Sensitivity: General

Transport Modelling Methodology

For determining greenhouse gas emissions from vehicles

Prepared for Waka Kotahi NZ Transport Agency - National
Prepared by Beca Limited

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Contents

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1	Vicky Li	Final draft addressing internal review comments (Andrew and Nyan)	30/01/2024
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on behalf of	Beca Limited		

1 Introduction

Beca was commissioned by New Zealand Transport Agency Waka Kotahi (NZTA) to provide advice on transport modelling to support guidance provided by NZTA on the quantification and assessment of greenhouse gas (GHG) emissions from vehicles. This report provides guidance around the application of the Vehicle Emissions Prediction Model (VEPM) emissions rates to traffic data or transport model outputs for the purpose of estimating the change in vehicle emissions from specific transport interventions.

1.1 Background

Vehicle emissions (sometimes called enabled emissions) are the GHG emissions that arise from use of the transport system, as distinct from other categories of GHG emissions associated with the construction, maintenance and operation of transport infrastructure (such as embodied emissions, construction emissions and operations emissions). Sources of enabled emissions include emissions from vehicles (including cars, buses, trucks, and trains) using the transport system.

The standard vehicle emissions model used in New Zealand is VEPM, which predicts emissions of GHGs as well as local air quality pollutants and brake and tyre wear, for the current and expected future NZ vehicle fleet. VEPM's predicted emission factors are expressed as a function of the mean speed over a complete driving cycle of several kilometres.This allows appropriate emission rates to be applied to different speed environments within a network before aggregation to system totals.

To assess changes in vehicle emissions during business case development, the Monetised Benefits and Costs Manual (MBCM) sets out the current NZTA methodology for estimating changes in GHG emissions from transport activities. The approach uses the emissions factors from VEPM, calculated using the average speed of traffic, gradient and traffic composition on individual parts of the network. These are typically assessed by vehicle class based on assessment year, which includes light (vehicles less than 3.5 tonnes) and heavy (vehicles greater than 3.5 tonnes). It applies the factors (in g/km) for the section of road under consideration to the time period's total light and heavy vehicle volumes and the road's length to give the emission load (g).

Typically, the average speed on individual sections of the network and the vehicle volumes used to calculate the emission load are estimated by transport models. Few existing transport models include gradient which may require additional steps to the study. NZTA provides guidelines on the development of transport models, which are developed for various purposes and designed to estimate transport outcomes with various levels of granularity. Some are more suitable for capturing the transport impacts from certain transport studies than others. Therefore, when estimating enabled emissions using transport modelling outputs, the practitioner needs to take account of the limitations and constraints in both VEPM and the transport model used, making sure they are fit for purpose in the context of the transport study (as illustrated in **Figure 1**).

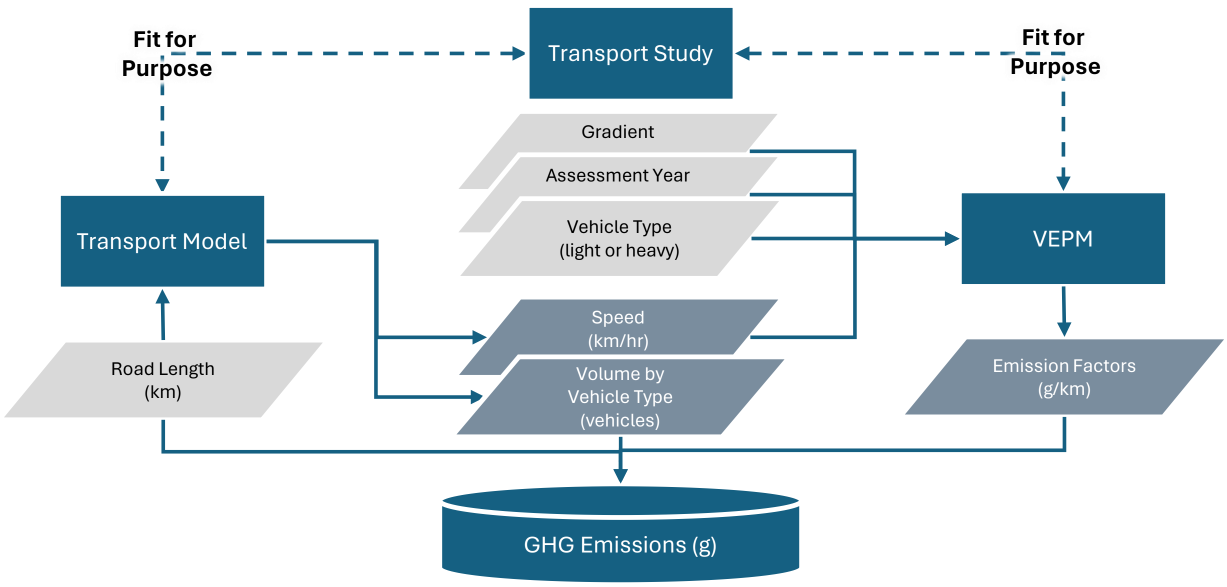

Figure 1 Process for Estimating Enabled Emissions for Transport Study using Transport Model and VEPM

This document presents a high-level review of different types of transport models and transport studies, with the aim to provide guidance on the critical considerations for practitioners when using transport modelling outputs with VEPM to estimate enabled emissions from different transport interventions.

1.2 Report Structure

The structure of the report is:

- **Literature review** - Collate and summarise past research and case studies on using transport modelling outputs to estimate GHG emission.
- **Key concepts** – Provide a glossary of key concepts used in this guideline.
- **Summary of types of transport models** - Provide high-level summary of different types of models commonly implemented in New Zealand for transport planning. For each type of model, list its limitations and typical use cases, where possible drawing on examples from tier 1 urban environments.
- **Summary of types of transport studies** - Discuss different types of studies, type of model required for each type of study.
- **Modelling principles** - Define key principles for undertaking modelling for vehicle kilometres travelled (VKT) and GHG assessment.
- **Model output and VEPM interface** - Recommend processes for interfacing between VEPM and transport modelling outputs.
- **Emission output interpretation** - Recommend metrics for assessment (e.g. VKT per capita and analysis time period) and ways to interpret the emission outputs in the wider context.
- **Emission output sense check** – Provide examples of high level regional level emission outputs, which can be used for output sense checks.

2 Literature Review

VEPM has been developed by NZTA and Auckland Council to predict emissions from vehicles in the New Zealand fleet under typical road, traffic and operating conditions. NZTA hosts a webpage for VEPM from which current (latest version 7.0 at time of this report) and past versions (from version 5.1) of the model can be accessed, with summary of key updates and links to user guides and technical information for each model version. Reports associated with the application of VEPM sourced from this website and other sources associated with transport modelling are reviewed for relevant insights.

