VEHICLE EMISSIONS PREDICTION MODEL (VEPM 6.0) USER GUIDE

Version 3.0 July 2019

Ministry of Transport TE MANATŪ WAKA

emission: impossible ltd

NIWA Taihoro Nukurangi

Auckland Council

NZ TRANSPORT AGENCY WAKA KOTAHI

New Zealand Government

Vehicle emissions prediction model (VEPM 6.0) user guide v3.0

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Contents

Foreword

Vehicle emission models are frequently used for assessing potential environmental effects that arise from land transport projects. The Vehicle Emissions Prediction Model (VEPM) has been developed by the NZ Transport Agency and Auckland Council to predict emissions from vehicles in the New Zealand fleet under typical road, traffic and operating conditions. The model provides estimates that are suitable for air quality assessments and regional emissions inventories. An important feature of the model is the ability to estimate changes to vehicle emissions in future years (out to 2050).

VEPM is an Excel spreadsheet which is publicly available on request from the Transport Agency:

email: **environment@nzta.govt.nz**

VEPM was originally developed for the Auckland Regional Council in 2008[01]. The model was developed to:

- predict emissions for vehicles in the New Zealand fleet under typical road, traffic and operating conditions, and
- be suitable for air quality assessment projects on a regional and national basis.

Since its release in 2008, VEPM has been successfully used in Auckland and around New Zealand to estimate vehicle emissions in air quality assessments of road projects. An important feature of vehicle emissions, however, is that they change significantly over time. This is because vehicle emissions, collectively, can be significant sources of air pollution and governments around the world have acted to successively tighten emissions regulations.

In recognition of the changing emissions profile for the New Zealand fleet, and reflecting the widespread use of VEPM, regular updates of VEPM have been released.

Key technical changes to VEPM in each public release date are summarised below:

- 2008 VEPM 3.0 based on emissions measurements in the United Kingdom National Atmospheric Emissions Inventory (UK NAEI) database from the 1990s and early 2000s. 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 emissions measurements from the UK NAEI database (2009) and the European COPERT 4, version 8, 2011 database. VEPM 5.0 includes emissions from hybrid vehicles, the effects of gradient, $PM_{2.5}$ as output and updated (2010) fleet profile data for New Zealand vehicles. Extensive work was undertaken to calibrate VEPM 5.0 against all available emissions data from New Zealand.
- 2012 VEPM 5.1 incorporates emission factors for light duty vehicles at different road gradients from the World Road Association[02, 03].
- 2017 VEPM 5.3 incorporates nitrogen dioxide, speeds for light vehicles up to 110km/h, updates to the emission standard introduction date and country of origin assumptions, updated emissions factors for Euro 5, Euro 6 and Euro V based on COPERT, and addition of Euro VI category[08].

Additional supporting technical information may be found in references [04], [05], [06] and [07].

01 Energy and Fuels Research Unit, Auckland University (2008) *Development of a vehicle emissions prediction model.*

02 Energy and Fuels Research Unit, Auckland University (2012) *Vehicle emissions prediction model (VEPM) version 5.1.*

03 World Road Association, PIARC Technical Committee on Road Tunnel Operation (C5) (2004) *Road tunnels: vehicle emissions and air demand for ventilation.* www.piarc.org

04 Energy and Fuels Research Unit, Auckland University (2010) *Vehicle emissions prediction model update: phase 1.*

05 Energy and Fuels Research Unit, Auckland University (2010) *Vehicle emissions prediction model update: Phase 2 progress report.*

06 Energy and Fuels Research Unit, Auckland University (2011) *Vehicle emissions prediction model update: COPERT 4 review.*

07 Energy and Fuels Research Unit, Auckland University (2011) *Cold start exhaust emissions performance: comparison of vehicle build technologies.*

08 Emission Impossible Ltd (2017) *Vehicle emission prediction model technical updates:* technical report www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Air-and-climate/Planning-and-assessment/Vehicle-emissions-prediction-model/VEPM-5.3-update-technical-report-April-2017.pdf

1 Introduction

1.1 Emissions models

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

Emissions factors are the amount of emissions of the various pollutants – carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM) – produced per kilometre driven.

Vehicle emissions are primarily dependent on the vehicle type and fuel. Carbon monoxide and hydrocarbon emissions from petrol vehicles are much higher compared with diesel vehicles, while diesel vehicles tend to have much higher emissions of particulate and nitrogen oxides. 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.

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 1.1, together with their applications:

TABLE 1.1 **Emissions models**

TYPE	INPUT DATA REQUIRED TO DEFINE VEHICLE OPERATION	CHARACTERISTIC	APPLICATION
Aggregate	Area or road type	Simplest level, no speed or vehicle specific dependency	National inventories
Average speed	Average trip speed	Speed and vehicle type/ technology specific	National and regional inventories
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 (UTM) assessment
Modal	Driving pattern, vehicle specific data – power, speed, emissions	Micro-scale modelling, typically 1 second intervals, individual vehicle specific	UTM assessment

1.2 The vehicle emissions prediction model (VEPM)

The vehicle emissions prediction model (VEPM) is an average speed model which predicts emission factors for the New Zealand fleet under typical road, traffic and operating conditions. VEPM provides tailpipe exhaust emission factors for CO, HC, NO_x CO_2 and particulates, as well as particulates from brake and tyre wear. VEPM does not currently estimate evaporative or crank case emissions.

VEPM was originally developed for the Auckland Regional Council in 2008 to estimate tailpipe exhaust emission factors for the regional emissions inventory. The model has also been widely used for assessments of air quality effects of transport projects.

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.

The emissions factors used for average speed models are based on the results of thousands of empirical tests. These tests use drive cycles representing real life driving conditions rather than the cycles used for regulatory compliance. The cycles have a wide range of different operating conditions, ie acceleration rates, maximum speeds, periods of idle etc, and hence a similarly wide range of average speeds. A low average speed is typical of driving in congested traffic and vice versa.

In addition to the range of driving conditions, the data must also cover the range of vehicle types and technologies. These include:

- vehicle type – passenger cars, light commercial and heavy commercial
- fuel type (diesel or petrol) and specification (eg sulphur content)
- engine capacity[A]
- engine technology – emissions standard to which the vehicle is built.

At time of preparation (pre-2008) 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, eg emission factors for heavy duty vehicles and cold start emissions factors from the European Computer Model to Calculate Emissions from Road Transport (COPERT). This is a model that has been under development since the 1990s for the creation of national emissions inventories for EU countries.

A Engine capacity is important for estimation of fuel consumption and CO_2 emissions but is less important for other emissions of other pollutants. Harmful emissions (PM, CO etc) are primarily dependent on the engine technology and are not a direct function of fuel use.

Since the development of VEPM in 2009, 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 6.0 have been updated based on emission factors from the COPERT model for all vehicles manufactured to European emission standards[09].

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 at the time that VEPM was developed, available emissions data was insufficient to be able to develop a comprehensive model based on Japanese data. 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[01]. This approach has also been used internationally[B].

Changes in cars manufactured overseas will eventually be seen in the New Zealand fleet. It is therefore important that VEPM contains the latest internationally available information and that its relevance for New Zealand conditions is optimised.

VEPM was released as version 3.0 in 2008[01] with subsequent releases as version 5.0 and 5.1 in 2012, 5.3 in 2017 and and 6.0 in 2019.

Details of this process are available in the supporting technical reports which are available on the Transport Agency's website at www.nzta.govt.nz/roads-and-rail/highways-information-portal/

09 COPERT emission factors are published in an excel spreadsheet in the EMEP/EEA Air pollutant emission inventory guidebook 2016 – Update Jul.2018 1.A.3.bi-iv Road transport hot EF's Annex 2018_Dic.xlsx. (http://www.eea.europa.eu/publications/emep-eea-guidebook-2016)

1.3 Version 6.0

In 2019, the Transport Agency commissioned an update of key assumptions and emission factors in Vehicle Emission Prediction Model. These include:

- extending VEPM to 2050
- creating separate categories for light duty hybrid, plug-in hybrid, and heavy duty electric vehicles
- replacing all emission factors for vehicles built to European standards with emission factors from the latest version of COPERT
- updating brake and tyre wear emission factors.

Details are provided in the *Vehicle emission prediction model technical updates: technical report*.[10]

10 Emission Impossible Ltd (2019) Vehicle emission prediction model (VEPM 6.0) update: technical report

B 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.

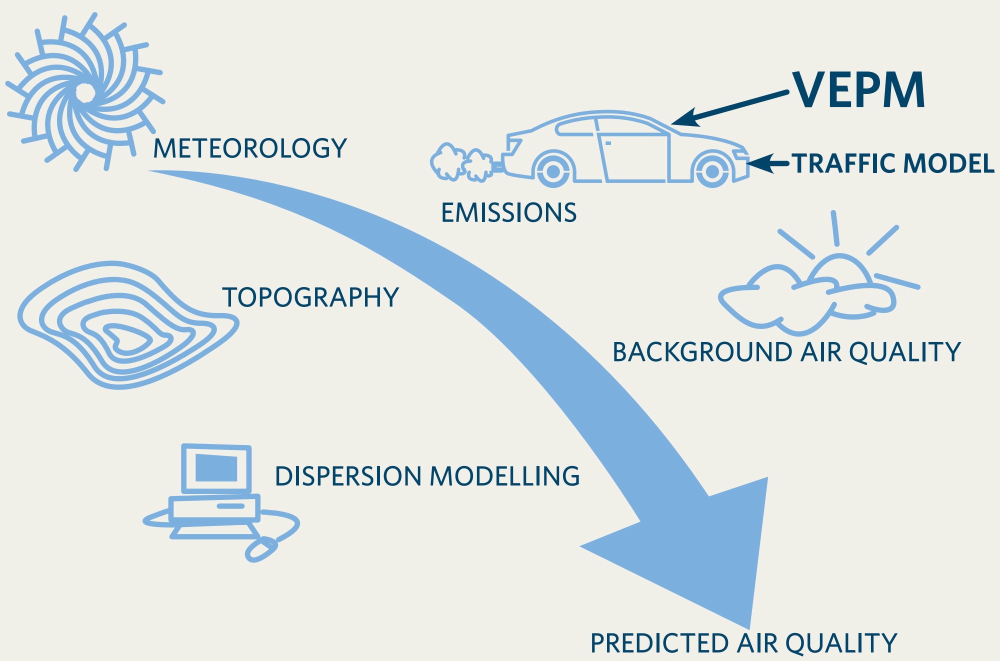
1.4 Purpose

VEPM has been developed by Auckland Council, and the Transport Agency 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. This is done through the use of back-casting for previous years, estimates for current years and projections for future years.

The model can be used in regional and national emissions inventories to determine whether 'business-as-usual' policies and trends will be sufficient to ensure the national environmental standards for air quality (AQNES) and other ambient air quality guidelines will be met.

VEPM is also a critical tool used in assessments of environmental effects (AEEs) 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 Transport Agency Screening Tool (www.nzta.govt.nz/roads-and-rail/highways-information-portal/), 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 1.1.

FIGURE 1.1 **VEPM and the assessment process**



The Transport Agency Guide to assessing air quality impacts from state highway projects[11] provides specific guidance for using VEPM to assess potential air quality effects associated with state highway asset improvement projects.

11 NZ Transport Agency (2018) *Guide to assessing air quality impacts from state highway projects* v2.1 July 2018) https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/

1.5 Limitations

As discussed in previous sections, VEPM is an average speed model which provides fleet averaged emission factors. It is intended to represent:

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

Emission factors from VEPM will not accurately represent:

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

VEPM is generally appropriate for assessments of 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 (eg the proportion of heavy duty vehicles) and local data should be used where possible.

Some specific limitations of the VEPM model are summarised below.

EVAPORATIVE AND CRANK CASE EMISSIONS

- VEPM does not include evaporative or crank case emission factors.

