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Assessing the Impact of Gross Emitting Vehicles – Summary Report

Waka Kotahi NZ Transport Agency

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Assessing the Impact of Gross Emitting Vehicles - Summary Report

Prepared for

Waka Kotahi NZ Transport Agency

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1.0 Background and Project Objective

Road-side vehicle emission monitoring using remote sensing device (RSD) technology is recognised internationally as a useful and cost-effective method of collecting large amounts of real-world vehicle emission data. The RSD measures the emissions of four pollutants: carbon monoxide (CO), hydrocarbons (HC), nitrogen monoxide (NO) and uvSmoke (a proxy for particulate emissions (PM)).

Between 2003 and 2015, five RSD monitoring campaigns were completed in Auckland. The most recent 2015 RSD database is used for this assessment. Emission measurements can be linked to data contained in the national Motor Vehicle Register (MVR) allowing investigation into the correlation between vehicle characteristics and pollutant emissions.

Previous RSD campaigns have showed the increasing age of New Zealand's on-road vehicle fleet and the disproportionate impact of a small number of high or "gross" emitting vehicles. Characterisation and modelling of gross emitting vehicles (GEVs) enables the identification of possible interventions for these vehicles.

Characterisation of GEVs from the RSD database to identify common characteristics of potential GEVs combined with the 3.6 million light duty vehicle (LDV) records contained in the MVR allows the identification of likely numbers, locations, and annual travel distances of potential GEVs in the national fleet. This facilitates an assessment of the impact of GEVs on total pollutant emissions.

Gaining an understanding of the impact of GEV emissions can potentially inform targeted policies to reduce the impact of emissions from these vehicles.

The objective of this project was to determine the impact that gross emitters have on emissions of pollutants harmful to human health from the vehicle fleet across New Zealand. The project was undertaken in two stages:

- Stage 1 - Assessment of the number, characteristics, activity, and regional distribution of GEVs, including:
  - Defining the proportion of the fleet to be considered as GEVs and defining a set of GEVs for each of the four pollutants monitored by the RSD;
  - Investigating whether GEVs had been measured more than once in the 2015 RSD campaign and whether monitored emissions had changed to confirm the repeatability and therefore suitability of RSD measurements for identifying GEVs;
  - Assessment of characteristics of the GEV set for each RSD-monitored pollutant including fuel type, age, odometer reading, and emission control;

  - Development of a predictive GEV model using observed trends in vehicle characteristics of GEVs;
  - Assessing the rate of retirement of GEVs within the monitored fleet;
  - Calculation of the annual average distance travelled (AADT) by GEVs compared to typical emitting vehicles (TEVs); and
  - Identifying the likely number and regional distribution of GEVs in New Zealand's vehicle fleet.
- Stage 2 –Assessing the Impact of GEVs, including:
  - Determination of the potential impact of harmful pollutant GEVs compared to the emissions from the wider LDV fleet; and
  - Estimation of the emission reduction benefit of removing GEVs from the fleet.

This report provides a summary of findings from Stage 1 and Stage 2 presenting CO results as an example. A brief overview of the results from HC, NO and PM is also provided. The complete set of results are presented in detail in the full-length report[1].

2.0 Stage 1: Definition of GEVs and Assessment of GEV Characteristics

2.1 Definition of GEVs

The vehicles which fell within the highest 3% of valid emissions readings were classified as GEVs. It is more typical for the highest 10% of emissions records to be used to define GEVs but the 3% definition was recommended as it captures a significant proportion of the total emissions while including a relatively small number of vehicles which could potentially be targeted through policy interventions. For CO, 3% of valid readings accounted for 44% of total CO emissions as shown in Figure 1. The top 3% of valid readings accounted for 25% of total emissions for HC, 26% of total emissions for NO, and 31% of total emissions for PM. Table 1 shows the absolute RSD measurement values associated with the 3% GEV cut-off.

[1] Pattle Delamore Partners Ltd. (2020). *Assessing the Impact of Gross Emitting Vehicles.* Waka Kotahi NZ Transport Agency.