Table 2-1 summarises the key points relevant to the development of this guideline from all literature reviewed as part of this project.

Overall, the documents reviewed highlighted that:

VEPM is the most appropriate tool in NZ for estimating GHG emissions for transport projects, although limitations in the model predictions need to be clearly understood and documented (see further discussions in EIL 2023 report).

In terms of applying VEPM to traffic models:

- It is important to use the different speeds on individual sections in the network rather than use a network-wide average speed.
- It is important to separate traffic volume by vehicle classification (light and heavy).
- Link by link method is the preferred method compared with origin destination method.
- Caution should be used when considering traffic calming interventions in low speed environment (see specifically section 4 and 5 in EIL 2023 report).

Transport model development guidelines along with the MBCM provide solid foundations for building transport models that are suitable for their modelling purpose. Concepts and approaches recommended in the model development guideline and MBCM (Section 2) form the basis of our guidelines in particular around defining scenarios (as discussed further in **Section 6**).

Various attempts have been made in the past to stocktake or unify transport models and their outputs, through which the complexity and variability in transport models is apparent. There also appears to be some underlying ambiguity around the terminologies and categorisation of models, some may be more appropriate depending on the context.

Table 2-1 Literature Review Summary

Title	Summary
Monetised benefits and costs manual (MBCM) (June 2023, NZTA)	This document is NZTA's standardised guidance for assessing the monetised benefits and costs of proposed investments in land transport (activities). The primary purpose of this manual is to establish consistency, transparency and comparability between activities to aid the evaluation of their economic efficiency. It sets the framework for assessing the impact of an intervention, including guidance on the counter-factual scenario (defined as the do-minimum). Section 2 of the document brings together the different elements of travel demand estimation. Definition of key terms and concepts related listed in section 2.2 is adopted for this guideline (see **Section 3**). In section 2.4, the manual summarised the estimation methods into four categories, including: • first principle estimates • simple mathematical models • project transport models, and • regional transport models. The main transport models are further defined as project / assignment model, regional transport model and land-use model. Section 3.4 documents the procedure to assess changes in the level of GHG emissions as the result of transport activities. It also provides shadow price of carbon emissions ($ per tonne of CO_2 equivalent) to convert emission load to dollar values for calculating benefits.
Transport Model Development Guidelines (September 2019, NZTA)	The key purpose of this document is to provide guidance on the development of transport models and procedures, ranges for the comparisons carried out between observed and modelled data to confirm acceptable model validation. A core aspect of this guide is identifying the different purposes and types of model, for which different model development criteria applies. It provides the following purpose categories: • **A**: Regional transportation assessments • **B**: Strategic network assessments • **C**: Urban area assessments • **D**: Transport Agency scheme assessment / project evaluation (within area of influence / focus) • **E**: Small area with limited route choice / corridor assessment • **F**: Single intersection / short corridor assessment • **G**: Special case high flow / high speed / multi-lane corridors assessment The document also provides guidance on important aspects that need to be considered when applying a model for transport studies (referred to as transport projects in the document). Appendix A lists the definitions commonly used in transport modelling, part of which is adopted for this guideline (see **Section 3**).
Effect of speed on greenhouse gas emissions from road transport – a review	This document presents a review of the average-speed modelling approach, with the aim of improving the understanding of VEPM's applicability to GHG assessments, and to improve the understanding of VEPM's limitations with respect to assessing the impacts of projects and policies. The likely emission impacts of some common speed related interventions

Title	Summary
(September 2023, Emission Impossible Ltd, EMM Consulting)	are also investigated, including changes in intersection design, implementation of traffic calming measures and changes in speed limits. The study confirms that the average speed modelling approach used by VEPM is the appropriate approach for GHG assessment for assessing project and policy impacts. For projects assessing the emission impact of speed limit changes, it is appropriate to use VEPM to estimate the impact on GHG emissions for speed limits above 60 km/hr. For changes below 60 km/hr, the review suggested that the limitations of the model predictions should be made clear and considered in any conclusions or recommendations based on the assessment.
Discovery Phase Study: Integrating regional transport model outputs with the VEMT Scenario Modelling Tool (July 2021, Tonkin & Taylor Ltd)	This document summarises a discovery and scoping phase for linking New Zealand's regional transport models ("Models") with the Vehicle Emissions Mapping Tool (VEMT). The tool is a Geographical Information Systems (GIS) tool, which can be used to calculate and display estimated emissions levels for all roads in New Zealand. It contains an overview of the regional transport models and their purposes (i.e. purpose category A models). With the focus on models for Auckland, Christchurch and the Waipa region, this research explored options for linking the VEMT and the regional transport models. The study was largely explorative with the main findings pending further investigation. The difficulty in its attempt at the stocktake of transport models used in different regions, highlighted the variability in transport models.
Urban transport modelling in New Zealand – data, practice and resourcing (September 2019, Stantec NZ)	This document includes a review and comparison of the Household Travel Survey already undertaken in New Zealand and a stocktake of the existing models used throughout the country. It summarises the transport models within New Zealand into three styles by their precision levels and areas they cover, including: • Strategic models • Project models • Provincial centre models
National Vehicle Emission GIS Mapping (September 2018, Jacobs)	This document outlines the methodology behind the Vehicle Emissions Mapping Tool (VEMT) and its application to create National Vehicle Emission Dataset 2016 (NVED2016). The key to the methodology is being able to gather all of the required emission parameters (traffic count, fleet profile, speed and gradient) into the same road sections. Once a road section contains all the necessary information then the appropriate emission factors can be applied to calculate its emission values. These results are then organized into suitable outputs for further analysis and visualisation. For the NVED, traffic volumes on road sections are derived from traffic counts for light and heavy vehicle types. Speed data on road sections is sourced from average operating speed estimated using fleet telematics data.
Traffic Emission Modelling (July 2012)	This document analyses the practicalities of traffic modellers undertaking the process of emission analysis using VEPM. It details steps undertaken to use VEPM and describes a study that has been undertaken using traffic model data (from a SATURN model built from an NZTA road scheme assessment). The analysis in the report focuses on production, processing and transfer of data from the SATURN model to VEPM and how emissions vary based on what processes, outputs and procedures are applied. The key findings were: • It is important to pick up different speeds in the network rather than use network-wide average speed. • It is important to separate traffic volume by vehicle classification (light and heavy). • Link by link method is the preferred method compared with origin destination method.