BUS EMISSION FACTORS

- Bus emission factors are assumed to be the same as heavy commercial vehicle emission factors in VEPM. Auckland Council has a bus emissions prediction model which provides for more detailed analysis of emissions from buses and covers emissions classes up to and including Euro V, J05, US07 and factors for alternative fuels/hybrid buses. In late 2016, Greater Wellington Regional Council established emission factors for a more comprehensive and up to date range of bus technologies but these are yet to be incorporated into a specific bus emission prediction model. Further information about modelling undertaken by these councils is available from **environment@nzta.govt.nz**

BRAKE AND TYRE WEAR EMISSION FACTORS

- Brake and tyre wear emission factors in VEPM are based on European emission factors. In New Zealand most roads are chipseal, so brake and tyre wear emission factors could potentially be higher.

HEAVY COMMERCIAL VEHICLE EMISSION FACTORS

- Heavy commercial vehicles contribute disproportionately to emissions. There has been very limited calibration and comparison of heavy commercial vehicle emission factors in VEPM with New Zealand specific test data. This is a significant gap in our current knowledge of vehicle emissions in New Zealand.

2 Using VEPM

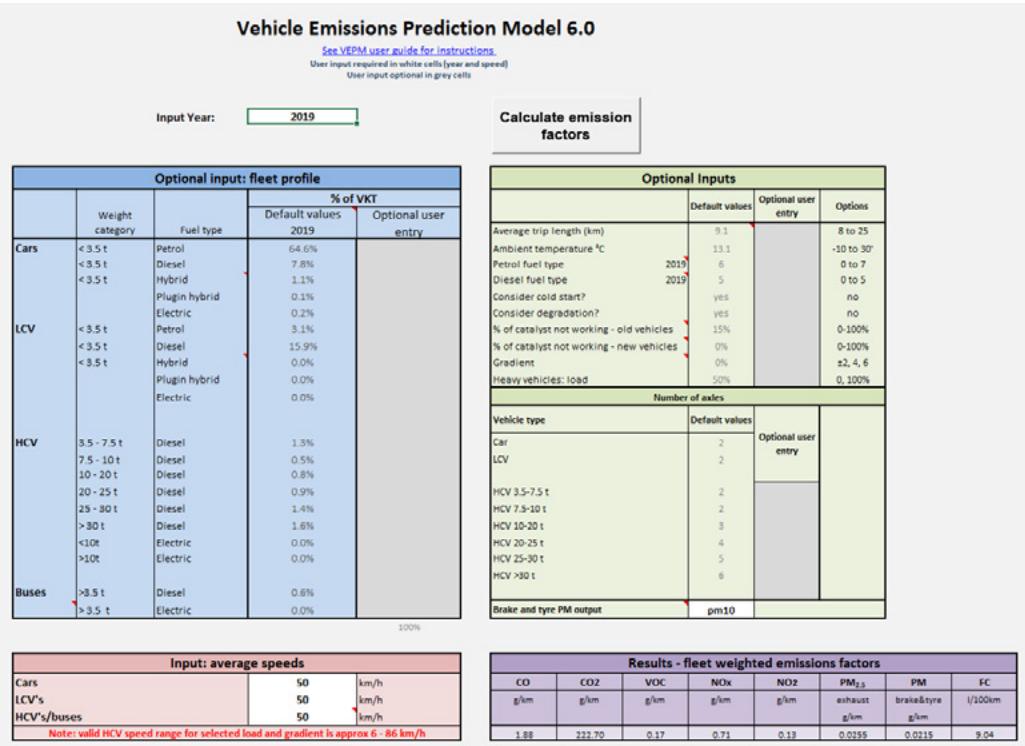
This section provides step-by-step instructions on running VEPM and the various options available to users.

Technical user support is available from **environment@nzta.govt.nz**

2.1 Getting started

Open the spreadsheet and enable macros. The spreadsheet should open in sheet named VEPM 6.0 as shown in figure 2.1.

FIGURE 2.1 **Screen shot of VEPM worksheet for entering fleet/emissions data**



The main worksheets the user will use or view are:

- VEPM: enter fleet/emissions data (shown above in figure 2.1)
- fleet emission factors: calculated fleet weighted emissions factors (green coloured tab)
- bulk run: enables the user to perform many runs automatically (blue coloured tab)
- bulk input: enables the user to input data for performing many runs automatically (dark blue coloured tab)
- fuel types: for information only – summary of fuel properties (light green coloured tab).

Some users may also wish to view the sheets which calculate emissions factors:

- EU and NZ front: emission factor calculation for the European and New Zealand new fleets.
- Japan front: emission factor calculation for the Japanese fleet.
- Brake and Tyre: emission factor calculation for brake and tyre wear particulate.

All other worksheets are hidden to avoid confusion. The user may unhide worksheets by right clicking on the worksheet name tab and then selecting unhide. All worksheets are password protected to avoid accidental changes or deletion.

2.2 Input data - VEPM worksheet

To calculate emissions for a single scenario data is input on the *VEPM* worksheet shown in figure 2.1. Data entry is required in cells that are white, and is optional for cells shaded light grey. All other cells are locked to prevent accidental changes or deletion. Some cells have informative comments entered (as indicated by the red triangle at the top right of the cell) which are displayed when the cursor is moved over that cell.

Details of input parameters on the *VEPM* worksheet are described as follows:

YEAR

The analysis year must be between 2001 and 2050. VEPM selects a fleet profile for the New Zealand fleet using the year selected.

FLEET PROFILE (OPTIONAL USER ENTRY)

Percentage of vehicle kilometres travelled (VKT) by each vehicle class can be based on either user defined or default values. Wherever possible, site-specific data, or data from nearby locations should be used to estimate the proportion of diesel vehicles, particularly HCVs.

The default fleet profile is based on results from the Ministry of Transport Vehicle fleet emissions model (VFEM). The VFEM output includes actual fleet data up to 2017, with projections out to 2050.

For the selected year, the model will use the MOT fleet profile for that particular year. When user defined values are inputted, the %VKT must add to 100%. The model will use default values for any vehicle class where a user defined value is not specified. This means that for any vehicle class with no VKT, the user must specify 0% to override default values.

AVERAGE SPEED

The model allows the user to define different average speeds for light and heavy duty vehicles. Average speeds must be between 10 and 110km/h.

For heavy duty vehicles the valid speed range depends on the vehicle size, the gradient and the load. If the specified speed is outside the valid range, the model will calculate emissions at the closest valid speed (eg if the user specified speed is 100km/h and the highest valid speed is 87km/h for a particular vehicle class, the model will calculate emissions at 87km/h for that vehicle class).

OPTIONAL MODEL INPUTS

The optional model inputs are described in section 2.5.

2.3 Calculating emissions factors – VEPM worksheet

When the 'calculate emission factors' button is selected on the VEPM worksheet, the default fleet profile, fuel types are updated and emission factors are calculated.

Calculated fleet average (or weighted) emissions factors are displayed on the VEPM worksheet. Detailed emission factors by vehicle class are displayed in the Fleet emissions factors worksheet.

C Land Transport New Zealand merged with Transit New Zealand to form the NZ Transport Agency on 1 August 2008.

FIGURE 2.2 **Fleet emission factors in VEPM**

Emission factors

Fleet average emissions factors		
CO	1.88	g/km
CO2	222.70	g/km
VOC	0.17	g/km
NOx	0.71	g/km
NO2	0.13	g/km
$PM_{2.5}$ exhaust	0.0255	g/km
pm10 B and T	0.0215	g/km
FC	9.04	l/100km

Light vehicle fleet average emission factors		
CO	1.93	g/km
CO2	194.73	g/km
VOC	0.17	g/km
NOx	0.48	g/km
NO2	0.11	g/km
$PM_{2.5}$ exhaust	0.0167	g/km
pm10 B and T	0.0186	g/km
FC	8.06	l/100km

Heavy vehicle fleet average emission factors		
CO	1.19	g/km
CO2	583.50	g/km
VOC	0.14	g/km
NOx	3.63	g/km
NO2	0.40	g/km
$PM_{2.5}$ exhaust	0.1415	g/km
pm10 B and T	0.0628	g/km
FC	21.76	l/100km

Petrol car		
CO	2.43	g/km
CO2	195.46	g/km
VOC	0.21	g/km
NOx	0.26	g/km
NO2	0.01	g/km
$PM_{2.5}$ exhaust	0.0018	g/km
pm10 B and T	0.0186	g/km
FC	8.35	l/100km

Diesel car		
CO	0.17	g/km
CO2	181.90	g/km
VOC	0.03	g/km
NOx	0.76	g/km
NO2	0.29	g/km
$PM_{2.5}$ exhaust	0.0760	g/km
pm10 B and T	0.0186	g/km
FC	6.78	l/100km

Petrol LCV		
CO	5.26	g/km
CO2	251.64	g/km
VOC	0.48	g/km
NOx	0.65	g/km
NO2	0.03	g/km
$PM_{2.5}$ exhaust	0.0020	g/km
pm10 B and T	0.0186	g/km
FC	10.75	l/100km

Diesel LCV		
CO	0.30	g/km
CO2	200.36	g/km
VOC	0.05	g/km
NOx	1.27	g/km
NO2	0.45	g/km
$PM_{2.5}$ exhaust	0.0524	g/km
pm10 B and T	0.0186	g/km
FC	7.47	l/100km

Hybrid (Cars and LCV's)		
CO	0.037	g/km
CO2	89.709	g/km
VOC	0.001	g/km
NOx	0.012	g/km
NO2	0.000	g/km
$PM_{2.5}$ exhaust	0.000	g/km
pm10 B and T	0.019	g/km
FC	3.831	l/100km

Plug in hybrid (Cars and LCV's)		
CO	0.018	g/km
CO2	43.060	g/km
VOC	0.000	g/km
NOx	0.006	g/km
NO2	0.000	g/km
$PM_{2.5}$ exhaust	0.000	g/km
pm10 B and T	0.019	g/km
FC	1.839	l/100km

Electric		
CO	0.000	g/km
CO2	0.000	g/km
VOC	0.000	g/km
NOx	0.000	g/km
NO2	0.000	g/km
$PM_{2.5}$ exhaust	0.000	g/km
PM2.5 exhaust	0.019	g/km
FC	0.000	l/100km

Diesel HCV (3.5-7.5t)		
CO	0.52	g/km
CO2	285.74	g/km
VOC	0.09	g/km
NOx	1.90	g/km
NO2	0.22	g/km
$PM_{2.5}$ exhaust	0.08	g/km
pm10 B and T	0.0186	g/km
FC	10.65	l/100km

Diesel HCV (7.5-10.0t)		
CO	1.11	g/km
CO2	426.39	g/km
VOC	0.15	g/km
NOx	3.07	g/km
NO2	0.34	g/km
$PM_{2.5}$ exhaust	0.13	g/km
pm10 B and T	0.0186	g/km
FC	15.90	l/100km

Diesel HCV (10.0 - 20.0t)		
CO	1.24	g/km
CO2	539.55	g/km
VOC	0.21	g/km
NOx	4.03	g/km
NO2	0.45	g/km
$PM_{2.5}$ exhaust	0.15	g/km
pm10 B and T	0.0292	g/km
FC	20.12	l/100km

Diesel HCV (20.0 - 25.0t)		
CO	1.38	g/km
CO2	671.42	g/km
VOC	0.18	g/km
NOx	4.70	g/km
NO2	0.54	g/km
$PM_{2.5}$ exhaust	0.19	g/km
pm10 B and T	0.0798	g/km
FC	25.03	l/100km

Diesel HCV (25.0 - 30.0t)		
CO	1.36	g/km
CO2	704.49	g/km
VOC	0.13	g/km
NOx	4.37	g/km
NO2	0.48	g/km
$PM_{2.5}$ exhaust	0.17	g/km
pm10 B and T	0.0885	g/km
FC	26.27	l/100km

Diesel HCV (> 30.0t)		
CO	1.54	
CO2	791.07	g/km
VOC	0.09	g/km
NOx	3.89	g/km
NO2	0.42	g/km
$PM_{2.5}$ exhaust	0.15	g/km
pm10 B and T	0.0972	g/km
FC	29.49	l/100km

Electric HCV		
CO	0.00	g/km
CO2	0.00	g/km
VOC	0.00	g/km
NOx	0.00	g/km
NO2	0.00	g/km
$PM_{2.5}$ exhaust	0.00	g/km
pm10 B and T	0.0197	g/km
FC	0.00	l/100km

The fleet weighted emissions factors are calculated based on the fraction of vehicle kilometres travelled (%VKT) by each vehicle class, and the emissions factors for each vehicle class (from *EU & NZ front* and *Japan front* worksheets).