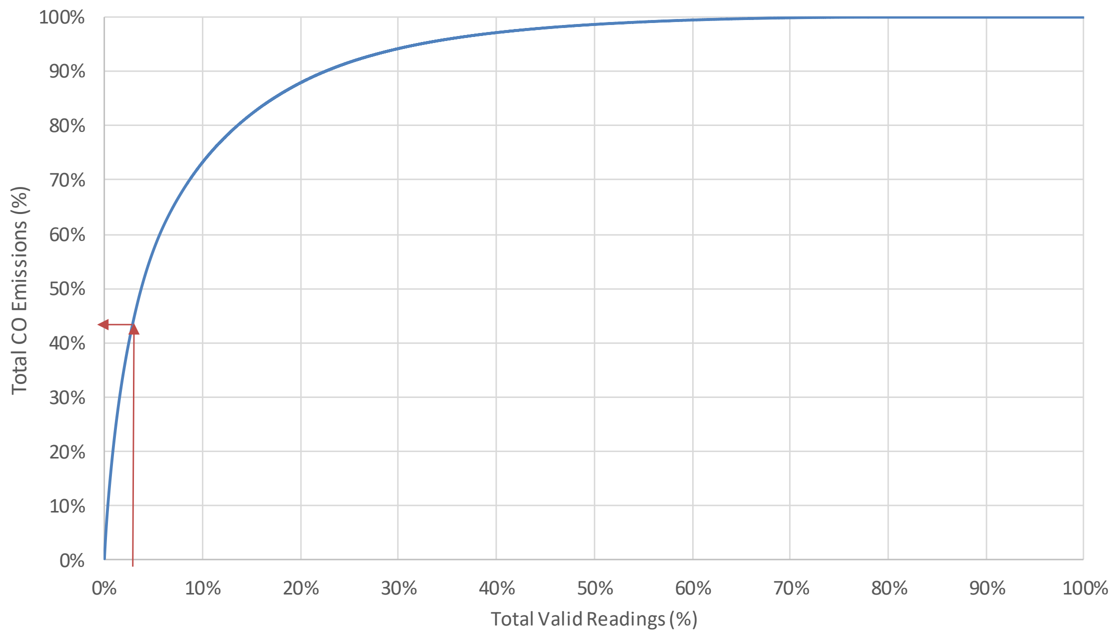

Figure 1: CO Cumulative Distribution Plot

Table 1: Measurement Values for GEV Classification (Top 3% of emissions, 2015 RSD Data Set)		
Pollutant	**GEV Values (≥)**	**Units**
CO	1.935	% CO
HC	469.81	ppm HC
NO	2367	ppm NO
PM	0.279	g PM/kg fuel

Gross emitters for each of the four pollutants measured by RSD were cross-referenced to investigate whether GEVs discharged high amounts of all four pollutants or high amounts of a limited number of pollutants. The crossover of GEVs for the four pollutants measured by the RSD measurements is shown in Figure 2.

With the exception of HC, each pollutant had more vehicles classified as GEVs solely for that pollutant than in the combined crossover with other pollutants. The highest crossover between two pollutants was CO and HC with 163 vehicles (21% of both CO and HC GEVs). The crossover between HC and PM was over 10% of the total GEVs for each pollutant (12% of HC GEVs and 13% of PM GEVs) with 95 vehicles.

Crossover between three pollutants returned 6% of the total GEVs for CO, HC, and PM and for HC, NO and PM whereas the other two groups returned less than 1%. There were 9 vehicles recorded as GEVs for all four pollutants of interest (around 1%). The implications of this are that it is unlikely that it will be possible to develop a single policy to target GEVs of all pollutants and it is likely that pollutant-specific targeting of potential GEVs will be the most effective approach.