3 Key Concepts and Definitions

This section summarises the key transport modelling concepts referred to in this guideline. It is recognised that there are subtly differing industry definitions for some concepts and some ambiguity within common industry usage. These definitions are therefore provided for the purposes of this guidance and have used terminology from the Waka Kotahi MBCM where appropriate.

Demand: The representation of movements (vehicles, persons etc.) across the area. Commonly in the form of origin – destination (OD) trip matrices, often segmented by mode, trip purpose, vehicle type and time of day.

Network: The transport infrastructure (links, intersections and services) and features that provide for, control, and influence travel across a (study) area.

Calibration: The process of tuning model parameters to reflect the observed data.

Validation: The process of comparing model outputs against independent data that has not been used for calibration.

Model time period: The time period over which the transport model represents travel demand, travel behaviour and network characteristics.

Deterministic vs. Stochastic Models: In the transport modelling context, these terms have typically been used to describe the traffic assignment process, which determines the route vehicles/people take through the network and how they interact with other users. However, some model types use stochastic simulation methods for other modelling processes such as population and demand estimation (such as agent-based or activity-based models). For the purposes of this Report:

- A **deterministic** model (often called a static model) uses representative averages without randomness for both inputs and outputs (such as average user behaviour, flow rates and network capacities).
- A **stochastic** model seeks to simulate behaviour of individuals and the interactions between them via random sampling from distributions of behaviour and system variables. Outputs are an aggregation of the individuals choices, dependent on the random seed used. The use of random sampling means that multiple simulations are required to obtain representative outputs.

Demand vs. Actual or Arrival Flows: Related to the assignment process (deterministic or stochastic simulation), demands assigned to the network may either fully complete their trip within the defined period or be constrained when demand exceeds capacity. All simulation models and some deterministic models[1] do full capacity-constrained assignments, meaning that within a defined time period some trips may not have reached their destination when the model period ends. In most deterministic models capacity will influence route choice and congestion, but all trips are assumed to complete their trip.

Demand flows represent the volume of vehicles that would have travelled on the road section if there was enough capacity; actual flows represent the traffic throughput that can travel through the network within the time period. The difference between the two is assumed to have to travel in the next (not modelled) time period. Flows downstream of a capacity constraint/bottleneck should therefore be lower than the demand

[1] Such as models using the SATURN software

flows. Deterministic models typically do not make a distinction between demand and actual flows[2]. Capacity-constrained models will provide actual flows, but not all software platforms will also provide demand flows[3].

This concept is relevant to emissions modelling as changes to journeys completing their trips can bias the aggregate network results when comparing scenarios.

Annualisation factors (daily and annual expansion factors): Factors to expand time period results to daily average and then annual average results. Typically, these factors are calculated based on observed traffic profiles and assumed to remain constant for all scenarios.

Diversion Rate: This is the amount of equivalent VKT replaced by increases in other modes. For example, a diversion rate of 0.7 for new cycle travel implies that each new km of cycle travel would displace 0.7km of vehicle travel.

Fleet Composition: VEPM uses detailed fleet composition data from the Vehicle Fleet Emissions Model (VFEM) to calculate fleet weighted emission factors by emission class (i.e. light and heavy). Changes in fleet composition are projected by VFEM and reflected in the emission factors through the selection of the analysis year in VEPM.

Diverted travel: Shifts in route of travel through a network (without changes in the frequency, destination, mode or time of day of travel)

Induced travel: An increase in total travel for a specific time period, mode and destination. This can include changes that alter vehicle trip frequency, destination choice, mode or time of day, but excludes diverted travel shifted from other routes. This is an over-arching term that covers the following individual concepts:

- **Pure induced demand/trip frequency:** Pure induced travel demand relates to entirely new trips that would not have been made without the activity or supply. For example, if an activity (or collection of activities) improves access to a shopping location, a person who in the counter-factual scenario would make an average of one trip to the shop per week may make an average of two trips to the shop. However, it is noted that transport models attempt to reflect the average behaviour for regular, repeated travel. This means that pure induced travel can be considered in terms of an increase in **frequency of travel**.
- **Suppressed demand** is effectively the opposite of induced demand. It is when people would like to undertake trips but the travel impedance is perceived to be too great for the trip to occur.
- **Latent demand:** Additional induced travel that would be made if travel conditions improved (reduced congestion, trip variability and costs etc.). Transport modelling theory posits that travellers are seeking to maximise the utility of their trip by reducing its cost, hence there is likely to often be a latent demand for more travel at a lower cost. This is related to the concept of induced/suppressed travel, in that induced traffic is effectively releasing latent demand.
- **Re-distributed trips:** A trip where the destination is changed due to the travel costs or land use activity causing another destination to become more attractive. For example, a home-to-shop trip, where the shopping destination alters as a particular retail location has become easier to travel to or provides greater opportunities with the activity in place.
- **Mode-shifted trips:** A trip which switches from one travel mode to an alternative mode due to changes in the transport system and/or land use bought about by the activity. For example, when a home-to-work

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[2] Such models often uses an extended time period so that the assumption of completed journeys is less likely to exceed practical reality.

[3] The SATURN software will provide demand and actual flows on each link, while few micro-simulation platforms provide demand flows.

trip previously made by car changes to being made on public transport due to transport system changes.

- **Macro-time shifted trips** (*between* one discrete time period to another): A trip which shifts from one discrete time period to be made in another period. For example, if the morning commuter period is assessed as 7am to 9am, a trip which no longer occurs within this time period and instead is made in the inter-peak (after 9am, and before the start of the afternoon or evening period).
- **Micro-time of day shift:** Changes in the time of travel within a defined period to reduce travel times (often referred to as peak-spreading).
- **Disruptive behaviour change**: Change in traditional travel behaviour often in response to new technology or policy (e.g. working / studying from home, internet shopping and online medical appointments).

It is worth noting that the response to a change in the transport system can include all or most of the above influences, however, it is typically difficult to isolate the individual effects through analysis of available data.

Although the above concepts refer to all modes, the focus of this report is on the net effect on vehicle travel (VKT), and on network efficiency (network speed).

4 Summary of Types of Transport Models

This section provides a high-level summary of different types of transport models commonly implemented in New Zealand for transport planning. For each type of model, their typical variations are listed with examples from tier 1 urban environments[4] where applicable.

As documented from the literature review, the Transport Model Development Guidelines categorises transport models into seven categories based on the intended purpose for which the model would be applied and geographic coverage. As part of its purpose was for separating calibration and validation targets, the categories contained a mixture of project type and jurisdictions and general model purpose.