BULK RUNS

Instructions for conducting bulk runs are given in section 2.4 below and the *Bulk Runs* worksheet.

2.4 Input data – bulk run

The *Bulk Runs* worksheet provides the option for users to perform multiple runs at the same time. The input format is tabular and allows users to repeat a run multiple times with an incremental change in one (or more) parameters, such as running through every speed from 10 to 110km/h (100km/h for heavy vehicles[d]) for the same year.

In the *Bulk Run* worksheet, click the *Go To Input Sheet* button to open the *Bulk Input* worksheet to enter bulk run parameters (as detailed below for the *Bulk Input* worksheet).

BULK INPUT

Similar to the *VEPM* worksheet, users are required to input the year, average speed for cars, LCVs and HCVs, and the desired brake and tyre wear particulate size fraction.

Year – analysis year must be between 2001 and 2050.

Average speeds must be between 10 and 110km/h (refer Average Speed section above).

Brake & tyre wear particulate size fraction options are:

- TSP - total suspended particles
- PM_{10} – particulate matter less than 10µm in diameter
- $PM_{2.5}$ – particulate matter less than 2.5µm in diameter
- PM_{1} – particulate matter less than 1µm in diameter
- $PM_{0.1}$ – particulate matter less than 0.1µm in diameter.

Optional model inputs, as described in section 2.5, can also be specified in the *Bulk Input* worksheet. Up to 1,000 multiple runs can be selected. Figure 2.3 shows an example of a bulk run input. The bulk run in figure 2.3 varies the average speed between 10km/h and 110km/h for light vehicles and between 10km/h and 100km/h for heavy vehicles[d] (for the years 2010, 2020 and 2040).

D Valid average speed range for heavy vehicles varies depending upon load and gradient. If the user specified speed is outside the valid speed range, emissions will be calculated for the closest valid speed.

FIGURE 2.3 **Example bulk input worksheet, varying speed (10–110km/h) and year (2001, 2020, 2040)**

Required Inputs						Light Duty Vehicles <3.5t					
Run number	Year	Speed Car	Speed LCV	Speed HCV	B&T PM size	% Car petrol	% Car diesel	% Car hybrid	% Car plugin hy	% Car electric	% LCV petrol
1	2001	10	10	10	pm10						
2	2001	20	20	20	pm10						
3	2001	30	30	30	pm10						
4	2001	40	40	40	pm10						
5	2001	50	50	50	pm10						
6	2001	60	60	60	pm10						
7	2001	70	70	70	pm10						
8	2001	80	80	80	pm10						
9	2001	90	90	90	pm10						
10	2001	100	100	100	pm10						
11	2001	110	110	100	pm10						
12	2020	10	10	10	pm10						
13	2020	20	20	20	pm10						
14	2020	30	30	30	pm10						
15	2020	40	40	40	pm10						
16	2020	50	50	50	pm10						
17	2020	60	60	60	pm10						
18	2020	70	70	70	pm10						
19	2020	80	80	80	pm10						
20	2020	90	90	90	pm10						
21	2020	100	100	100	pm10						
22	2020	110	110	100	pm10						
23	2040	10	10	10	pm10						
24	2040	20	20	20	pm10						
25	2040	30	30	30	pm10						
26	2040	40	40	40	pm10						
27	2040	50	50	50	pm10						
28	2040	60	60	60	pm10						
29	2040	70	70	70	pm10						
30	2040	80	80	80	pm10						
31	2040	90	90	90	pm10						
32	2040	100	100	100	pm10						
33	2040	110	110	100	pm10						

Once all inputs for the bulk run have been entered, return to the *Bulk Run* worksheet to run the model.

BULK RUNS

Click the *Start Bulk Run* button to run the model once the inputs for the bulk runs have been entered in the *Bulk Input* worksheet. If the user requires a breakdown of emission factors by vehicle type, rather than total fleet emission factors, select the *Vehicle Type Breakdown* checkbox beneath the *Start Bulk Run* button. Ensure this box is checked before starting the model.

BULK OUTPUT

Results for the bulk runs selected by the user are displayed in the *Bulk Output* worksheet. Emission factors for CO, CO_2, VOC, NOx, NO_2, $PM_{2.5}$ exhaust and PM brake and tyre are provided according to the bulk inputs. If the *Vehicle Type Breakdown* checkbox had been selected by the user on the *Bulk Input* worksheet, then the remaining columns in the *Bulk Output* worksheet will also be populated.

Figure 2.5 presents the *Bulk Output* worksheet for the example input data shown in figure 2.4.

FIGURE 2.5 **Example bulk output worksheet, varying speed (10–110km/h) and year (2001, 2020, 2040)**

Run number	CO g/km	CO2 g/km	VOC g/km	NOx g/km	NO2 g/km	$PM_{2.5}$ Exhaust g/km	PM brake and tyre g/km	FC l/100km	Year	Speed Car	Speed LCV	Speed HCV	B&T PM size
1	28.385	494.3633	3.045344	2.196792	0.203665	0.16376744	0.023688555	20.32159	2001	10	10	10	pm10
2	17.50109	345.2072	1.951928	1.893876	0.164445	0.121939226	0.023688555	14.15606	2001	20	20	20	pm10
3	12.68132	277.1554	1.483603	1.729687	0.141778	0.096530954	0.023688555	11.36425	2001	30	30	30	pm10
4	10.46674	239.3675	1.225122	1.661022	0.129456	0.00160000	0.023691456	9.013969	2001	40	40	40	pm10
5	8.705865	216.7788	1.017578	1.653977	0.123206	0.072623817	0.020784965	8.886903	2001	50	50	50	pm10
6	7.310415	203.0766	0.042634	1.605507	0.121025	0.067900354	0.017070473	0.356607	2001	60	60	60	pm10
7	6.551333	198.1402	0.716235	1.756862	0.122477	0.0666933	0.014971982	8.119721	2001	70	70	70	pm10
0	6.390033	190.2799	0.637952	1.062111	0.127009	0.060574623	0.012065491	0.122946	2001	00	00	00	pm10
9	6.872671	203.7904	0.602047	1.998228	0.134625	0.073510769	0.009159	8.345267	2001	90	90	90	pm10
10	8.050692	214.309	0.603018	2.161193	0.144706	0.0812414	0.008048771	8.77295	2001	100	100	100	pm10
11	10.02825	229.7892	0.636852	2.350262	0.157326	0.091370999	0.008048771	9.405454	2001	110	110	100	pm10
12	4.21829	467.7206	0.422565	1.479735	0.258771	0.053857333	0.02447652	18.98321	2020	10	10	10	pm10
13	2.760343	339.8259	0.273527	1.072394	0.196952	0.039725837	0.02447652	13.79564	2020	20	20	20	pm10
14	2.09277	278.17	0.209189	0.876124	0.164455	0.031439298	0.02447652	11.29145	2020	30	30	30	pm10
15	1.875064	243.3239	0.176514	0.761759	0.144108	0.026432384	0.024479549	9.874504	2020	40	40	40	pm10
16	1.684437	222.5546	0.151034	0.691641	0.131129	0.023548853	0.021486412	9.029044	2020	50	50	50	pm10
17	1.525038	210.734	0.129953	0.649872	0.123829	0.02236704	0.018493276	8.546269	2020	60	60	60	pm10
18	1.475067	205.4275	0.115008	0.632807	0.121802	0.022692235	0.015500139	8.326704	2020	70	70	70	pm10
19	1.535244	205.4193	0.105583	0.638745	0.125234	0.024430166	0.012507002	8.320414	2020	80	80	80	pm10
20	1.720383	210.1746	0.101529	0.674871	0.135447	0.027582697	0.009513866	8.505084	2020	90	90	90	pm10
21	2.061874	219.0602	0.102689	0.739538	0.153077	0.032009407	0.008375452	8.856162	2020	100	100	100	pm10
22	2.630454	232.0295	0.108751	0.829935	0.178422	0.037660158	0.008375452	9.372109	2020	110	110	100	pm10
23	0.614904	257.8879	0.058543	0.364561	0.065078	0.006316664	0.023521287	10.32094	2040	10	10	10	pm10
24	0.384577	184.8576	0.037049	0.251074	0.04827	0.004398182	0.023521287	7.420178	2040	20	20	20	pm10
25	0.29676	152.0508	0.028921	0.206142	0.041035	0.003499349	0.023521287	6.104726	2040	30	30	30	pm10
26	0.259608	134.1229	0.024401	0.180783	0.036736	0.002976166	0.023524184	5.382448	2040	40	40	40	pm10
27	0.234145	123.6377	0.021087	0.165165	0.034081	0.002672911	0.020643704	4.958804	2040	50	50	50	pm10
28	0.21507	117.6541	0.0184	0.15602	0.032709	0.002535938	0.017763224	4.716337	2040	60	60	60	pm10
29	0.207171	114.8143	0.016321	0.152744	0.032618	0.002543979	0.014882744	4.600429	2040	70	70	70	pm10
30	0.212532	114.5028	0.014871	0.155936	0.034054	0.002692078	0.012002265	4.585978	2040	80	80	80	pm10
31	0.236861	116.4259	0.014184	0.168717	0.037652	0.002992186	0.009121785	4.660894	2040	90	90	90	pm10
32	0.29032	120.0091	0.014354	0.192373	0.043972	0.003424704	0.008024178	4.803276	2040	100	100	100	pm10
33	0.392813	125.3252	0.015407	0.227323	0.05336	0.004005051	0.008024178	5.015882	2040	110	110	100	pm10

2.5 Optional model inputs

This section discusses optional model inputs for VEPM as shown in figure 2.1.

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.

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.

PETROL/DIESEL FUEL TYPE

The default fuel type correlates with the fuel that was, or is expected to be available at the analysis year (year selected in VEPM worksheet). Fuel specifications are summarised in the *Fuel types* worksheet.

CONSIDER COLD START?

When a vehicle is started from cold, emissions are substantially higher, until the engine and catalyst warm up. Cold start emissions are estimated in the model for each vehicle class except heavy commercial vehicles (HCVs). Cold start emissions are affected by the user defined ambient temperature and average trip length. Cold start emissions factors are not available for HCVs. It is likely that commercial vehicles spend the majority of their life in use, hence cold start is not a significant factor in their operation.

CONSIDER DEGRADATION?

The model includes some allowance for degradation of emissions over time. This option allows the user to ignore degradation effects. If the user chooses to ignore degradation effects, the results will reflect vehicles with 50,000km of accumulated mileage for cars and light duty vehicles, and no accumulated mileage (ie new) for heavy duty vehicles.

PERCENTAGE OF CATALYTIC CONVERTERS NOT WORKING – OLD VEHICLE

Emissions from vehicles without catalytic converters are substantially higher than from vehicles with a functioning catalytic converter. This option allows the user to estimate the percentage of catalytic converters that are broken or have been removed. The default value of 15% for old vehicles is based on studies undertaken by the MOT[12, 13]. This variable is applied to petrol vehicles approximately 11 years and older.

For diesel vehicles, there is currently no option in VEPM to estimate the percentage of removed or broken emission control equipment.

PERCENTAGE OF CATALYTIC CONVERTERS NOT WORKING – NEW VEHICLE

This variable is applied to petrol vehicles less than 11 years old. The Ministry of Transport studies indicated that very few vehicles younger than 11 years had catalytic converters removed, hence the default value is set at 0. However, the sample size of newer vehicles from which the data was obtained was very small.