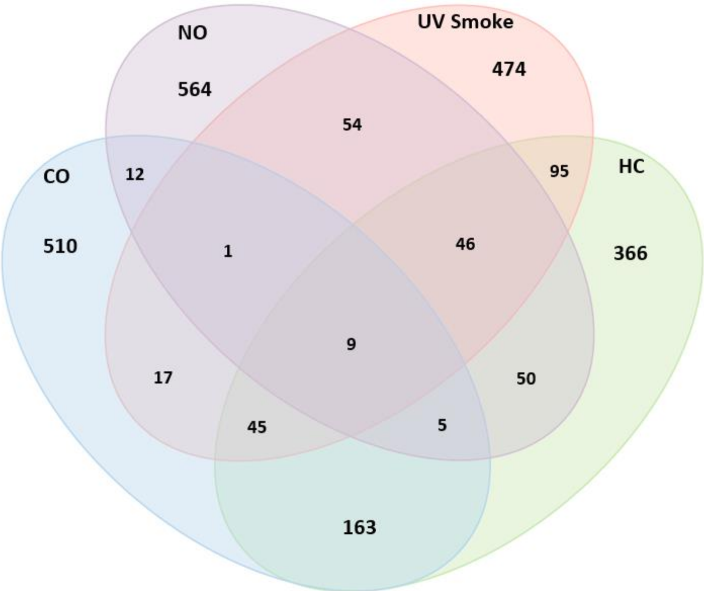

Figure 2: Venn diagram to show crossover of GEVs for the four RSD-measured pollutants

2.2 Repeatability of GEV Measurements

The repeatability of GEV measurements was investigated with the intention of understanding whether vehicles that record an RSD emissions measurement that categorises them as a GEV will consistently produce a similar level of emissions that would be high enough to result in consistent categorisation as a GEV. This gives a useful indication of test to test variability of emissions from GEVs.

For GEVs with more than one valid emissions record, highest emissions values were plotted alongside corresponding second highest emissions records and compared to TEV readings to assess the repeatability of the RSD method for identifying GEVs. The second highest records data set were still significantly higher than the TEV emissions readings.

The data set of second highest emissions records was compared to the absolute emissions value as defined by the 3% cut-off in the 2015 RSD data set. The proportion of second highest records that would still be categorised as GEVs was 25% for CO GEVs, and between 14% and 40% for HC, NO and PM GEVs.

Assessment of GEVs with more than one associated emissions record showed that second measurements for the same vehicle were higher than the majority of

TEV measurements in the fleet indicating that GEVs tend to produce consistently higher emissions measurements. While the second highest measurement from GEVs are frequently below the GEV cut-off value, they are still higher as a group than TEV emissions as shown by a lack of overlap between the interquartile ranges of the two sample groups. Given this result, PDP consider the use of RSD measurements to identify GEVs is a robust and pragmatic method.

2.3 GEV Characteristics

2.3.1 Fuel Type, Vehicle Age, Odometer Reading, and Vehicle Emission Standards

To enable the identification of GEVs in the national fleet, an analysis of the fuel type, vehicle age, odometer reading and emission standards of GEVs in the monitored fleet was undertaken. Each of these four vehicle characteristics were divided into categories, for example two-year age bands (see Figure 3).

To provide a clear visual reference of which categories had higher and lower proportions of GEVs than the wider monitored fleet, the number of GEVs within each category was divided by the total number of vehicles from the RSD data set (the monitored fleet) in each category, and this was compared to the overall proportion of GEVs in the fleet (3%). Figure 3 shows an example of this for vehicle age of CO GEVs. Figure 3 shows that vehicles over 14 years old in the monitored fleet have a higher proportion of CO GEVs than the overall monitored fleet, with the proportion of CO GEVs increasing with age. Conversely, vehicles under 14 years old have a lower proportion of CO GEVs than that seen in the monitored fleet.

