>=2030	Euro 6 d	PFI
Light Commercial Vehicles	Diesel	<1996	Conventional	-
Light Commercial Vehicles	Diesel	1996-1999	Euro 1	-
Light Commercial Vehicles	Diesel	2000-2003	Euro 2	-
Light Commercial Vehicles	Diesel	2004-2007	Euro 3	DPF
Light Commercial Vehicles	Diesel	2008-2015	Euro 4	DPF
Light Commercial Vehicles	Diesel	2016-2029	Euro 5	DPF
Light Commercial Vehicles	Diesel	>=2030	Euro 6 d	DPF
Heavy Duty Trucks	Diesel	<1995	Conventional	-
Heavy Duty Trucks	Diesel	1995-1999	Euro I	-

Category	Fuel Type	Year of Manufacture	EMEP Standard	EMEP Technology
Heavy Duty Trucks	Diesel	2000-2002	Euro II	-
Heavy Duty Trucks	Diesel	2003-2007	Euro III	-
Heavy Duty Trucks	Diesel	2008-2011	Euro IV	SCR
Heavy Duty Trucks	Diesel	2012-2029	Euro V	SCR (75%) EGR (25%)
Heavy Duty Trucks	Diesel	>=2030	Euro VI D/E	DPS + SCR
Buses	Diesel	<1995	Conventional	-
Buses	Diesel	1995-1999	Euro I	-
Buses	Diesel	2000-2002	Euro II	-
Buses	Diesel	2003-2007	Euro III	-
Buses	Diesel	2008-2011	Euro IV	SCR
Buses	Diesel	2012-2029	Euro V	SCR (75%) EGR (25%)
Buses	Diesel	>=2030	Euro VI D/E	DPS + SCR

Australian

Table 32: Emission standards assumed by year of manufacture for **Australian manufactured vehicles up to 2009**

Category	Fuel Type	Year of Manufacture	EMEP Standard	EMEP Technology
Passenger Cars	Petrol	<1972	PRE ECE	-
Passenger Cars	Petrol	1972-1977	ECE 15/00-01	-
Passenger Cars	Petrol	1978-1980	ECE 15/02	-
Passenger Cars	Petrol	1981-1984	ECE 15/03	-
Passenger Cars	Petrol	1985-2002	Euro 1	-
Passenger Cars	Petrol	2003-2004	Euro 2	-
Passenger Cars	Petrol	2005-2007	Euro 3	PFI
Passenger Cars	Petrol	2008-2009	Euro 4	PFI
Passenger Cars	Diesel	<1992	Conventional	-
Passenger Cars	Diesel	1992-2002	Euro 1	-
Passenger Cars	Diesel	2003-2006	Euro 2	-
Passenger Cars	Diesel	2007-2009	Euro 4	DPF
Light Commercial Vehicles	Petrol	<1993	Conventional	-
Light Commercial Vehicles	Petrol	1993-2002	Euro 1	-
Light Commercial Vehicles	Petrol	2003-2004	Euro 2	-
Light Commercial Vehicles	Petrol	2005-2007	Euro 3	PFI
Light Commercial Vehicles	Petrol	2008-2009	Euro 4	PFI
Light Commercial Vehicles	Diesel	<1993	Conventional	-
Light Commercial Vehicles	Diesel	1993-2002	Euro 1	-
Light Commercial Vehicles	Diesel	2003-2006	Euro 2	-
Light Commercial Vehicles	Diesel	2007-2009	Euro 4	DPF
Heavy Duty Trucks	Diesel	<1993	Conventional	-
Heavy Duty Trucks	Diesel	1993-2002	Euro I	-
Heavy Duty Trucks	Diesel	2003-2006	Euro III	-
Heavy Duty Trucks	Diesel	2007-2009	Euro IV	SCR
Buses	Diesel	<1993	Conventional	-
Buses	Diesel	1993-2002	Euro I	-
Buses	Diesel	2003-2006	Euro III	-
Buses	Diesel	2007-2009	Euro IV	SCR