12 Ministry of Transport (2009) *A vehicle scrappage trial for Christchurch and Wellington.* www.transport.govt.nz

13 Ministry of Transport (2008) *Trial vehicle scrappage report.* www.transport.govt.nz

GRADIENT

Road gradients between -6% and +6% can be selected in 2% increments for both light and heavy duty vehicles.

For light duty **petrol** vehicles, emissions factors for gradients other than 0% are only available for CO and NO_X. For light duty **diesel** vehicles, emission factors are only available for CO, NO_X and PM.

NB: This means that when the model is run for selected gradients for light duty vehicles, the outputs for HC and CO_2 will be for 0% gradient.

The impact of gradient on emissions is complex, affecting different pollutants by differing amounts. This is discussed in greater detail in section 4.

LOAD

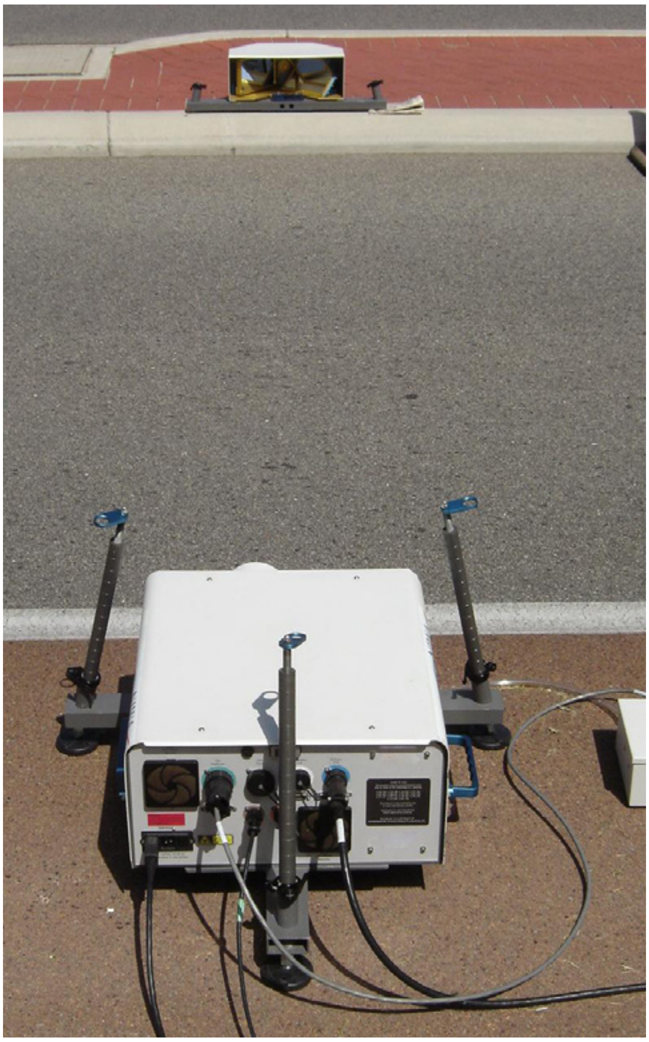
Loading factors for HCVs of 0, 50% and 100% can be selected. The default loading is 50%.

NUMBER OF AXLES

The amount of particulate matter from brake and tyre wear is calculated based on the average number of axles for each vehicle class. The number of axles for the HCV class can be adjusted if required.

BRAKE AND TYRE WEAR PM OUTPUT

The size fraction of PM from brake and tyre wear is selectable – total suspended particles (TSP), PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$ (see glossary for definitions).



3 Emission factor calculations in VEPM

This section of the user guide provides a brief introduction to the calculations and assumptions in VEPM and refers users to the relevant parts of the technical reports (references [01], [08], [10], [14] and [03]) and the VEPM spreadsheet for further details.

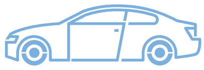
14 Energy and Fuels Research Unit, Auckland University (2011) *Vehicle emissions prediction model (VEPM) version 5.0: development and user information report*.

3.1 Overall structure of VEPM

VEPM calculates total emission factors for each vehicle category. Vehicle categories in VEPM include:

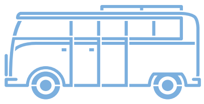
CARS

- Petrol cars (<1.4L, 1.4L to 2L, and >2L)
- Diesel cars (<2L and > 2L)
- Hybrid cars
- Plug in hybrid cars
- Electric cars



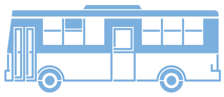
LIGHT COMMERCIAL VEHICLES

- Petrol light commercial vehicles (LCVs)
- Diesel LCVs



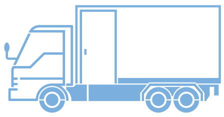
BUSES

- All buses are assumed to have equivalent emissions to HCV's in VEPM



HEAVY COMMERCIAL VEHICLES

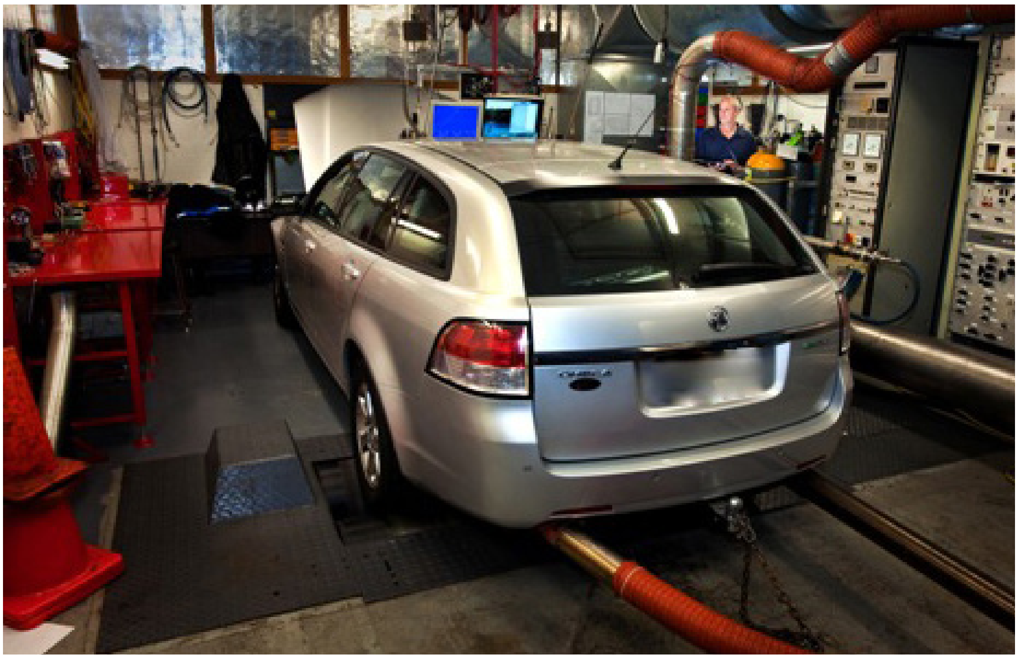
- Diesel HCVs
- Electric HCVs



- Broken down by gross vehicle weight

These categories are further broken down by country of origin and year of manufacture. The vehicle categories included in VEPM are listed in full in Tables A.1, A.2 and A.3 in appendix A.

The calculation of total emission factors for each vehicle category is described in section 3.2. These total emission factors are combined with detailed fleet composition data to calculate fleet weighted emission factors as described in section 3.3.



3.2 Calculation of total emission factors

The calculation of total emission factors is shown schematically in figure 3.2. This shows the key steps of the emission factor calculation, as well as the user defined inputs that provide variables for each key step. Figure 3.2 also provides references to the relevant sections of the technical reports where the methodology and assumptions are described in detail.

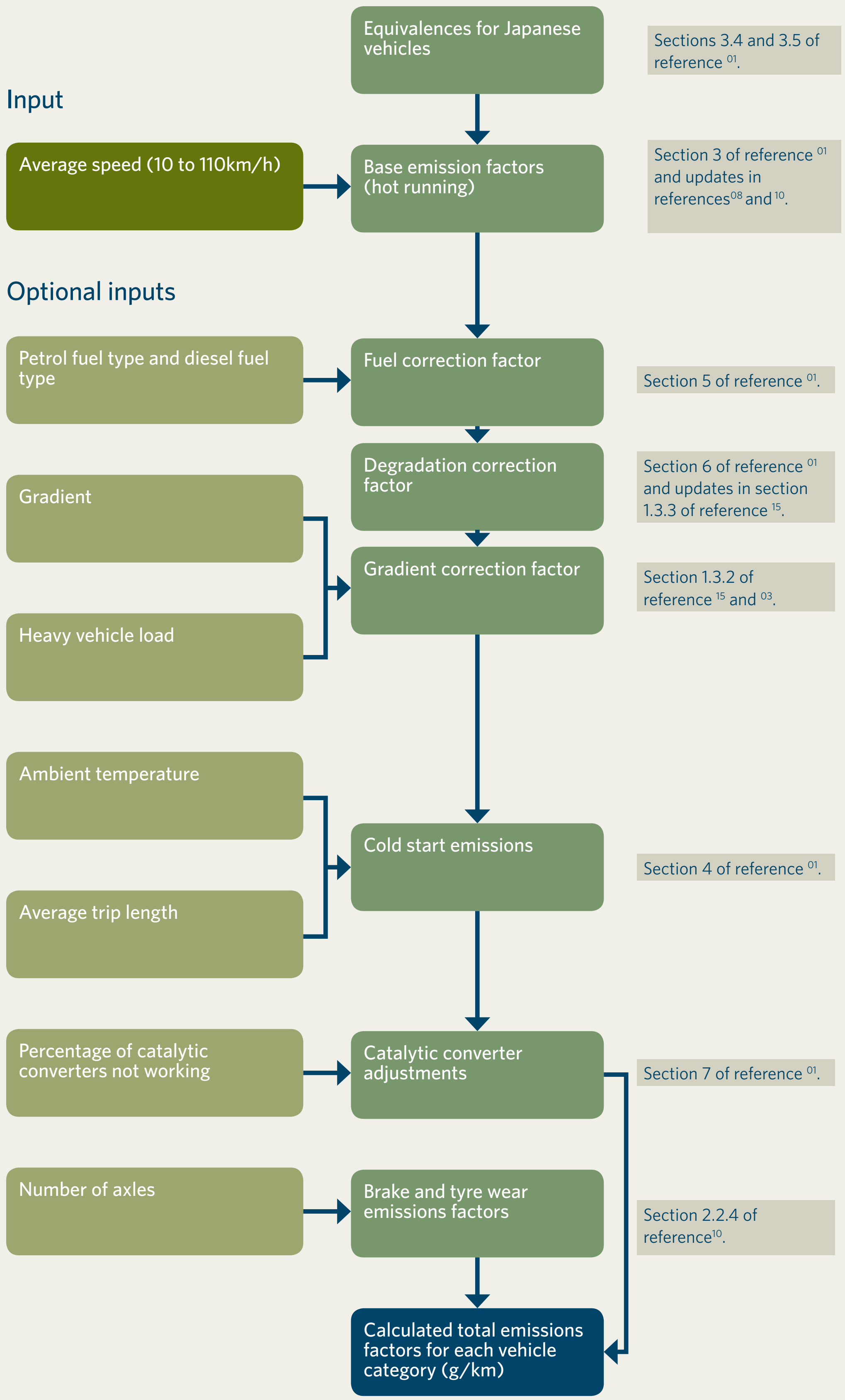
Total emissions for each vehicle category are calculated in the *EU and NZ front* worksheet (for European and New Zealand manufactured vehicles) and in the *Japan front* worksheet (for Japanese vehicles).

Users can see all calculations in these worksheets. The total emission factors for each vehicle category are calculated and displayed in columns CF to CM of the *EU and NZ front* and the *Japan front* worksheets. For example, as shown in figure 3.1, VEPM estimates a total NO_x emission factor of 0.5g/km for Japanese vehicles manufactured between 1986 and 1999 with engine capacity between 1.4 and 2L. This is based on speed of 50km/hour and default input values, these are discussed in section 2.5.