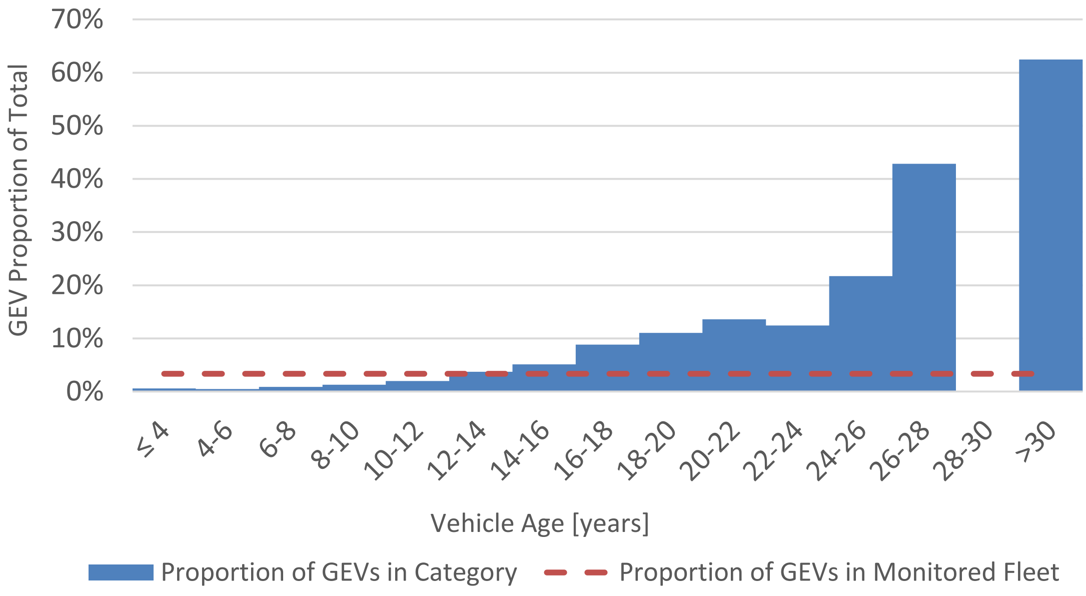

Figure 3: Vehicle Age of CO GEVs

The characteristics and patterns identified for CO GEVs for the four key vehicle characteristics are summarised in Table 2.

Table 2: Patterns in Vehicle Characteristics Identified for CO GEVs

Characteristic	Proportion of CO GEVs lower than monitored fleet	Proportion of CO GEVs higher than monitored fleet	General Pattern
Fuel Type[1]	Diesel	Petrol	
Vehicle Age	Less than 14 years old	Over 14 years old	GEV proportion increases with vehicle age
Odometer Reading	Less than 150,000 km	More than 150,000 km	GEV proportion increases with odometer reading
Emission Standards Categories			GEV proportion reduces with more recent standards

Notes:

1. *Similar trend for CO GEVs and NO GEVs with respect to fuel type. The trend is opposite for PM GEVs (proportion of petrol PM GEVs is lower than monitored fleet, proportion of diesel PM GEVs is higher than monitored fleet). Proportions of petrol and diesel HC GEVs are similar to HC GEV proportion in the monitored fleet.*
2. *Trends were generally consistent for vehicle age, odometer reading, and emission standards categories.*

2.3.2 Identifying Common Characteristics of GEVs

Regression tree analysis (RTA) was applied to identify the vehicle characteristics that had the strongest correlation with GEVs. RTA was used to create tree models for each pollutant which cluster the vehicles into groups or 'nodes' with similar emission values using rules based on the characteristics of the vehicles. Up to 5 nodes were selected from the model for each pollutant based on the highest median emission value of the node and the number of vehicles within the node.

For CO GEVs, 5 nodes were selected which modelled 3.9% of the monitored fleet as GEVs. This group of modelled GEVs included 31% of the vehicles measured as GEVs (correctly modelled GEVs) and 3.4% of the vehicles measured as TEVs.

2.3.3 GEV Rate of Retirement and Annual Travel Distance

The vehicle registration status and updated odometer reading for vehicles in the 2015 RSD data set was accessed in 2018 and appended to the associated records in the data set. Updated information on vehicle registration status was used to find the proportion of vehicles in the GEV and TEV subsets that had become inactive during the three-year time period. Of the vehicles categorised as CO GEVs in 2015, 62% remained active in 2018 indicating a 38% removal of GEVs from the fleet over a three-year period. In comparison, 85% of vehicles categorised as CO TEVs remained active in 2018 indicating a 15% removal of TEVs from the fleet over the same time period.