New Zealand

Table 33: Emission standards assumed by year of manufacture for **New Zealand manufactured vehicles up to 2009**

Category	Fuel Type	Year of Manufacture	Ratio	EMEP Standard	EMEP Technology
Passenger Cars	Petrol	<1988	100%	ECE 15/02	-
Passenger Cars	Petrol	1988-1992	80%	ECE 15/02	-
Passenger Cars	Petrol	1988-1992	20%	Euro 1	-
Passenger Cars	Petrol	1993-1997	40%	ECE 15/02	-
Passenger Cars	Petrol	1993-1997	60%	Euro 1	-
Passenger Cars	Petrol	1998-2002	10%	ECE 15/02	-
Passenger Cars	Petrol	1998-2002	90%	Euro 1	-
Passenger Cars	Petrol	2003-2009	100%	Euro 1	-
Passenger Cars	Diesel	<1992	100%	Conventional	-
Passenger Cars	Diesel	1992-2002	100%	Euro 1	-
Passenger Cars	Diesel	2003-2006	100%	Euro 2	-
Passenger Cars	Diesel	2007-2009	100%	Euro 4	DPF
Light Commercial Vehicles	Petrol	<1993	100%	Conventional	-
Light Commercial Vehicles	Petrol	1993-2002	100%	Euro 1	-
Light Commercial Vehicles	Petrol	2003-2004	100%	Euro 2	-
Light Commercial Vehicles	Petrol	2005-2007	100%	Euro 3	PFI
Light Commercial Vehicles	Petrol	2008-2009	100%	Euro 4	PFI
Light Commercial Vehicles	Diesel	<1993	100%	Conventional	-
Light Commercial Vehicles	Diesel	1993-2002	100%	Euro 1	-
Light Commercial Vehicles	Diesel	2003-2006	100%	Euro 2	-
Light Commercial Vehicles	Diesel	2007-2009	100%	Euro 4	DPF
Heavy Duty Trucks	Diesel	<1993	100%	Conventional	-
Heavy Duty Trucks	Diesel	1993-2002	100%	Euro I	-
Heavy Duty Trucks	Diesel	2003-2006	100%	Euro III	-
Heavy Duty Trucks	Diesel	2007-2009	100%	Euro IV	SCR
Buses	Diesel	<1993	100%	Conventional	-
Buses	Diesel	1993-2002	100%	Euro I	-
Buses	Diesel	2003-2006	100%	Euro III	-
Buses	Diesel	2007-2009	100%	Euro IV	SCR

Japanese

Table 34: Emission standards assumed by year of manufacture for vehicles assigned **Japanese emission standard origin** (includes Japanese used vehicles, and all used vehicle imports from 2010)

Category	Fuel Type	Year of Manufacture	Standard[28]
Passenger Cars	Petrol	1950-1974	Pre 1973, J73
Passenger Cars	Petrol	1975-1977	J75, J76
Passenger Cars	Petrol	1978-1985	J78
Passenger Cars	Petrol	1986-1999	J78, J88
Passenger Cars	Petrol	2000-2004	J00
Passenger Cars	Petrol	2005-2009	J05
Passenger Cars	Petrol	2010-2017	Euro 5
Passenger Cars	Petrol	2018-2023	Euro 6 a/b/c
Passenger Cars	Petrol	2024-2050	Euro 6 d
Passenger Cars	Diesel	1950-1985	Pre 1986
Passenger Cars	Diesel	1986-1991	J86
Passenger Cars	Diesel	1992-1997	J92, J94
Passenger Cars	Diesel	1998-2001	J98
Passenger Cars	Diesel	2002-2004	J02
Passenger Cars	Diesel	2005-2009	J05
Passenger Cars	Diesel	2010-2050	Euro 5
Light Commercial Vehicles	Petrol	1950-1979	J73, J75, J79
Light Commercial Vehicles	Petrol	1980-1987	J79, J81
Light Commercial Vehicles	Petrol	1988-2000	J88
Light Commercial Vehicles	Petrol	2001-2004	J01
Light Commercial Vehicles	Petrol	2005-2009	J05
Light Commercial Vehicles	Petrol	2010-2050	Euro 5
Light Commercial Vehicles	Diesel	1950-1976	Pre 1974, J74
Light Commercial Vehicles	Diesel	1977-1981	J77, J79
Light Commercial Vehicles	Diesel	1982-1987	J82, J83, J87
Light Commercial Vehicles	Diesel	1988-1992	J88
Light Commercial Vehicles	Diesel	1993-1996	J93
Light Commercial Vehicles	Diesel	1997-2004	J97, J03
Light Commercial Vehicles	Diesel	2005-2009	J05
Light Commercial Vehicles	Diesel	2010-2050	Euro 5
Heavy Duty Trucks	Diesel	<1974	Pre 1974
Heavy Duty Trucks	Diesel	1974-1987	J74, J77, J79, J82, J83, J87
Heavy Duty Trucks	Diesel	1988-1993	J88
Heavy Duty Trucks	Diesel	1994-1997	J94, J97
Heavy Duty Trucks	Diesel	1998-2002	J97
Heavy Duty Trucks	Diesel	2003-2004	J03
Heavy Duty Trucks	Diesel	2005-2009	J05
Heavy Duty Trucks	Diesel	2010-2050	Euro VI D/E
Buses	Diesel	<1974	Pre 1974