To summarise transport models for GHG assessment, categorisation following the conventional transport modelling hierarchy[5] based on details and scale is used as follows:

- Macroscopic (strategic model)
- Mesoscopic (detailed network model)
- Microscopic (micro-simulation model)
- Intersection models

The above hierarchy represents more of a spectrum than rigid categories, with some hybrid models including characteristics of more than one type.

The following tables list the key features for each of the model categories and their typical variation in New Zealand with local model examples.

[4] As defined by National Policy Statement, the tier 1 urban environments include: Auckland, Christchurch, Wellington, Tauranga and Hamilton.

[5] Austroads, Standard Transport Modelling Hierarchy (2020)

Table 4-1 Model Summary – Macroscopic Models

Macroscopic Models	
Description	**Typical Variations and Examples**
Most strategic models are trip-based (e.g. MSM[6] for Auckland, WTSM for Wellington[7], WRTM[8] for Waikato, CTM[9] for Christchurch and TTSM[10] for Tauranga), consisting of four stages or steps, including: • Trip Generation • Trip Distribution • Mode Choice • Time of Day • Route Choice (i.e. Assignment) All of these models cover a wide regional area. **Key model features include:** • Travel is estimated as a function of land use inputs. • Estimation of trips between origin and destination at specific time periods. • Estimation of mode choice, destination choice and route choice. • Estimation of link, route, area and network travel statistics. • Use of static, average inputs and outputs.	Common software choices include Cube Voyager, EMME, TRACKS and PTV Visum. **Land use input** • Could range from simple population growth rates to land use transport interaction (LUTI) models **Network representation** • The models are designed to represent travel on the strategic road network. This means that not all road are modelled (e.g. typically local roads or those with low traffic volume are excluded); some intersections are coded in simplified format (e.g. only key phases at signalised intersections are coded). • Most of the models source their raw network from geographically accurate road centreline information, therefore can provide relatively accurate modelled distance. But gradient is typically not explicitly built in. **Treatment of modes** • Most of the models provide estimates of transport trips at a daily person level, but some of them only take account of mechanised modes (e.g. TTSM only considers light vehicle, heavy vehicle and public transport trips). However, many models also have complementary active mode model, that can predict the impact of incremental mode shifts between mechanised and non-mechanised trips (e.g. TTSM has a separate cycle model, TCM which predicts the number of commuter cycle trips). **Time period assumptions** • Most models estimate daily person trips based on data representing a normal weekday. That is, a weekday outside of public and school holidays. • Most of these models convert estimates of daily transport trips into time periods when distributing the trips between origin and destination (ODs) and modes. The time periods are defined based on local traffic conditions (e.g. morning peak may be 2 hours or 3 hours), and may not always add up to a full 24 hours (e.g. some models may only contain morning, interpeak and afternoon peaks, but no overnight peak).

[6] Macro Strategic Model, built in EMME, latest model calibrated to 2018 census

[7] Wellington Transport Strategic Model, built in EMME, latest model calibrated to 2018 census

[8] Waikato Regional Transport Model, built in TRACKS, latest model calibrated to 2013 census

[9] Christchurch Transportation Model, built in Cube Voyager, latest model calibrated to 2018 census

[10] Tauranga Transport Strategic Model, built in Cube Voyager, latest model calibrated to 2018 census

Table 4-2 Model Summary – Mescoscopic Models

Mesoscopic Models	
Description	**Typical Variations and Examples**
A key distinction between mesoscopic and macroscopic is that mesoscopic models tend to have more refined inputs (including both network and zoning systems) and assignment method (e.g. dynamic feedback of link overcapacity from warm up assignment). **Key model features include:** • Simplified simulation of individual vehicles by the propagation of flow in discrete time intervals along a sequence of links. • Static and dynamic traffic assignment.	Common software choices include Aimsun, Cube Avenue, Dynameq, SATURN and PTV Visum / Vissim. **Network representation** • While these models tend to have a more refined network, some are built for specific project work and therefore only have detailed network or assignment within the main project area (e.g. S3M[11] for Auckland when compared with MSM). • Others that do cover a large region similar to that of the macroscopic model (e.g. CAST[12] for Christchurch) tend to have buffer network in rural areas that does not have detailed assignment when compared with the urban areas. **Study area** • Some of these models are created from cordoning the project area from the bigger macroscopic model. To ensure the full impact of the project is captured adequately, the cordoned area would cover the area of the influence from the project, where alternative routes that traffic may be diverted to post project implementation are also included. **Treatment of modes** • Typically, these models only deal with the assignment of mechanised modes (i.e. light, heavy and public transport). **Time period assumptions** • Often mesoscopic models would consist of pre-peak periods prior to the peak periods (e.g. 30mins pre-peak periods before the average hour model of the morning peak period from 7am to 9am). They are included to capture conditions at the start of the peak periods. • The models are typically built for peak periods only. Factors derived from traffic counts are often used to convert outputs to daily level.

[11] Southern Sector SATURN Model, focusing on South Auckland, built in SATURN, latest model calibrated to 2016 counts.

[12] Christchurch Assignment and Simulation Traffic Model, built in SATURN, latest model calibrated to 2018 census.

Table 4-3 Model Summary – Microscopic Models

Microscopic Models	
Description	**Typical Variations and Examples**
These models include the modelling of individual vehicle movements which would allow for lane changing and acceleration and deceleration. Demand is typically profiled within a time period (e.g. for the morning peak period from 7am to 9am, demand is profiled for every 15mins within the peak period). Greater detail is included in network coding with regard to signal timings, road geometry, lane restrictions, gap acceptance and etc. **Key model features include:** • Detailed simulation of individual vehicles and their interactions with each other. • Static and dynamic traffic assignment.	Common software choices include Aimsun, Paramics and PTV Vissim. **Study area** • Some of these models are created from cordoning the project area from the bigger macroscopic model. To ensure the full impact of the project is captured adequately, the cordoned area would cover the area of the influence from the project, where alternative routes that traffic may be diverted to post project implementation are also included. **Treatment of modes** • While these models can simulate cyclists and pedestrians, individual models typically only deal with the assignment of mechanised modes (i.e. light, heavy and public transport). **Time period assumptions** • The models are typically built for peak periods only. Factors derived from traffic counts are often used to convert outputs to daily level.

Table 4-4 Model Summary – Intersection Models

Intersection Models	
Description	Typical Variations and Examples
These models are often created to assess the performance for individual intersection or a corridor of intersections. **Key model features include:** • Simplistic calculation of intersection performance and operation. • Static traffic assignment.	Common software choices include LinSig, SIDRA and TRANSYT. **Travelling speed assumptions** • Typically, each intersection arm or approach can have their separate approach speed assumptions, which is used to derive travel time outputs based on input lane length data.