FIGURE 3.1 **Data from the 'Japan front' worksheet for the 2001 default fleet in VEPM**

			Total Emissions Factors							
1.0 Cars			**CO**	**CO2**	**HC**	**NOx**	**NO2**	**PM**	**PM (Brake & Tyre wear)**	**FC**
1.1 Petrol			**(g/km)**	**(g/km)**	**(g/km)**	**(g/km)**	**(g/km)**	**(g/km)**	**(g/km)**	**(l/100km)**
Title		**Model yr**								
Pre 1973, J73	< 1.4 l	**50 - 74**	46.1	161	3.7	2.2	0.1	0.023	0.0096	9.9
Pre 1973, J73	1.4 - 2.0 l	**50 - 74**	38.9	198	3.7	2.7	0.1	0.019	0.0096	11.1
Pre 1973, J73	> 2.0 l	**50 - 74**	33.8	271	3.5	3.7	0.1	0.017	0.0096	14.0
J75, J76	< 1.4 l	**75 - 77**	21.0	142	1.2	3.9	0.2	0.005	0.0096	7.5
J75, J76	1.4 - 2.0 l	**75 - 77**	13.5	185	0.8	4.7	0.2	0.005	0.0096	8.9
J75, J76	> 2.0 l	**75 - 77**	7.8	271	0.6	6.6	0.3	0.006	0.0096	12.4
J78	< 1.4 l	**78 - 85**	19.9	144	1.1	1.1	0.0	0.005	0.0096	7.5
J78	1.4 - 2.0 l	**78 - 85**	12.5	187	0.7	1.0	0.0	0.005	0.0096	8.9
J78	> 2.0 l	**78 - 85**	7.0	273	0.5	0.9	0.0	0.006	0.0096	12.4
J78, J88	< 1.4 l	**86 - 99**	18.5	140	0.3	0.3	0.0	0.003	0.0096	7.2
J78, J88	1.4 - 2.0 l	**86 - 99**	10.8	182	0.4	0.6	0.0	0.002	0.0096	8.6
J78, J88	> 2.0 l	**86 - 99**	5.1	266	0.2	0.6	0.0	0.005	0.0096	11.9
J00	< 1.4 l	**00 - 04**	1.3	151	0.1	0.1	0.0	0.002	0.0096	6.7
J00	1.4 - 2.0 l	**00 - 04**	0.3	183	0.0	0.1	0.0	0.001	0.0096	8.0
J00	> 2.0 l	**00 - 04**	0.2	252	0.0	0.1	0.0	0.005	0.0096	11.0
J05	< 1.4 l	**> 05'**	0.6	141	0.009	0.0	0.0	0.002	0.0096	6.2
J05	1.4 - 2.0 l	**> 05'**	0.6	166	0.028	0.0	0.0	0.001	0.0096	7.3
J05	> 2.0 l	**> 05'**	0.3	239	0.0	0.1	0.0	0.005	0.0096	10.4
Total			**10.6**	**192**	**0.4**	**0.6**	**0.0**	**0.003**	**0.0096**	**9.0**

FIGURE 3.2 **Calculation of total emissions factors by vehicle category in VEPM**



EQUATION 3.1 **Total emission factor**

EQUATION	PARAMETER	DESCRIPTION	UNIT
$E = s(m) \times f \times g \times E_{hot} + E_{cold}$	E	Total emission factor	g/km
	s	Degradation correction factor for a given accumulated vehicle mileage m	-
	f	Fuel correction factor and is the ratio of emissions for the test fuel compared with a base or reference fuel	-
	G	Gradient correction factor	-
	E_{hot}	Hot running emissions factor	-
	E_{cold}	Cold emissions contribution to E (function of trip duration and ambient temperature)	g/km

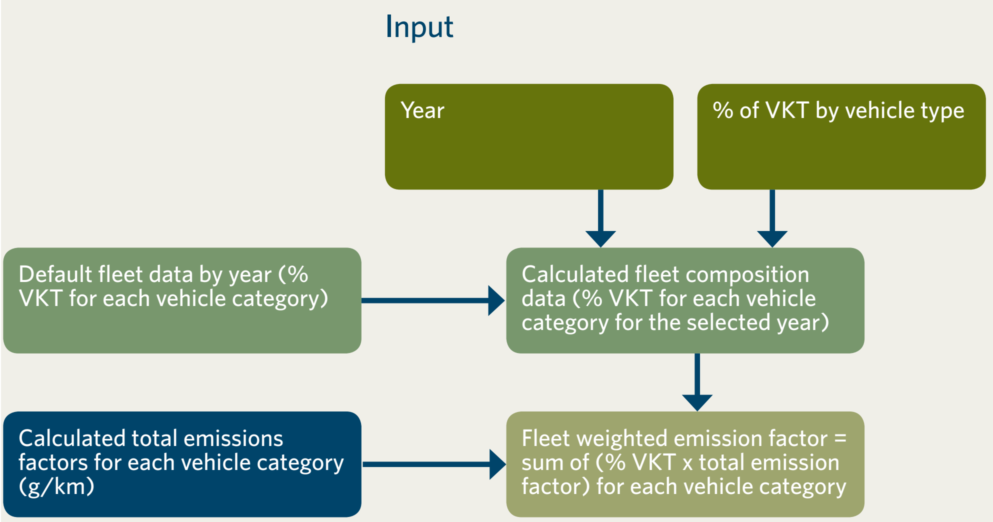
The equation is expanded to account for the proportion of vehicles with catalytic converters not working, as described in section 7 of reference [01].

Brake and tyre wear particulate emission factors are calculated separately. These are based on European emission factors as described in reference[10].

3.3 Calculation of fleet weighted emission factors in VEPM

The calculation of fleet weighted emission factors is shown schematically in figure 3.3.

FIGURE 3.3 **Calculation of fleet weighted emission factors in VEPM**



DEFAULT FLEET DATA

Default fleet data (percentage VKT for each vehicle category) is included in VEPM for all years between 2001 and 2050. The default is based on data provided by Ministry of Transport from the Vehicle Fleet Emissions Model (VFEM). VFEM outputs include actual fleet composition data, projected fleet composition data and estimated average annual VKT for each vehicle category.

The assumptions for calculating default percentage VKT in VEPM based on the VFEM outputs is described in reference [08] and [10].

CALCULATED FLEET COMPOSITION DATA

The percentage VKT for each vehicle category is calculated within VEPM based on the default fleet data for the year selected. If the user defines the % of VKT by vehicle category, the default fleet data is adjusted proportionally.

The percentage of VKT for each vehicle category can be seen in the EU and NZ front and the Japan front worksheets. For example, VEPM estimates that 19.99% of all VKT for the default 2001 fleet is from Japanese vehicles manufactured between 1986 and 1999 with engine capacity between 1.4L and 2L (figure 3.4).

CALCULATION OF FLEET WEIGHTED EMISSION FACTORS

The fleet weighted average emission factor per kilometre is calculated as the sum of the percentage of VKT for each vehicle category x total emission factor for each vehicle category.

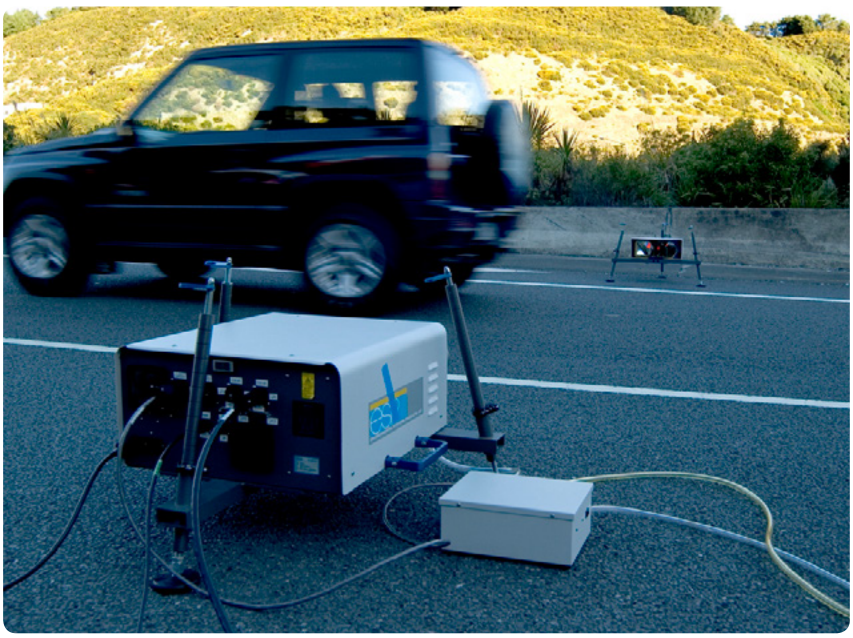
Vehicle categories are shown in tables A.1, A.2 and A.3 in appendix A.

The calculation of total emission factors for each vehicle category is described in section 3.2.

Fleet weighted emission factors are displayed in the *Fleet emission factors* worksheet as described in section 2.3.

FIGURE 3.4 **Data from the *Japan front* worksheet for the 2001 default fleet in VEPM**

			Fleet info
1.0 Cars			% VKT
1.1 Petrol			
Title		Model yr	
Pre 1973, J73	< 1.4 l	50 – 74	0.00%
Pre 1973, J73	1.4 - 2.0 l	50 – 74	0.00%
Pre 1973, J73	> 2.0 l	50 – 74	0.00%
J75, J76	< 1.4 l	75 – 77	0.00%
J75, J76	1.4 - 2.0 l	75 – 77	0.00%
J75, J76	> 2.0 l	75 – 77	0.00%
J78	< 1.4 l	78 – 85	0.32%
J78	1.4 - 2.0 l	78 – 85	1.97%
J78	> 2.0 l	78 – 85	0.28%
J78, J88	< 1.4 l	86 – 99	1.09%
J78, J88	1.4 - 2.0 l	86 – 99	20.29%
J78, J88	> 2.0 l	86 – 99	3.60%
J00	< 1.4 l	00 – 04	0.00%
J00	1.4 - 2.0 l	00 – 04	0.02%
J00	> 2.0 l	00 – 04	0.00%
J05	< 1.4 l	> 05'	0.00%
J05	1.4 - 2.0 l	> 05'	0.00%
J05	> 2.0 l	> 05'	0.00%
Total			27.57%



4 Emissions information

4.1 Particulate matter

VEPM includes emission factors for particulate matter from two sources:

- Exhaust
- Road/tyre wear.

In reality, almost all particulate matter (PM) from both petrol and diesel exhaust is less than 1 micron, with the majority of PM from both fuels being in the 10–100 nanometre range. In VEPM, exhaust PM is denoted as $PM_{2.5}$.

PM from road and tyre wear, however, are substantially larger with around 40% of PM being total suspended particulate (10–300 nanometre)[15].