[28] Up to 2010 the standard relates to emission categories in the JCAP Japanese emission model, based on year of manufacture, as described in EFRU 2008. From 2010 the standard refers to the closest equivalent European standard that is assumed based on comparison of emission standards and test requirements (Metcalfe & Peeters 2022)

Category	Fuel Type	Year of Manufacture	Standard[28]
Buses	Diesel	1974-1987	J74, J77, J79, J82, J83, J87
Buses	Diesel	1988-1993	J88
Buses	Diesel	1994-1997	J94, J97
Buses	Diesel	1998-2002	J97
Buses	Diesel	2003-2004	J03
Buses	Diesel	2005-2009	J05
Buses	Diesel	2010-2050	Euro VI D/E

Appendix 3: Japanese European equivalence table

Notes:

- Up to 2010 the "Japan Standard" column relates to emission categories in the JCAP Japanese emission model, based on year of manufacture, as described in the VEPM development report (EFRU 2008). From 2010, the "Japan Standard' refers to the closest equivalent European standard that is assumed based on comparison of emission standards and test requirements (Metcalfe & Peeters 2022)
- For CH_4 and N_2O, equivalences are the same as VOC and NOx respectively.
- The "tech" column shows the technology sub-category, which is specified in the EMEP/EEA emission factors. These are:
    - **PFI**: port fuel injection
    - **GDI**: gasoline direct injection
    - **DPF**: diesel particulate filter – a particulate emission control system
    - **EGR**: exhaust gas recirculation – a nitrogen oxide emission control system
    - **SCR**: selective catalytic reduction – a nitrogen oxide emission control system