5 Summary of Types of Transport Studies

This section lists different types of studies, with suitable types of models. Key differentiators between studies include the study horizon year (short term operational versus long-range strategic), the likely scale of impact (local, sub-area, regional) and the level of network precision (detailed, simplistic). The relationship between study type and model type is shown conceptually in **Figure 2**.

Table 5-1 Summary of Transport Studies

Typical Model Category	Typical Transport Study
Macroscopic/Strategic model	**Policy, land use planning, transport strategy** - Studies to identify long-term spatial planning (for land use and network improvement projects) - Model outputs are typically aggregated and over long horizons - Simplified network representation assumptions, - Simplified operation strategy
Mesoscopic/Sub-area network model	**Subarea Operational or Project assessment** - Network improvement projects - Project appraisal - Greater network precision
Microscopic model Intersection model	**Local Operational Upgrades or Assessments** - performance of existing traffic controls and intersection - Assessment of traffic management - Detailed network and operational precision

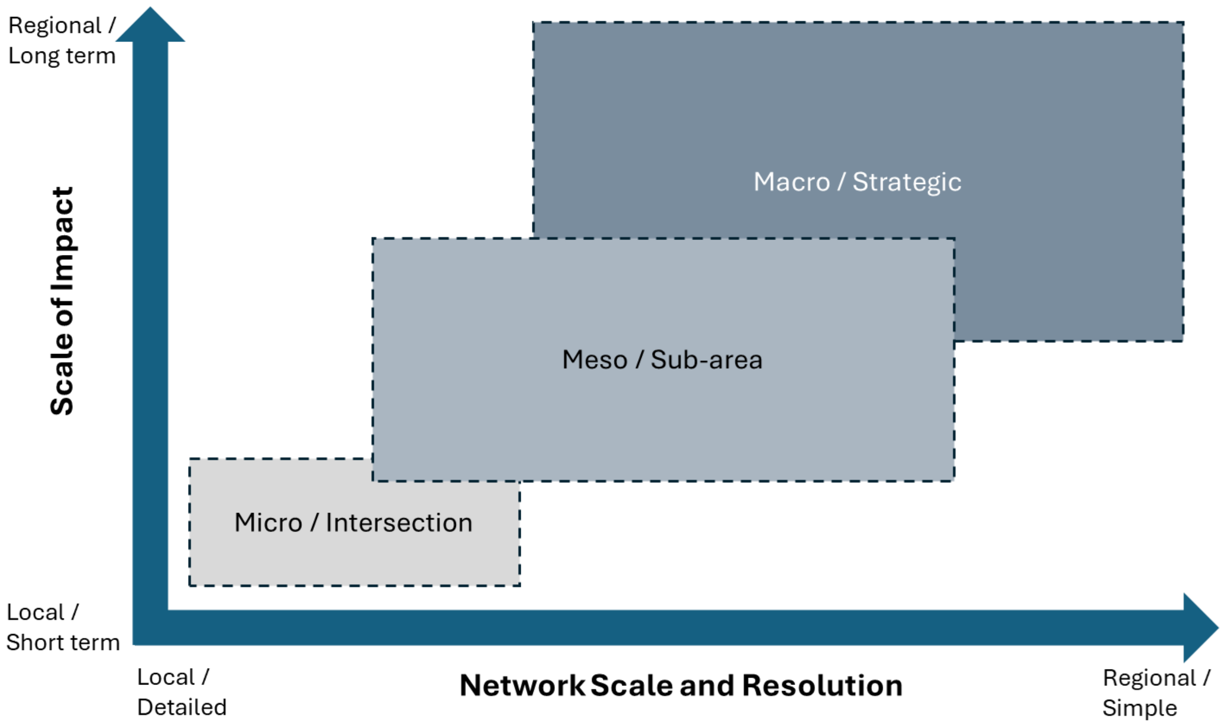

Figure 2 Relationship Between Model Type and Study Type

6 Modelling Principles for GHG Assessment

Given the range of transport models and studies discussed in the previous sections, the practitioner should seek to match the model type to the type of study and expected impact of the intervention being assessed. Typically, existing available models will be used so it is important to recognise the limitations of the available tools as they relate to estimating emissions impacts. This section lists the key principles and steps for undertaking transport modelling and associated GHG assessment.

The key principles and steps for measuring vehicle emissions using VEPM and transport modelling outputs are illustrated in **Figure 3**, which consists of the following:

1. Identifying the likely system **response** to the intervention being assessed, which would inform the purpose of the model that is needed
2. Selection of **appropriate models and methods** to match the expected response or the required purpose, including identifying known limitations relevant to emissions assessment
3. Development of appropriate model **scenarios**, particularly the option (do intervention) and the counter-factual (do minimum) scenarios
4. Ensuring an appropriately **closed system** for comparison, especially for the modelled area, total population and completed journeys
5. Development of appropriate **VEPM emission rates**, particularly for analysis years, vehicle segments and consideration of gradient
6. **Application of VEPM** rates to transport models
7. **Verification and reporting**