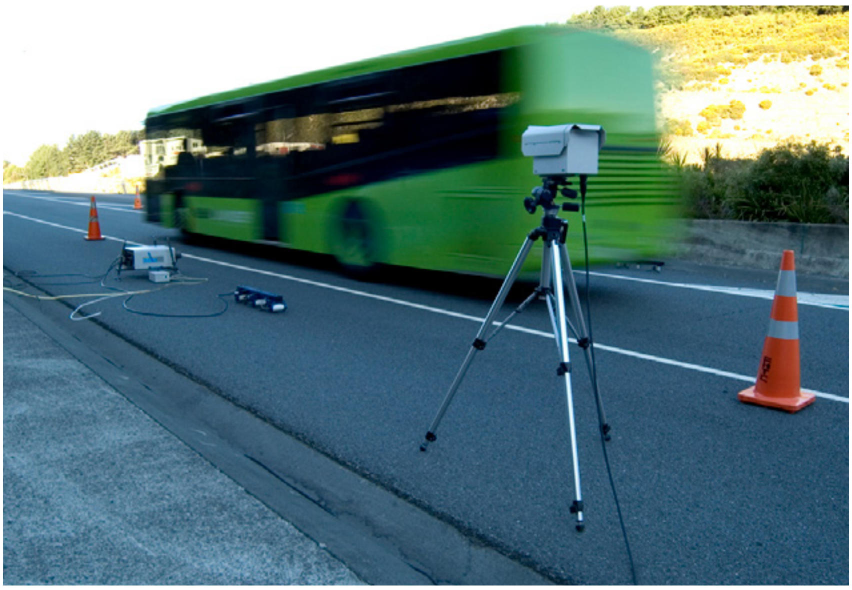
In VEPM, the size fraction of PM from brake and tyre wear is selectable – total suspended particles (TSP), PM_{10}, $PM_{2.5}$, PM_1 and $PM_{0.1}$. Brake and tyre wear emission factors are split into these fractions according to the proportions given in table 4.1.

15 EMEP/EEA (2016) *Air pollution emission inventory guidebook, 1.A.3.b.vi Road vehicle tyre and brake wear.*

TABLE 4.1 **Size distribution of tyre and brake wear particles as proportions of total suspended particulate (TSP)**

PARTICLE SIZE CLASS	MASS FRACTION OF TSP	
	TYRE WEAR	BRAKE WEAR
TSP	**1.000**	**1.000**
PM_{10}	0.600*	0.980
$PM_{2.5}$	0.420*	0.390
PM_1	**0.060***	**0.100**
$PM_{0.1}$	**0.048***	**0.080**

*Denotes that 60% (by mass) of tyre wear particles are smaller than 10 micron, 42% are smaller than 2.5 micron, 6% are smaller than 1 micron and 4.8% are smaller than 0.1 micron.



4.2 Gradient effects

As noted above, the impact of gradient on emissions is complex. It cannot be assumed that if the region over which emissions are being assessed has a net zero change in elevation, the increase in emissions due to uphill sections within the region will be cancelled out by the effects of the corresponding downhill sections. This is because, depending on the gradient, emissions going uphill are significantly greater than the reduction in emissions going downhill.

For example, NO_x is only produced when the combustion temperature exceeds a threshold temperature, and is highly dependent on the fuel/air mixture strength. Maximum NO_x occurs with mixtures slightly leaner that the chemically correct mixture, and falls rapidly with mixtures leaner or richer than this. Consequently the increase in NO_x as a result of the increased power demand on an uphill section will be larger than the corresponding decrease on a similar downhill section.

This is illustrated in table 4.2 which shows the emissions rates predicted using VEPM 5.1 for CO, HC, NO_x, PM and CO_2 for fully laden 15 to 20 tonne trucks (combined fleet) over a number of routes at 50km/h average speed. The first route is a constant zero gradient, the others consist of positive (uphill) gradients of 2%, 4% and 6%, followed by equal length corresponding negative (downhill) gradients. Table 4.2 also includes arithmetic averages of the positive and negative gradients, i.e. an **average** of zero gradient, and the difference between the arithmetic average and constant zero gradient.

TABLE 4.2 **Emissions rates for fully laden trucks for a level road and different gradients**

GRADIENT	EMISSIONS RATES (G/KM)				
	CO	HO	NO_2	PM	CO_2
0%	1.46	0.46	5.00	0.22	679
+2%	2.00	0.47	8.80	0.29	1164
-2%	0.78	0.30	1.84	0.14	_262
Average 0% (+2%/-2%)	1.39	0.39	5.32	0.22	713
Difference wrt 0%	-5%	-15%	+6%	0	+5%
+4%	2.90	0.49	12.49	0.41	1735
-4%	0.42	0.19	0.73	0.10	111
Average 0% (+4%/-4%)	1.66	0.34	6.61	0.26	923
Difference wrt 0%	+14%	-26%	+32%	+18%	+36%
+6%	3.82	0.53	15.97	0.54	2312
-6%	0.26	0.14	0.36	0.08	56
Average 0% (+6%/-6%)	2.04	0.34	8.17	0.31	1184
Difference wrt 0%	+40%	-26%	+63%	+41%	+74%

The difference in NO_x emissions between the level road and the positive gradients is clearly greater than between the level road and negative gradients, with the difference increasing with increasing gradient/engine load.

The overall result of these characteristics is that assuming a net zero gradient change for a region that contains significant changes in gradient (ie more than 2%) could significantly underestimate the emissions of CO, NO_x, PM and CO_2, and overestimate HC, for heavy duty vehicles.

4.3 Link lengths

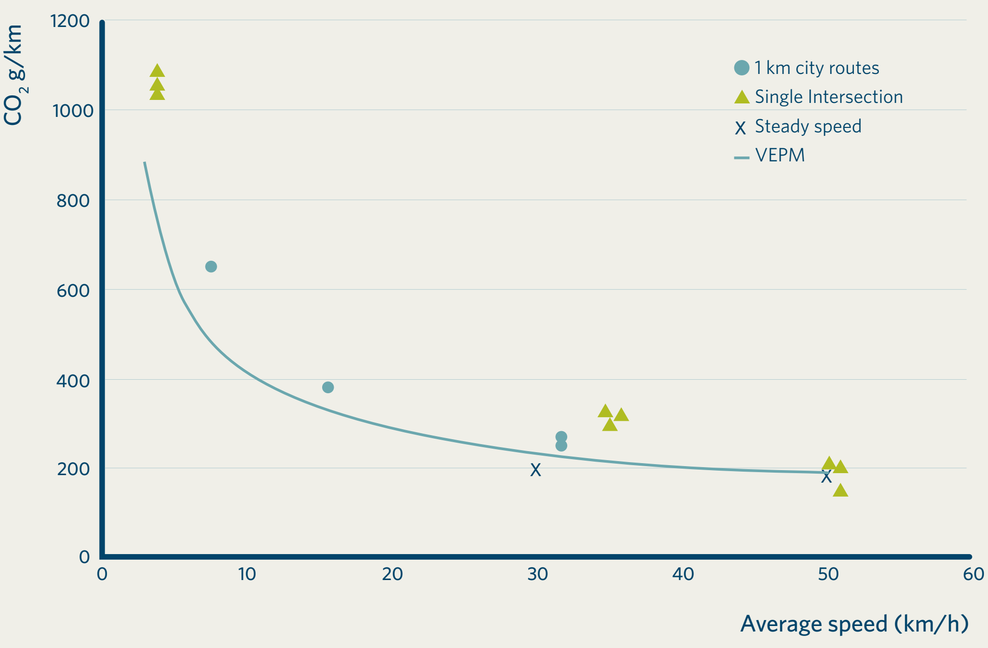
When VEPM was originally developed, the recommendation was that the minimum grid size (or single link length) should be 1km.

In order to investigate the accuracy of VEPM over these short distances a test programme was undertaken[15]. Emissions from real drive cycles with a variety of speed profiles were compared with VEPM emission factors using a suitably instrumented vehicle driven repeatedly over a 1km length of mainly flat road in the Auckland CBD containing nine intersections in one direction and eight in the other.

From the data obtained using on-board instrumentation, three speed ~ time profiles were selected representing the lowest (7.5km/h), highest (32km/h) and one intermediate (15.5km/h) average speed. All three profiles were then reproduced on the University of Auckland's transient chassis dynamometer. The fuel consumption/ CO_2 and regulated emissions (CO, HC and NO_X) were measured over these profiles and compared with VEPM predictions based on the average speed for each profile.

Figure 4.1 shows measured CO_2 emissions and predicted CO_2 emissions over an average speed range of 3km/h to 50km/h. Results are shown for the full 1km route length and for a 100m length with an intersection in the middle. Two runs were also done at steady speeds of 30km/h and 50km/h for reference.

FIGURE 4.1 **CO_2 emissions ~ average speed: predicted and measured**



Taking into account that the test vehicle had a 3L engine, and VEPM uses aggregated emissions factors for engine sizes over 2L, both the full 1km route and the intersection figures show good agreement between measurements and predictions. On the basis of this test[15], albeit on only one vehicle, it would appear that VEPM can be used with equal confidence for regional size studies down to short link length studies.

The results for the other emissions were not as good as for CO_2. This is considered to be a reflection of the variation in emissions that occurs between vehicles, as has been reported by other researchers, rather than of the fundamental accuracy of VEPM.

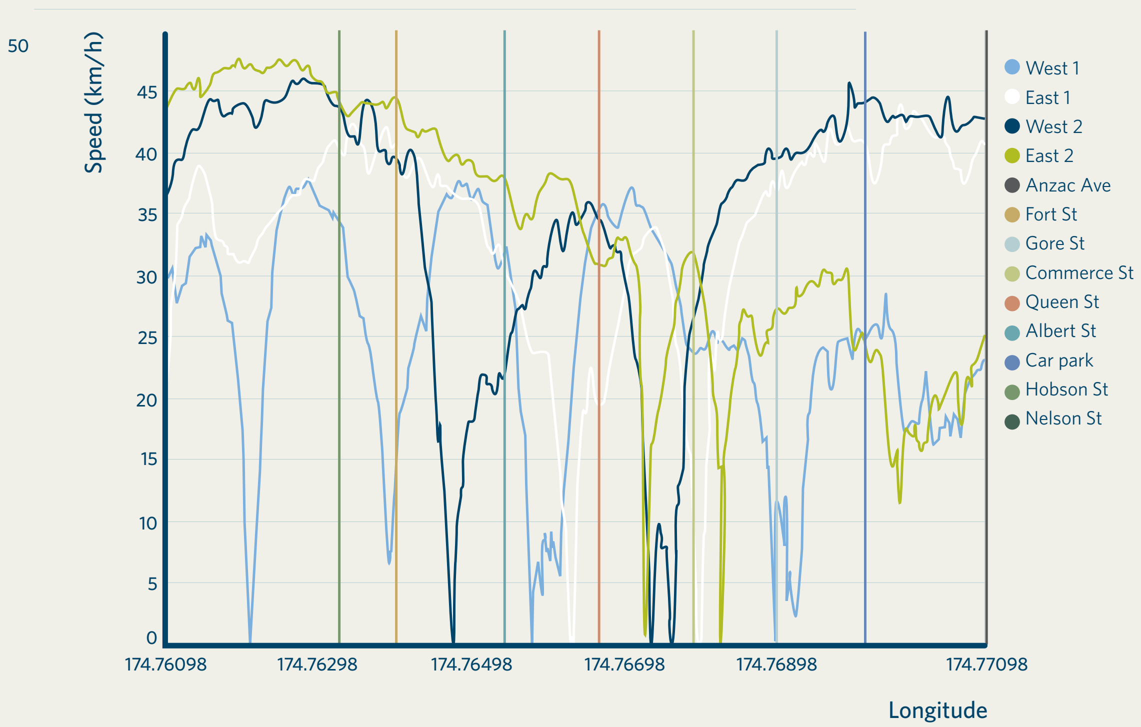
4.4 Speed variation

Other than under motorway or rural conditions, driving speeds are seldom constant. While the emissions factors used in VEPM are based on a wide range of real life driving conditions, comprising of accelerations, decelerations, cruise and idle, there have been questions over the accuracy of an average speed model when there are significant variations in speed around the average.

The test programme described in section 4.2 also provides useful data from which some conclusions may be drawn as to the speed variation ~ average speed relationship.

Figure 4.2 shows the speed ~ longitude/distance profile for the various runs along the test route. As can be seen, the speeds varied widely over the route, with some runs having speeds varying from 0km/h to 47km/h. However, as illustrated in figure 4.1, the measured CO_2 agreed well with the VEPM predictions over the whole average speed range.

FIGURE 4.2 **Longitude profile for 1km Auckland CBD test route (vertical coloured bars show intersections)**



4.5 Idle emissions rates

Emissions rates for vehicles at idle are often required for the purposes of estimating pollutant concentrations, particularly at intersections.