Category	Fuel Type	Segment	Japan Standard	CO Standard	CO Tech	VOC Standard	VOC Tech	NOx Standard	NOx Tech	PM Standard	PM Tech	EC Standard	EC Tech
CAR	Petrol	Small	Pre 1973, J73	PRE ECE	-	PRE ECE	-	PRE ECE	-	PRE ECE	-	PRE ECE	-
CAR	Petrol	Medium	Pre 1973, J73	PRE ECE	-	PRE ECE	-	PRE ECE	-	PRE ECE	-	PRE ECE	-
CAR	Petrol	Large-SUV-Executive	Pre 1973, J73	PRE ECE	-	PRE ECE	-	PRE ECE	-	PRE ECE	-	PRE ECE	-
CAR	Petrol	Small	J75, J76	Euro 1	-	Euro 1	-	PRE ECE	-	Euro 1	-	Euro 1	-
CAR	Petrol	Medium	J75, J76	Euro 1	-	Euro 1	-	PRE ECE	-	Euro 1	-	Euro 1	-
CAR	Petrol	Large-SUV-Executive	J75, J76	Euro 1	-	Euro 1	-	PRE ECE	-	Euro 1	-	Euro 1	-
CAR	Petrol	Small	J78	Euro 1	-	Euro 1	-	Euro 1	-	Euro 1	-	Euro 1	-
CAR	Petrol	Medium	J78	Euro 1	-	Euro 1	-	Euro 1	-	Euro 1	-	Euro 1	-
CAR	Petrol	Large-SUV-Executive	J78	Euro 1	-	Euro 1	-	Euro 1	-	Euro 1	-	Euro 1	-
CAR	Petrol	Small	J78, J88	Euro 1	-	Euro 2	-	Euro 2	-	Euro 2	-	Euro 2	-
CAR	Petrol	Medium	J78, J88	Euro 1	-	Euro 2	-	Euro 2	-	Euro 2	-	Euro 2	-
CAR	Petrol	Large-SUV-Executive	J78, J88	Euro 1	-	Euro 2	-	Euro 2	-	Euro 2	-	Euro 2	-
CAR	Petrol	Small	J00	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI
CAR	Petrol	Medium	J00	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI
CAR	Petrol	Large-SUV-Executive	J00	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI
CAR	Petrol	Small	J05	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI
CAR	Petrol	Medium	J05	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI
CAR	Petrol	Large-SUV-Executive	J05	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI
CAR	Petrol	Small	Euro 5	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI
CAR	Petrol	Medium	Euro 5	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI
CAR	Petrol	Large-SUV-Executive	Euro 5	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI

Category	Fuel Type	Segment	Japan Standard	CO Standard	CO Tech	VOC Standard	VOC Tech	NOx Standard	NOx Tech	PM Standard	PM Tech	EC Standard	EC Tech
CAR	Petrol	Small	Euro 6 a/b/c	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI
CAR	Petrol	Medium	Euro 6 a/b/c	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI
CAR	Petrol	Large-SUV-Executive	Euro 6 a/b/c	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI	Euro 6 a/b/c	PFI
CAR	Petrol	Small	Euro 6 d	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI
CAR	Petrol	Medium	Euro 6 d	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI
CAR	Petrol	Large-SUV-Executive	Euro 6 d	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI	Euro 6 d	PFI
CAR	Diesel	Medium	Pre 1986	Conventional	-	Conventional	-	Euro 1	-	Conventional	-	Conventional	-
CAR	Diesel	Large-SUV-Executive	Pre 1986	Conventional	-	Conventional	-	Euro 1	-	Conventional	-	Conventional	-
CAR	Diesel	Medium	J86	Euro 1	-	Euro 2	-	Euro 1	-	Conventional	-	Euro 1	-
CAR	Diesel	Large-SUV-Executive	J86	Euro 1	-	Euro 2	-	Euro 1	-	Conventional	-	Euro 1	-
CAR	Diesel	Medium	J92, J94	Euro 1	-	Euro 2	-	Euro 3	DPF	Conventional	-	Euro 1	-
CAR	Diesel	Large-SUV-Executive	J92, J94	Euro 1	-	Euro 2	-	Euro 3	DPF	Conventional	-	Euro 1	-
CAR	Diesel	Medium	J98	Euro 1	-	Euro 2	-	Euro 3	DPF	Euro 1	-	Euro 1	-
CAR	Diesel	Large-SUV-Executive	J98	Euro 1	-	Euro 2	-	Euro 3	DPF	Euro 1	-	Euro 1	-
CAR	Diesel	Medium	J02	Euro 1	-	Euro 2	-	Euro 3	DPF	Euro 3	DPF	Euro 1	-
CAR	Diesel	Large-SUV-Executive	J02	Euro 1	-	Euro 2	-	Euro 3	DPF	Euro 3	DPF	Euro 1	-
CAR	Diesel	Medium	J05	Euro 3	DPF	Euro 4	DPF	Euro 4	DPF	Euro 4	DPF	Euro 3	DPF
CAR	Diesel	Large-SUV-Executive	J05	Euro 3	DPF	Euro 4	DPF	Euro 4	DPF	Euro 4	DPF	Euro 3	DPF
CAR	Diesel	Medium	Euro 5	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF
CAR	Diesel	Large-SUV-Executive	Euro 5	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF
LCV	Petrol	N1-III	J73, J75, J79	Conventional	-	Conventional	-	Conventional	-	Conventional	-	Conventional	-
LCV	Petrol	N1-III	J79, J81	Euro 1	-	Conventional	-	Euro 1	-	Conventional	-	Conventional	-
LCV	Petrol	N1-III	J88	Euro 1	-	Euro 1	-	Euro 2	-	Euro 1	-	Euro 1	-
LCV	Petrol	N1-III	J01	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI	Euro 3	PFI
LCV	Petrol	N1-III	J05	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI	Euro 4	PFI
LCV	Petrol	N1-III	Euro 5	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI	Euro 5	PFI
LCV	Diesel	N1-III	Pre 1974, J74	Conventional	-	Euro 1	-	Conventional	-	Euro 1	-	Conventional	-
LCV	Diesel	N1-III	J77, J79	Conventional	-	Euro 1	-	Euro 1	-	Euro 1	-	Conventional	-
LCV	Diesel	N1-III	J82, J83, J87	Conventional	-	Euro 1	-	Euro 3	DPF	Euro 1	-	Conventional	-
LCV	Diesel	N1-III	J88	Euro 1	-	Euro 3	DPF	Euro 3	DPF	Euro 1	-	Euro 1	-
LCV	Diesel	N1-III	J93	Euro 1	-	Euro 3	DPF	Euro 3	DPF	Euro 3	DPF	Euro 1	-
LCV	Diesel	N1-III	J97, J03	Euro 1	-	Euro 3	DPF	Euro 4	DPF	Euro 3	DPF	Euro 1	-
LCV	Diesel	N1-III	J05	Euro 3	DPF	Euro 4	DPF	Euro 4	DPF	Euro 4	DPF	Euro 3	DPF
LCV	Diesel	N1-III	Euro 5	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF	Euro 5	DPF
HCV	Diesel	Rigid <=7,5 t	Pre 1974	Euro I	-	Euro II	-	Conventional	-	Conventional	-	Euro I	-
HCV	Diesel	Rigid 7,5 - 12 t	Pre 1974	Conventional	-	Euro I	-	Conventional	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid 14 - 20 t	Pre 1974	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid 20 - 26 t	Pre 1974	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid 26 - 28 t	Pre 1974	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid >32 t	Pre 1974	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid <=7,5 t	J74, J77, J79, J82, J83, J87	Euro I	-	Euro II	-	Conventional	-	Conventional	-	Euro I	-