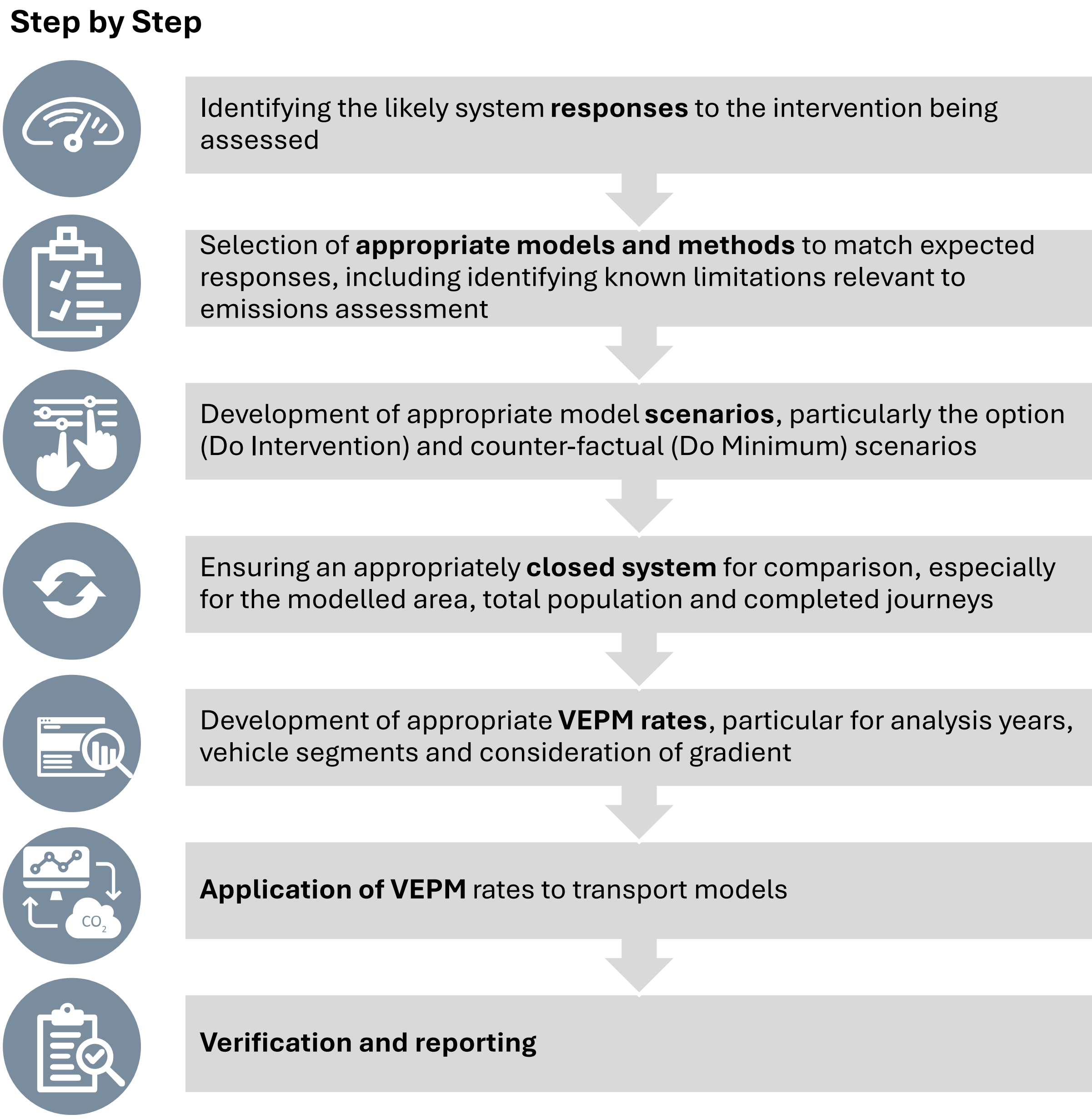

Figure 3 Step by step key principles in measuring vehicle emissions using VEPM and transport modelling outputs

These principles and steps are discussed further:

1 Likely System Response

This step is required to inform the selection of the appropriate transport models and assessment methodology. It involves identifying the predominant responses to the intervention to be tested and will be dependant on the network context and the scale and type of intervention. For example, a major new public transport facility within a congested urban network could expect a response that includes improved public transport user experience and route switching, along with mode shift from car users and consequential changes in network performance and routing. All these responses will impact emissions through changes in the amount (VKT) and efficiency of vehicle travel (speed).

2 Model Choice and Assessment Methodology

This step involves developing an appropriate methodology that captures the key responses expected to the intervention. Most studies are likely to utilise existing models, so will need to consider their limitations, including:

- Study area and model extent
- Demand modelling capability, including mode shift, redistribution
- Gradient effects
- Vehicle type segmentation
- Land use response

Judgement is required on the materiality of lower-order responses where suitable methodologies are not readily available. Where a materially important response is not available within the available transport models, additional calculation steps may be needed to address those limitations. Common examples could include:

- Use of simplified methods to estimate new cycle trips, with use of diversion rates to estimate avoided VKT
- Inclusion of road gradient factors or adjustments on specific routes critical to the intervention
- Use of multiple, separate models (e.g. vehicle, public transport and cycling), where single, integrated models are not available
- Use of additional adjustment or correction factors to obtain a closed-system comparison (see discussion below)

3 Development of Appropriate Model Scenarios

The calculation of enabled emissions will typically require development of two scenarios: an option scenario (representing the intervention to be tested, sometimes referred to as do intervention) and a counter-factual (do minimum) scenario. These would typically be consistent with the scenarios used to estimate economic benefits, so the guidance in the MBCM around the development of counter-factual and option scenarios should be referenced.

It is recommended that the VKT model assumptions and limitations of the forecast scenarios should be clearly documented in any transport assessment report, such as changes to land use and trip making patterns and profiles, model parameters and supply side network assumptions between the model base year and the forecast year or years.

4 Ensuring a Closed System for Comparison

Vehicle GHG emissions should be assessed across the whole impacted network, which could involve large areas and a significant amount of travel. The assessment is therefore likely to involve comparing relatively small changes in very large network-wide total emissions. Small model changes can potentially have a material impact on such comparisons, so careful consideration is required of potential bias from an 'open' system. In this context, an open system refers to modelled impacts that involve or imply changes beyond the assessment area that are not treated consistently between scenarios. The key concepts to ensuring a closed system include:

- **Common population** totals within the study area. While some interventions could increase the total population capacity or attractiveness of a region, a fixed-population total should be adopted for the modelled area to avoid bias due to implied migration between areas (which would otherwise require consideration of the impact on other jurisdictions from where the increased population is drawn from)[13]. For example, if an option scenario was predicted to have a greater population than the counter-factual for a specific area, consideration would need to be made of the emissions impact of the reduced population in adjacent areas from where that additional population is drawn. Spatial re-allocation of population within a modelled area in response to system changes can be considered as long as the aggregate totals are common between scenarios;
- **Study area** boundaries. Traffic diversion outside the modelled areas should be avoided or corrected to avoid inconsistent treatment of partially included trips. This can occur where a demand response is developed from a larger strategic model, with traffic flows cordoned for a sub-area model for emissions assessment. If such effects are considered material, manual adjustments could be required based on the change in VKT outside the sub-area model or by using comparable per capita VKT values;
- **Completed Trips**. Changes in completed trips between scenarios should be avoided. This can occur where the counter-factual has lower network capacity and fewer trips completing their journeys in the modelled period, and where the option scenario includes more VKT simply because more of those trips complete their journey. Where capacity-constrained models provide both demand and actual flows, the Demand flows should be used to estimate VKT. Micro-simulation models are prone to changes in partial trips so may require different techniques, such as extension of the modelled period to ensure all trips are completed.