These rates would normally be obtained empirically and quoted in grams per minute (g/min) or grams per hour (g/h). However, as this data is not available for the NZ fleet VEPM can be used to predict idle emissions rates. The emissions factors used in VEPM are taken from different drive cycles for a wide range of average speeds. Lower average speeds consist of a greater proportion of the cycle being idle. Consequently, by calculating the trend for emissions rates at low average speeds, an approximation of emissions rates at idle can be obtained.

The following gives examples of how this can be done.

Tables 4.3 and 4.4 show the 2011 fleet average CO and NO_x emissions factors and emissions rates from 10 to 25km/h and figures 4.3 and 4.4 show plots of the emission rates.

TABLE 4.3 **CO emissions factors and rates at low speeds**

SPEED (KM/H)	EMISSION FACTOR (G/KM)	EMISSION RATE (G/H)
25	6.11	153
20	7.01	140
15	8.46	127
10	11.32	113

TABLE 4.4 **NO_x emissions factors and rates at low speeds**

SPEED (KM/H)	EMISSION FACTOR (G/KM)	EMISSION RATE (G/H)
25	0.86	21.5
20	0.94	18.8
15	1.07	16.05
10	1.33	13.3

Extrapolating the lines back to the (zero speed) y-axis will give approximate values for the idle rates, ie 85g/h for CO and 8g/h for NO_x as shown by the dashed lines in figures 4.3 and 4.4.

FIGURE 4.3 **CO emissions rates at low speeds**

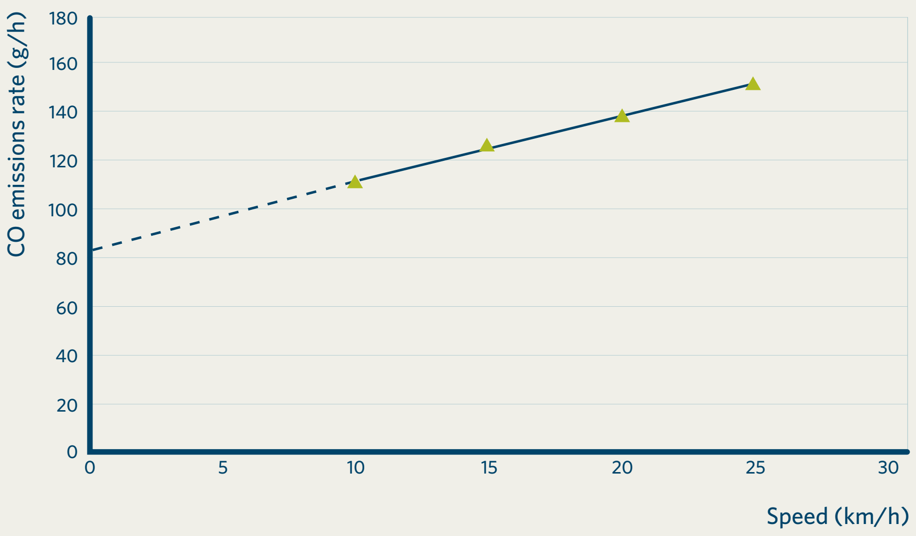
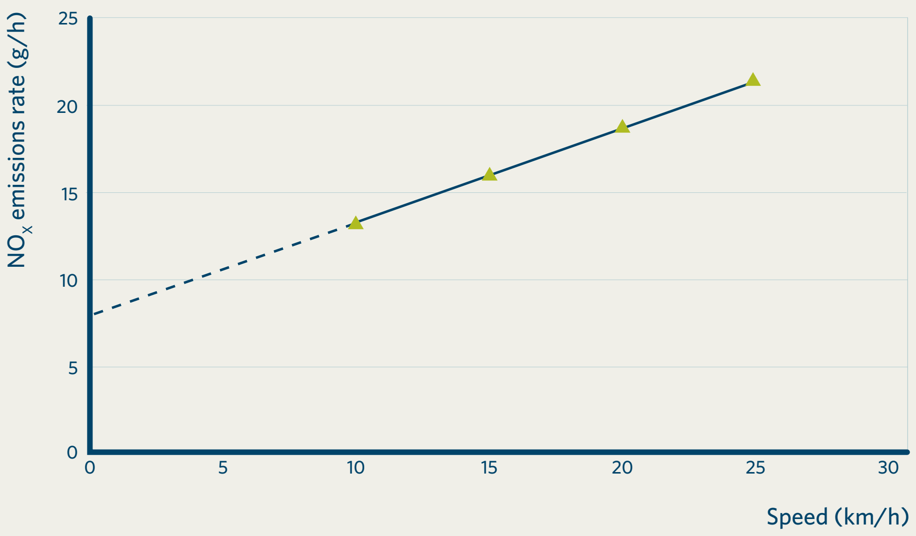


FIGURE 4.4 **NO_x emissions rates at low speeds**



5 Validation of VEPM

The emissions factors used in VEPM are primarily from overseas databases. To give confidence that VEPM is valid for New Zealand conditions, the correlation between VEPM emission factors and those obtained from local testing on New Zealand domiciled vehicles (where this data is available) has been investigated.

5.1 New Zealand vehicle emissions factors database

Over the past 20 years the University of Auckland has undertaken emissions tests on hundreds of vehicles and produced thousands of emissions factors. These factors have been collated into a single database[16].

The database has limitations in that it is made up of predominantly vehicles older than model year 2000, and also contains only a small number of diesel vehicles. However, within these constraints, there are sufficient factors to be able to make valid comparisons between the New Zealand test results and VEPM predictions.

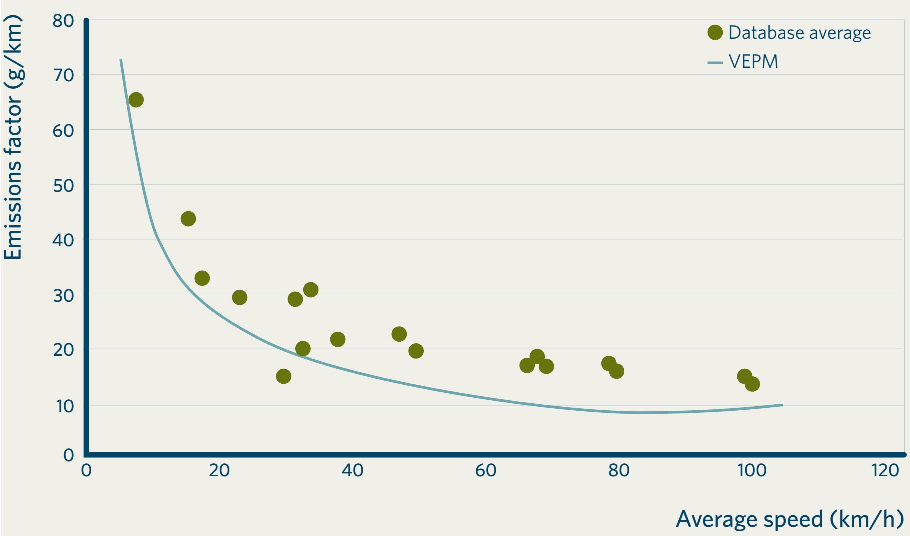
Figures 4.1, 4.2 and 4.3 show comparisons between CO for ECE15.03[D] emission specifications for petrol vehicles, HC for Euro 2 specification vehicles and NO_x for diesel Euro 3 vehicles. The database report includes comparisons for all other vehicle categories.

Overall, comparison of the database results with VEPM emission factors for light duty petrol vehicles shows that:

- in general the VEPM emission factors agree reasonably well with the database results for CO and HC
- for NO_x emissions, there is some discrepancy between the database results and the VEPM emission factors. For some vehicle classes there is not good agreement between the average emission factors from VEPM and the results in the database for NO_x and in some cases the emission-speed trends are different
- there is generally very good agreement between the database and the VEPM results for fuel consumption.

While the sample size was small for the diesel vehicles, there was reasonable correlation between VEPM predictions and the test results.

FIGURE 5.1 **Comparison between database and VEPM CO results for ECE 15.03, 1400-2000cc petrol**



16 Energy and Fuels Research Unit, Auckland University (2012) *New Zealand vehicle emissions factors database.*

D ECE is the Economic Commission for Europe vehicle emissions legislation (pre Euro). ECE15.03 applies to passenger cars manufactured between approximately 1981 and 1985.

FIGURE 5.2 **Comparison between database and VEPM HC results for Euro 2, 1400-2000cc petrol**

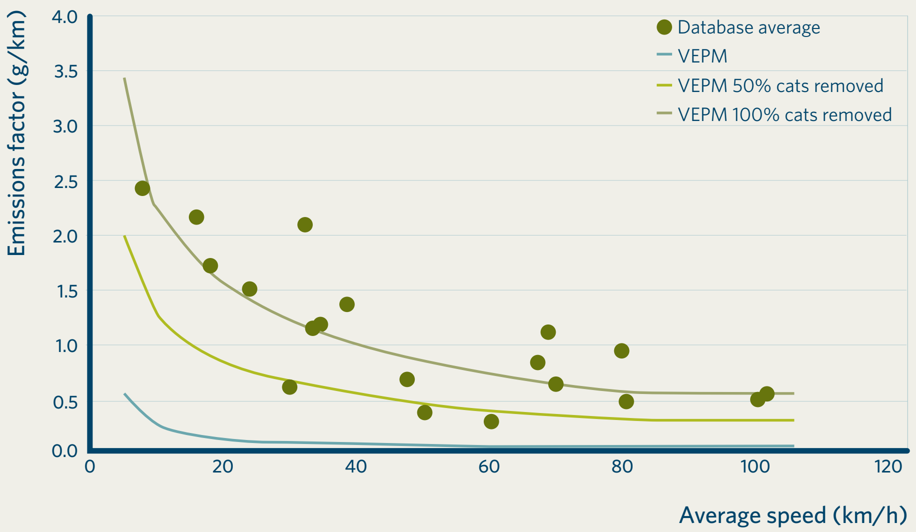
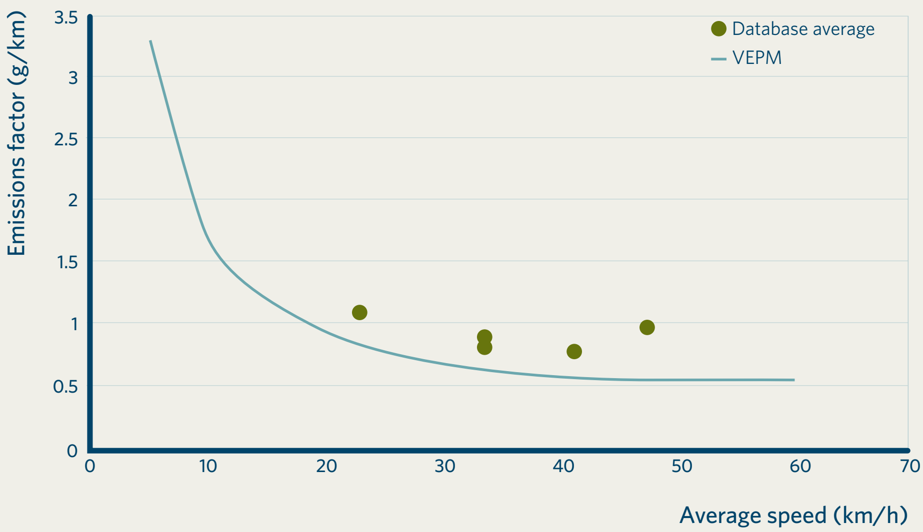


FIGURE 5.3 **Comparison between database and VEPM NO_x for Euro 3, >2000cc diesel LDVs**



5.2 Validation of trends predicted by VEPM by comparison with measured trends in on-road vehicle emissions

Research[12] has been undertaken to compare the trends predicted in VEPM with real-world emission trends observed in Auckland remote sensing campaigns. Remote sensing samples the actual exhaust emissions of a large number of real-world vehicles in an on-road situation. Remote sensing has limitations and cannot replace dynamometer drive cycle testing. However, it does provide complimentary information that can be used to check and validate findings derived from a smaller number of drive cycle tests.