Category	Fuel Type	Segment	Japan Standard	CO Standard	CO Tech	VOC Standard	VOC Tech	NOx Standard	NOx Tech	PM Standard	PM Tech	EC Standard	EC Tech
HCV	Diesel	Rigid 7,5 - 12 t	J74, J77, J79, J82, J83, J87	Conventional	-	Euro I	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid 14 - 20 t	J74, J77, J79, J82, J83, J87	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid 20 - 26 t	J74, J77, J79, J82, J83, J87	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid 26 - 28 t	J74, J77, J79, J82, J83, J87	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid >32 t	J74, J77, J79, J82, J83, J87	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
HCV	Diesel	Rigid <=7,5 t	J88	Euro I	-	Euro II	-	Euro I	-	Euro I	-	Euro I	-
HCV	Diesel	Rigid 7,5 - 12 t	J88	Conventional	-	Euro I	-	Euro II	-	Euro II	-	Conventional	-
HCV	Diesel	Rigid 14 - 20 t	J88	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
HCV	Diesel	Rigid 20 - 26 t	J88	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
HCV	Diesel	Rigid 26 - 28 t	J88	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
HCV	Diesel	Rigid >32 t	J88	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
HCV	Diesel	Rigid <=7,5 t	J94, J97	Euro I	-	Euro II	-	Euro II	-	Euro I	-	Euro I	-
HCV	Diesel	Rigid 7,5 - 12 t	J94, J97	Conventional	-	Euro I	-	Euro II	-	Euro II	-	Conventional	-
HCV	Diesel	Rigid 14 - 20 t	J94, J97	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
HCV	Diesel	Rigid 20 - 26 t	J94, J97	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
HCV	Diesel	Rigid 26 - 28 t	J94, J97	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
HCV	Diesel	Rigid >32 t	J94, J97	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
HCV	Diesel	Rigid <=7,5 t	J97	Euro I	-	Euro II	-	Euro III	-	Euro III	-	Euro I	-
HCV	Diesel	Rigid 7,5 - 12 t	J97	Conventional	-	Euro I	-	Euro III	-	Euro III	-	Conventional	-
HCV	Diesel	Rigid 14 - 20 t	J97	Conventional	-	Conventional	-	Euro III	-	Euro III	-	Conventional	-
HCV	Diesel	Rigid 20 - 26 t	J97	Conventional	-	Conventional	-	Euro III	-	Euro III	-	Conventional	-
HCV	Diesel	Rigid 26 - 28 t	J97	Conventional	-	Conventional	-	Euro III	-	Euro III	-	Conventional	-
HCV	Diesel	Rigid >32 t	J97	Conventional	-	Conventional	-	Euro III	-	Euro III	-	Conventional	-
HCV	Diesel	Rigid <=7,5 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-
HCV	Diesel	Rigid 7,5 - 12 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-
HCV	Diesel	Rigid 14 - 20 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-
HCV	Diesel	Rigid 20 - 26 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-
HCV	Diesel	Rigid 26 - 28 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-
HCV	Diesel	Rigid >32 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-
HCV	Diesel	Rigid <=7,5 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid <=7,5 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid 7,5 - 12 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid 7,5 - 12 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid 14 - 20 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid 14 - 20 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid 20 - 26 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid 20 - 26 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid 26 - 28 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR

Category	Fuel Type	Segment	Japan Standard	CO Standard	CO Tech	VOC Standard	VOC Tech	NOx Standard	NOx Tech	PM Standard	PM Tech	EC Standard	EC Tech
HCV	Diesel	Rigid 26 - 28 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid >32 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid >32 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
HCV	Diesel	Rigid <=7,5 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR
HCV	Diesel	Rigid 7,5 - 12 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR
HCV	Diesel	Rigid 14 - 20 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR
HCV	Diesel	Rigid 20 - 26 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR
HCV	Diesel	Rigid 26 - 28 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR
HCV	Diesel	Rigid >32 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR
BUS	Diesel	Urban Buses Midi <=15 t	Pre 1974	Conventional	-	Euro I	-	Conventional	-	Conventional	-	Conventional	-
BUS	Diesel	Urban Buses Standard 15 - 18 t	Pre 1974	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
BUS	Diesel	Coaches Standard <=18 t	Pre 1974	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
BUS	Diesel	Urban Buses Midi <=15 t	J74, J77, J79, J82, J83, J87	Conventional	-	Euro I	-	Euro I	-	Conventional	-	Conventional	-
BUS	Diesel	Urban Buses Standard 15 - 18 t	J74, J77, J79, J82, J83, J87	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
BUS	Diesel	Coaches Standard <=18 t	J74, J77, J79, J82, J83, J87	Conventional	-	Conventional	-	Euro I	-	Conventional	-	Conventional	-
BUS	Diesel	Urban Buses Midi <=15 t	J88	Conventional	-	Euro I	-	Euro II	-	Euro II	-	Conventional	-
BUS	Diesel	Urban Buses Standard 15 - 18 t	J88	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
BUS	Diesel	Coaches Standard <=18 t	J88	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
BUS	Diesel	Urban Buses Midi <=15 t	J94, J97	Conventional	-	Euro I	-	Euro II	-	Euro II	-	Conventional	-
BUS	Diesel	Urban Buses Standard 15 - 18 t	J94, J97	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
BUS	Diesel	Coaches Standard <=18 t	J94, J97	Conventional	-	Conventional	-	Euro II	-	Euro I	-	Conventional	-
BUS	Diesel	Urban Buses Midi <=15 t	J97	Conventional	-	Euro I	-	Euro III	-	Euro III	-	Conventional	-
BUS	Diesel	Urban Buses Standard 15 - 18 t	J97	Conventional	-	Conventional	-	Euro III	-	Euro III	-	Conventional	-
BUS	Diesel	Coaches Standard <=18 t	J97	Conventional	-	Conventional	-	Euro III	-	Euro III	-	Conventional	-
BUS	Diesel	Urban Buses Midi <=15 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-
BUS	Diesel	Urban Buses Standard 15 - 18 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-