5 Development of Appropriate VEPM Rates

This step involves the use of VEPM to provide emission rates by vehicle speed. Consideration will need to be given to:

- Forecast years: Which influences the forecast fleet composition. Because of considerable demographic, technological and economic uncertainty, caution should be used when interpreting longer term forecasts
- Vehicle segmentation: Which depends on the segmentation available in the transport model, but would typically involve separate rates for light and heavy vehicles
- Consideration of road gradient: Whether this is expected to be a material differentiation between scenarios and therefore require specific treatment

6 Application of VEPM Rates to Model Data

The general and recommended approach is:

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[13] Alternative would be to expand the model area sufficiently so that no net difference was expected.

- VEPM emission rates are allocated to each link in the model based on the average link speed[14] and for each vehicle class
- Emissions are estimated on each link by multiplying the emission rates by the vehicle volume and link length
- Network totals are determined by summing across all links and vehicle classes
- Daily and annual totals are estimated by applying expansion factors to the time-period results

Section 7 provides more details on the processes for interfacing between VEPM and the modelling outputs. The traffic model emissions tool can be used to apply emission rates from VEPM to link based output data from a traffic model.

Exceptions to this link-based approach should be limited to specific circumstances:

If the study is for an area-wide intervention and only aggregate change in VKT is available (e.g. if the change in VKT has been estimated from sources other than a detailed transport model), then the same speed (and hence the same emission factors) should be used across the scenarios. This is because the granular speed information is not available across the scenarios to support changing of speed assumptions. For example, if an option results in 5% VKT reduction when compared to the counter-factual scenario, which is calculated using a diversion rate from car to cycle outside of the transport model (because the transport model doesn't have a cycle component), then to calculate the emissions savings from the 5% reduction, the emission factor should be determined from the counter-factual network speed.

Average speeds calculated at an origin-destination level should be avoided, except in specific circumstances, such as:

- where the effect of congestion changes is not considered important, such as high-level strategic land use planning where specific details of future networks (and hence congestion levels) are not known
- In micro-simulation models to address the inconsistencies in completed trips where other methods to ensure a closed system are not feasible (such as extended model periods noted above)

Care should be taken when assessing interventions such as speed limit changes. In complex urban environments, using the average speed does not distinguish between freeflow conditions where travel is restricted by low speed limit and unrestricted but congested network conditions resulting in the same low average speed.

7 Verification

Within a large model area an individual transport intervention may only impact a small proportion of the total system VKT and emissions. This means that an emissions assessment is likely to involve quantifying small differences in large system totals, and can therefore be sensitive to model instability. Checking and testing of the models is therefore important to providing robust outputs. Similarly to the assessment of economic outputs, various checks should be undertaken on model predictions, including:

- **Model convergence**: This involves checking that convergence between iterative processes is within acceptable tolerances and consistent between scenarios
- **Representative sampling**: Sufficient replications of stochastic (micro-simulation) models are run to provide representative results
- **Model Stability and Sensibility**: this involves checking if the responses to the intervention are plausible and suitably stable in terms of other parameters. For example, checking that predicted changes are plausibly related to the intervention (not remote and seemingly unrelated), and that such changes are

[14] The link speeds should include intersection delays

stable when other, unrelated parameters are changed or additional replications run. This should include visual checks of the location and scale of predicted changes

- **Model sensitivity**: This involves understanding the sensitivity of the results to key assumptions. Typically sensitivity testing could include the fleet assumptions (via the use of different analysis years in VEPM), assumptions on wider network upgrades, different operational or demand management strategies etc

Guidance is provided on these matters in both the Waka Kotahi Transport Model Development Guidelines[15] and MBCM.

Verification of the emissions analysis should include:

- Correct use of units (this is important given the use of mass units spanning grams (such as VEPM rates) to tonnes (recommended for reporting annual totals)
- Sense checks of implied emissions rates from aggregate change in VKT and GHG emissions
- Sense-check of VKT against baselined regional data where feasible.

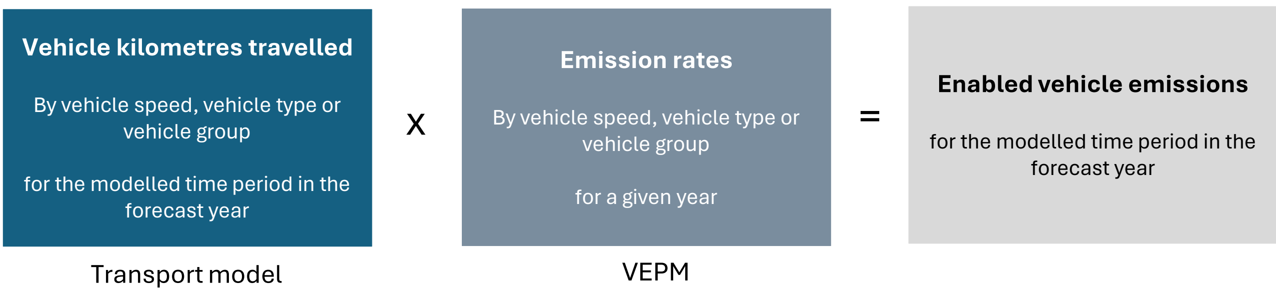
As an external process to the transport model, there will typically be a requirement to convert model output data from the modelled time periods of the transport model to an average annual day so that results can be annualised.

7 Model Outputs and VEPM Interface

This section recommends processes for interfacing between VEPM and the modelling outputs of the transport studies.

VEPM provides predictions of vehicle emissions rates for the New Zealand fleet between 2001 and 2050. The emissions rates are provided by vehicle speed for the vehicle fleet as a whole, but also by vehicle type (for engine types and size) and groupings of vehicle types (light vehicles, heavy vehicles and buses). The predictions of emissions rates allow for predicted changes in engine fuel efficiency over time and predicted changes to the composition of the New Zealand fleet over time.

The VEPM emissions rates, calculated as CO_2-equivalents (CO_2e) by vehicle group (light vehicles, heavy vehicles and buses), are what would be typically combined with outputs from traffic models to predict the total enabled vehicle emissions for a given scenario, or the change in enabled emissions resulting from a project. This calculation is illustrated below:



[15] Transport model development guidelines (nzta.govt.nz)

The level of detail needed in the calculation of the enabled vehicle emissions from a project will depend on the business case phase the project is in, and the limits of the available transport modelling tools and data:

For strategic planning such as programme business case phase, a high-level calculation[16] of the effect on VKT and vehicle emissions may be all that is required and would be commensurate with the available transport modelling tool and data available at this phase of a business case. In some cases a qualitative assessment of the potential emission impact may be appropriate.