This project used remote sensing results from 2003, 2005, 2009 and 2011. The trends in measured carbon monoxide, nitric oxide (NO), hydrocarbons and uvSmoke (as an indicator of particulate matter) emissions were compared with the trends in predicted carbon monoxide, nitrogen oxides (NO_X), hydrocarbons and particulate matter (PM_{10}) emission factors.

The analysis found good agreement between fleet average trends predicted by VEPM and measured trends in average vehicle emissions for the light duty fleet overall between 2003 and 2011. However, when the results were broken down by vehicle type, there were two key exceptions:

- The trend in measured NO emissions (increasing) is contrary to the trend in predicted NO_X emission factors (reducing) from diesel vehicles. This is consistent with the findings of a recent review undertaken in the UK[E].
- The measured reduction in uvSmoke emissions is less than the predicted reduction in PM_{10} emissions factors, especially for diesel vehicles.

The results suggest that the actual rate of reduction in NO_X and PM_{10} emissions from diesel vehicles is likely to be less than the theoretical rate of reduction predicted by VEPM.

6 Future updates

The Transport Agency regularly monitors international developments in emissions modelling. VEPM will be updated if any significant improvements or new data on emissions factors become available.

17 UK Department of Environment, Flood and Rural affairs (2011). *Trends in NO_X and NO_2 emissions and ambient measurements in the UK.* **www.accent-network.org**

E A recent review in the UK found that ambient concentrations of total nitrogen oxides and nitrogen dioxide have not decreased by as much as suggested by current emission factors[17].
This review also found that total nitrogen oxides emission estimates based on remote sensing are higher than suggested by published emission factors.

Appendix A
Reference tables

TABLE A.1 **Heavy duty vehicle categories in the VEPM model**

FUEL TYPE	EMISSION LEGISLATIONS	ENGINE SIZE	APPROXIMATE YEAR OF MANUFACTURE
Diesel	Europe Pre-Euro	3.5–7.5t	< 1992
		7.5–16t	
		16–32t	
		> 32t	
	Europe Euro I	3.5–7.5t	1992–1995
		7.5–16t	
		16–32t	
		> 32t	
	Europe Euro II	3.5–7.5t	2000–2002
		7.5–16t	
		16–32t	
		> 32t	
	Europe Euro III	3.5–7.5t	2003–2007
		7.5–16t	
		16–32t	
		> 32t	
	Europe Euro IV	3.5–7.5t	2008–2011
		7.5–16t	
		16–32t	
		> 32t	
	Europe Euro V	3.5–7.5t	2012–2019
		7.5–16t	
		16–32t	
		> 32t	
	Europe Euro VI	3.5–7.5t	>2020
		7.5–16t	
		16–32t	
	Japan Pre 1974	< 5t	1950–1973
		5–12t	
		> 12t	
	Japan J74, J77, J79, J82, J83, J87	< 5t	1974–1987
		5–12t	
		> 12t	
	Japan J88	< 5t	1988–1993
		5–12t	
		> 12t	
	Japan J94, J97	< 5t	1994–1997
		5–12t	
		> 12t	
	Japan J97	< 5t	1998–2002
		5–12t	
		> 12t	
	Japan J03	< 5t	1903–2004
		5 – 12t	
		> 12t	
	Japan J05	< 5t	> 2005
		5–12t	
		> 12t	

TABLE A.2 **Passenger car categories in the VEPM model**

FUEL TYPE	EMISSION LEGISLATIONS	ENGINE SIZE	APPROXIMATE YEAR OF MANUFACTURE
Gasoline	Europe Pre-ECE	< 1.4L	< 1971
		1.4-2.0L	< 1971
		> 2.0L	< 1971
	Europe ECE 15.00/15.01	< 1.4L	1972-1977
		1.4-2.0L	1972-1977
		> 2.0L	1972-1977
	Europe ECE 15.02	< 1.4L	1978-1980
		1.4-2.0L	1978 - 1980
		> 2.0L	1978 - 1980
	Europe ECE 15.03	< 1.4L	1981 - 1985
		1.4-2.0L	1981 - 1985
		> 2.0L	1981 - 1985
	Europe ECE 15.04	< 1.4L	1985 - 1992
		1.4-2.0L	1985 - 1992
		> 2.0L	1985 - 1992
	Europe Euro I	< 1.4L	1996 - 1999
		1.4-2.0L	1996 - 1999
		> 2.0L	1996 - 1999
	Europe Euro II	< 1.4L	2000-2003
		1.4-2.0L	2000-2003
		> 2.0L	2000-2003
	Europe Euro III	< 1.4L	2004-2008
		1.4-2.0L	2004-2008
		> 2.0L	2004-2008
	Europe Euro IV	< 1.4L	2009-2015
		1.4-2.0L	2009-2015
		> 2.0L	2009-2015
	Europe Euro V	< 1.4L	2016-2019
		1.4-2.0L	2016-2019
		> 2.0L	2016-2019
	Europe Euro VI (up to 2016)	< 1.4L	2020-2021
		1.4-2.0L	2020-2021
		> 2.0L	2020-2021
	Europe Euro VI (2017-19)	< 1.4L	2022-2024
		1.4-2.0L	2022-2024
		> 2.0L	2022-2024
	Europe Euro VI (2020+)	< 1.4L	>2025
		1.4-2.0L	>2025
		> 2.0L	>2025
	New Zealand	< 1.4L	< 1987
		1.4-2.0L	< 1987
		> 2.0L	< 1987
	New Zealand	< 1.4L	1988 - 1992
		1.4 - 2.0L	1988 - 1992
		> 2.0L	1988 - 1992
	New Zealand	< 1.4L	1993 - 1997
		1.4 - 2.0L	1993 - 1997
		> 2.0L	1993 - 1997
	New Zealand	< 1.4L	1998 - 2002
		1.4-2.0L	1998 - 2002
		> 2.0L	1998 - 2002
	New Zealand	< 1.4L	> 2003
		1.4-2.0L	> 2003
		> 2.0L	> 2003
	Japan Pre 1973, J73	< 1.4L	1950-1974
		1.4-2.0L	1950-1974
		> 2.0L	1950-1974

TABLE A.2 CONTINUED

FUEL TYPE	EMISSION LEGISLATIONS	ENGINE SIZE	APPROXIMATE YEAR OF MANUFACTURE
	Japan J75, J76	< 1.4L	1975-1977
		1.4-2.0L	1975-1977
		> 2.0L	1975-1977
	Japan J78	< 1.4L	1978-1985
		1.4-2.0L	1978-1985
		> 2.0L	1978-1985
	Japan J78, J88	< 1.4L	1986-1999
		1.4 - 2.0L	1986-1999
		> 2.0L	1986-1999
	Japan J00	< 1.4L	2000-2004
		1.4-2.0L	2000-2004
		> 2.0L	2000-2004
	Japan J05	< 1.4L	> 2005
		1.4-2.0L	> 2005
		> 2.0L	> 2005
Diesel	Europe Pre-Euro I	> 2.0L	< 2002
		< 2.0L	< 2002
	Europe Euro I	> 2.0L	1996–1999
		< 2.0L	1996–1999
	Europe Euro II	> 2.0L	2000–2003
		< 2.0L	2000–2003
	Europe Euro III	> 2.0L	2004–2007
		< 2.0L	2004–2007
	Europe Euro IV	> 2.0L	2008–2015
		< 2.0L	2008–2015
	Europe Euro V	> 2.0L	2016–2019
		< 2.0L	2016–2019
	Europe Euro VI (up to 2016)	> 2.0L	2020–2021
		< 2.0L	2020–2021
	Europe Euro VI (2017–2019)	> 2.0L	2022–2024
		< 2.0L	2022–2024
	Europe Euro VI (2020+)	> 2.0L	>2025
		< 2.0L	>2025
	Japan Pre 1986	> 2.0L	1950 - 1985
		< 2.0L	1950 - 1985
	Japan J86	> 2.0L	1986 - 1991
		< 2.0L	1986 - 1991
	Japan J92, J94	> 2.0L	1992 - 1997
		< 2.0L	1992 - 1997
	Japan J98	> 2.0L	1998 - 2001
		< 2.0L	1998 - 2001
	Japan J02	> 2.0L	2002 - 2004
		< 2.0L	2002 - 2004
	Japan J05	> 2.0L	> 2005
		< 2.0L	> 2005
Hybrid			All years
Plug in hybrid			All years
Electric			All years

TABLE A.3 **Light duty commercial vehicle categories in the VEPM model**

FUEL TYPE	EMISSION LEGISLATIONS	ENGINE SIZE	APPROXIMATE YEAR OF MANUFACTURE
Gasoline	Europe Pre-Euro 1	< 3.5t	< 1996
	Europe Euro I	< 3.5t	1996–99
	Europe Euro II	< 3.5t	2000–03
	Europe Euro III	< 3.5t	2004–08
	Europe Euro IV	< 3.5t	2009–15
	Europe Euro V	< 3.5t	2016–2019
	Europe Euro VI (up to 2017)	< 3.5t	2020–2022
	Europe Euro VI (2018–20)	< 3.5t	2023–2025
	Europe Euro VI (2021+)	< 3.5t	>2026
	Japan J73, J75, J79	< 3.5t	1950-1979
	Japan J79, J81	< 3.5t	1980-1987
	Japan J88	< 3.5t	1988-2000
	Japan J01	< 3.5t	2001-2004
	Japan J05	< 3.5t	> 2005
Diesel	Europe Pre-Euro 1	< 3.5t	< 1996
	Europe Euro I	< 3.5t	1996–1999
	Europe Euro II	< 3.5t	2000–03
	Europe Euro III	< 3.5t	2004–08
	Europe Euro IV	< 3.5t	2009–15
	Europe Euro V	< 3.5t	2016–19
	Europe Euro VI (up to 2017)	< 3.5t	2020–22
	Europe Euro VI (2018–20)	< 3.5t	2023–25
	Europe Euro VI (2021+)	< 3.5t	>2026
	Japan Pre 1974, J74	< 3.5t	1950-1976
	Japan J77, J79	< 3.5t	1977-1981
	Japan J82, J83, J87	< 3.5t	1982-1987
	Japan J88	< 3.5t	1988-1992
	Japan J93	< 3.5t	1993-1996
	Japan J97, J03	< 3.5t	1997-2004
	Japan J05	< 3.5t	> 2005

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Glossary

AVERAGE SPEED	The average speed for a transient driving cycle
cc	Cubic centimetre
CO	Carbon monoxide
CO_2	Carbon dioxide
COPERT	Computer programme to calculate emissions from road transport
ECE	Economic Commission for Europe vehicle emissions legislation (pre Euro)
EMEP/EEA	European Monitoring and Evaluation Programme/European Environmental Agency
EPEFE	European Program on Emissions, Fuels and Engine Technologies
Euro	European vehicle emissions legislation
g/km	grams per kilometre
HC	Total hydrocarbons
HCV	Heavy commercial vehicle
kg	kilogram
km/h	kilometres per hour
L	Litre
LINK	In a road network, a portion of road between two intersections, junctions, interchanges or nodes. Its basic characteristics are length, vehicle speeds, travel times and number of lanes
MoT	Ministry of Transport
NAEI	National Atmospheric Emissions Inventory (United Kingdom)
NO_x	Oxides of nitrogen, including nitric oxide, nitrogen dioxide and nitrous oxide
PM	Particulate matter
PM_{10}	Particulate matter less than 10 µm in diameter
$PM_{2.5}$	Fine particulate matter less than 2.5 µm in diameter
$PM_{1.0}$	Fine particulate matter less than 1 µm in diameter
$PM_{0.1}$	Fine particulate matter less than 0.1 µm in diameter
TSP	Total suspended particulates
VFEM	Vehicle Fleet Emissions Model
VKT	Vehicle kilometres travelled

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