Category	Fuel Type	Segment	Japan Standard	CO Standard	CO Tech	VOC Standard	VOC Tech	NOx Standard	NOx Tech	PM Standard	PM Tech	EC Standard	EC Tech
BUS	Diesel	Coaches Standard <=18 t	J03	Euro III	-	Euro III	-	Euro IV	SCR	Euro III	-	Euro III	-
BUS	Diesel	Urban Buses Midi <=15 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR
BUS	Diesel	Urban Buses Midi <=15 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
BUS	Diesel	Urban Buses Standard 15 - 18 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR
BUS	Diesel	Urban Buses Standard 15 - 18 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
BUS	Diesel	Coaches Standard <=18 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	SCR	Euro IV	SCR	Euro IV	SCR
BUS	Diesel	Coaches Standard <=18 t	J05	Euro IV	SCR	Euro IV	SCR	Euro V	EGR	Euro IV	SCR	Euro IV	SCR
BUS	Diesel	Urban Buses Midi <=15 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR
BUS	Diesel	Urban Buses Standard 15 - 18 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR
BUS	Diesel	Coaches Standard <=18 t	Euro VI D/E	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR	Euro VI D/E	DPF+SCR

Appendix 4: Emission factor and correction factor data sources in VEPM 7.0

Factor	Vehicle category	Reference/source	Comments
Hot running	All vehicle categories	EEA 2021a and EEA 2020	All hot emission factors updated to the latest version from EMEP/EEA (EEA, 2021a) except PM based on previous version (EEA 2020)
Hot running	Japanese domestic imports (light duty) up to YOM 2010	Based on EURO/JCAP equivalent emissions factors	All hot emission factors are from EMEP/EEA (EEA, 2021a) except PM based on previous version (EEA 2020) and are assigned based on the Japan/Europe equivalencies described in Chapter 5
Cold start	All light duty	EEA 2021	
Fuel correction	All gasoline and diesel	EEA 2021	Based on introduction dates of improved fuels and vehicle technology in New Zealand as described in Chapter 5
Degradation	Light duty	Various sources. Refer Table 13, Chapter 5	Light duty CO and NOx factors updated in 2021 based on Carslaw et al 2019, however these should be reviewed when COPERT is updated. All other factors unchanged from EFRU (2008) and should be reviewed and updated when new information becomes available as discussed in Chapter 5.
Degradation	Heavy duty diesel	Ubanwa et al 2003 + Lindhjem & Jackson 1999 as described in EFRU (2008).	No change to assumptions described in EFRU (2008). EMEP/EEA does not include degradation factors for HCV. Factors should be reviewed and updated when new information becomes available as discussed in Chapter 5.
Gradient	Light duty	PIARC (2019)	CO, NOx and PM gradient correction factors for light duty vehicles.
Gradient and load	Heavy duty	EEA 2021a	Heavy duty hot emission factors are adjusted for gradient and load in the EMEP/EEA spreadsheet
f-NO_2	All	EEA 2016	Updated factors available (EEA 2021) for Euro 5 and Euro 6 vehicles. These should be updated.
Brake and tyre wear	All	EEA 2019	
NZ real world fuel consumption	Light duty diesel	Metcalfe, Kuschel and Gimson (2020)	Correction factors based on methodology and assumptions described in Metcalfe, Kuschel and Gimson (2020). Proposed factors have been developed for VEPM 6.2 (Metcalfe et al 2021) however they have not been implemented at this stage.