- At indicative business case phase and beyond, calculations would be required using outputs from a transport model. In most circumstances, detailed calculations would be required using link level detailed outputs from a transport model combined with emissions rates by vehicle group type (lights, heavies, buses) for all speed bands.

Two methods of calculating enabled emissions resulting from a project are presented in the table below. It is worth noting that:

- The link by link based method is the recommended method over the average network speed method.
- The use of an average speed over the OD pair or network may provide an unreliable estimate of enabled emissions. The average network speed method is not recommended in congested or complex networks where the use of an average network speed will hide the effects of traffic choosing alternative routes with different speed conditions. It should only be used when detailed project model is not available.
- These assessments are generally undertaken outside of PEET, although the average speed method can be used as an input to PEET.

Table 7-1 Application for VEPM – Link-by-Link Method

Link-by-link based method (recommended method when a traffic model is available)			
Calculation	**Traffic data**	**Emissions data**	**Outcome**
Total Do option enabled emissions minus Total counter-factual enabled emissions as determined by the link level calculation of emissions for each scenario using: VKT by link by vehicle group from the traffic model × Emissions rate by vehicle group type for the given link speed Traffic model emissions tool can be used	Detailed traffic model outputs of link distance (m), travel time (s) and volume by vehicle type (lights, heavies, buses). Modelling of the counter-factual and option scenarios for the baseline/opening year and forecast years (typically 10 and 20 years)	Emission rates by vehicle group type (lights, heavies, buses) for all speed bands.	A prediction of enabled vehicle emissions that accounts for the network effects of the project and some demand changes. The impact of local developments and planned transport schemes is accounted for in the prediction.

Table 7-2 Application for VEPM – Average Origin-Destination or Network Speed Method

Average network speed method (only used when suitable project traffic model is unavailable)			
Calculation	**Traffic data**	**Emissions data**	**Outcome**
Change in total VKT by vehicle type from the traffic model × Emissions rate by vehicle group type for the average origin-destination pair or network speed	Origin-destination (OD) pair or network wide traffic model outputs of VKT by vehicle type (lights, heavies, bus) and average OD pair or network speed. Modelling of the counter-factual and option scenarios for the baseline/opening year and forecast years (typically 10 and 20 years)	Emission rates by vehicle group type (lights, heavies, buses) for each average OD pair or network speed for each modelled scenario.	An estimate that accounts for the network effects of the project, the impact of local developments and planned transport schemes. Important: See caveats above; this may be an unreliable estimate in some scenarios.

8 Emission Outputs Interpretation

This section recommends metrics for emission assessment and the ways to interpret the emission outputs in the wider context.

Following the method described in the previous section, standard VEPM factors (in grams per kilometre travelled by vehicle group) would return emission estimates in grams of CO_2e. The majority of the transport models represent specific peak time periods, such as morning, inter-peak and afternoon peaks. Typically, factors are derived from observed data to convert traffic volume estimates from time periods to an average annual day so that results can be annualised. The practitioners can use the same factors to convert emission estimates from peak periods into total daily or annual emission estimates.

When interpreting the emission outputs, the practitioner should take into account the limitations and variations of the underlying transport models used to derive the emission estimates. Comparing emission outputs between different scenarios, within varied contexts, can yield more substantial insights.

For example, for land use planning studies, the overall land use growth difference between scenarios may be minimal comparing to the base land use (e.g. the only difference between scenario 1 and 2 is the displacement of industrial employment growth, which is only 4% of base year employment). In these scenarios, the overall emission changes should be considered in the context of the changes being assumed. In the example provided, a 2% change in emission estimates from the base year would appear to be significant in the context of the 4% employment change.

For consistency across projects, it is recommended that annual estimates of GHG emissions are reported in tonnes per annum.

The primary focus of this analysis should be for comparative purposes to inform decision making. As such, the limitations of the analysis should be considered and clearly documented along with suitable sensitivity tests on key inputs and assumptions.

9 Emission Outputs Sense Check

In addition to the verification steps outlined in **section 6** (step 7), this section provides examples on the high level regional level emission outputs, which can be used as for output sense checks.

The Climate Change Response Act sets a domestic target for Aotearoa to reduce net emissions of all GHGs (except biogenic methane) to zero by 2050. However there are no regional GHG targets set within the Act .

To help verify the emission outputs and provide context, here are the baseline GHG outputs by tier 1 and 2 urban environments with national summary. The figures are the annual total and per capita enabled emissions for the census year of 2018 by urban areas. These estimates are updated on an annual basis using data published from Ministry of Transport and NZTA, the latest regional estimates can be requested from NZTA.

Table 9-1 Baseline VKT and GHG emission for 2018 by urban environments

Tier	Urban Area	Vehicle Kilometre Travelled (2018, million kilometres)		Greenhouse Gas Emission (2018, kilo-tonnes CO_2 equivalent)	
		Light	Heavy	Light	Heavy
1	Auckland	14,757	893	3,242	1,030
1	Christchurch	4,409	286	969	330
1	Hamilton	2,664	171	585	197
1	Tauranga	1,526	142	335	163
1	Wellington	3,407	160	748	184
2	Dunedin	758	34	166	39
2	Napier-Hastings	1,145	88	252	102
2	Nelson Tasman	1,005	75	221	87
2	New Plymouth	626	44	137	51
2	Palmerston North	473	22	104	25
2	Queenstown	556	41	122	48
2	Rotorua	553	56	122	64
2	Whangarei	743	64	163	74
National Total		44,176	3,327	9,706	3,834

Table 9-2 Baseline VKT and GHG emission per capita (based on census usual resident count) for 2018 by urban environments

Tier	Urban Area	Vehicle Kilometre Travelled (2018, kilometres per capita)		Greenhouse Gas Emission (2018, tonnes CO_2e per capita)	
		Light	Heavy	Light	Heavy
1	Auckland	9,389	568	2.1	0.7
1	Christchurch	9,015	585	2.0	0.7
1	Hamilton	9,193	590	2.0	0.7
1	Tauranga	8,116	755	1.8	0.9
1	Wellington	7,383	347	1.6	0.4
2	Dunedin	6,004	269	1.3	0.3
2	Napier-Hastings	7,964	612	1.8	0.7
2	Nelson Tasman	9,732	726	2.1	0.8
2	New Plymouth	7,759	545	1.7	0.6
2	Palmerston North	5,588	260	1.2	0.3
2	Queenstown	14,201	1,047	3.1	1.2
2	Rotorua	7,694	779	1.7	0.9
2	Whangarei	8,168	704	1.8	0.8
National Total		9,400	708	2.1	0.8