For HC, NO and PM, 85% of all TEVs remained active in 2018. The proportion of GEVs remaining active was 68% for HC, 64% for NO and 70% for PM. This analysis shows that GEVs are retired at a rate of about 2.5 times more quickly than TEVs over the period 2015-2018.

Updated odometer readings from 2018 were used to calculate the average annual distance travelled (AADT) for each vehicle and the average values for GEV and TEV subsets were compared. GEVs for CO, HC and NO had slightly lower AADT values (~10% lower) than their respective TEVs, whereas PM GEVs travelled slightly further (~5% higher) than PM TEVs as an annual average.

2.4 Identifying the number and regional distribution of potential GEVs in New Zealand's vehicle fleet

The GEVs characteristics identified by the work summarised in Section 2.3.2 were used to identify the number and regional distribution of potential GEVs in New Zealand's vehicle fleet.

The MVR for the entire national fleet as at December 2019 was filtered to isolate records for light duty vehicles (LDVs). This resulted in a data set containing 3.6 million records. The monitored fleet GEV characteristics were used to identify potential GEVs within the national fleet of LDVs. The number of vehicles identified as potential GEVs for each pollutant is shown in Table 3 along with the proportion of the national LDV fleet that this number represents and the corresponding proportion of the 2015 RSD-monitored fleet that was identified as potential GEVs using the same vehicle characteristics.

Table 3: Proportion of National Fleet Profiled as GEVs

Pollutant	Profiled GEVs		
	National Count	% of National Fleet[1]	% of 2015 RSD Data Set
CO	84,416	2.3 %	3.9 %
HC	61,730	1.7 %	3.3 %
NO	76,538	2.1 %	3.1 %
Particulate Matter	42,144	1.2 %	2.3 %

Notes:
1. *Total population size of 3,610,504.*

Vehicles from the national fleet were categorised by region and district (territorial land authority, TLA). The proportion of potential GEVs by region and district was calculated and these were plotted on heat maps to show the spatial distribution of vehicles identified as potential GEVs. The regional heat map for CO is shown in Figure 4. The numbers show the potential GEVs in each region, with colours representing the proportion of registered vehicles modelled as GEVs. Proportions of potential GEVs for regions at the highest and lowest ends of the scale are also notated alongside the potential GEV count.

The higher proportions of CO GEVs in Gisborne, Northland and the West Coast followed by middle proportions in the central North Island generally align with lower gross domestic product (GDP) per capita values, indicating a less affluent population[2]. Vehicle characteristics identified for CO GEVs include older vehicles and high odometer readings which are vehicle properties likely to be more prevalent in communities with lower income levels.

For all pollutants assessed, Auckland and Wellington regions have consistently lower proportions of potential GEVs compared to the rest of the country. Northland Regional Council consistently has one of the highest proportions of potential GEVs and West Coast Regional Council has a high proportion of potential GEVs for all pollutants except NO.

Although the proportions of GEVs in urban centres are often lower than those seen in the rest of the country, the corresponding number of vehicles is higher due to the density of vehicles in the urban centres. For example, although Auckland Region has one of the lowest regional proportions of potential CO GEVs in the country at 2.1%, it also has the highest number of potential GEVs at 24,729. Conversely, the highest proportion of potential CO GEVs is seen in Gisborne Region at 3%, but this is representative of under 1,000 vehicles.

Heat maps showing modelled GEVs by TLA show that there is significant variation of potential GEV proportions between districts.

Historical odometer readings were used to calculate the AADT for all vehicles in the national fleet which allowed for comparison of the AADT for GEVs and TEVs on a national and regional level. Vehicles identified as potential GEVs had a consistently higher AADT than those categorised as potential TEVs for all pollutants. This finding was inconsistent with that from the monitored RSD data set for CO, HC and NO GEVs which suggested AADTs of these GEVs was slightly lower than TEVs.

[2] Stats NZ. (2018) *Regional gross domestic product: Year ended March 2018.*

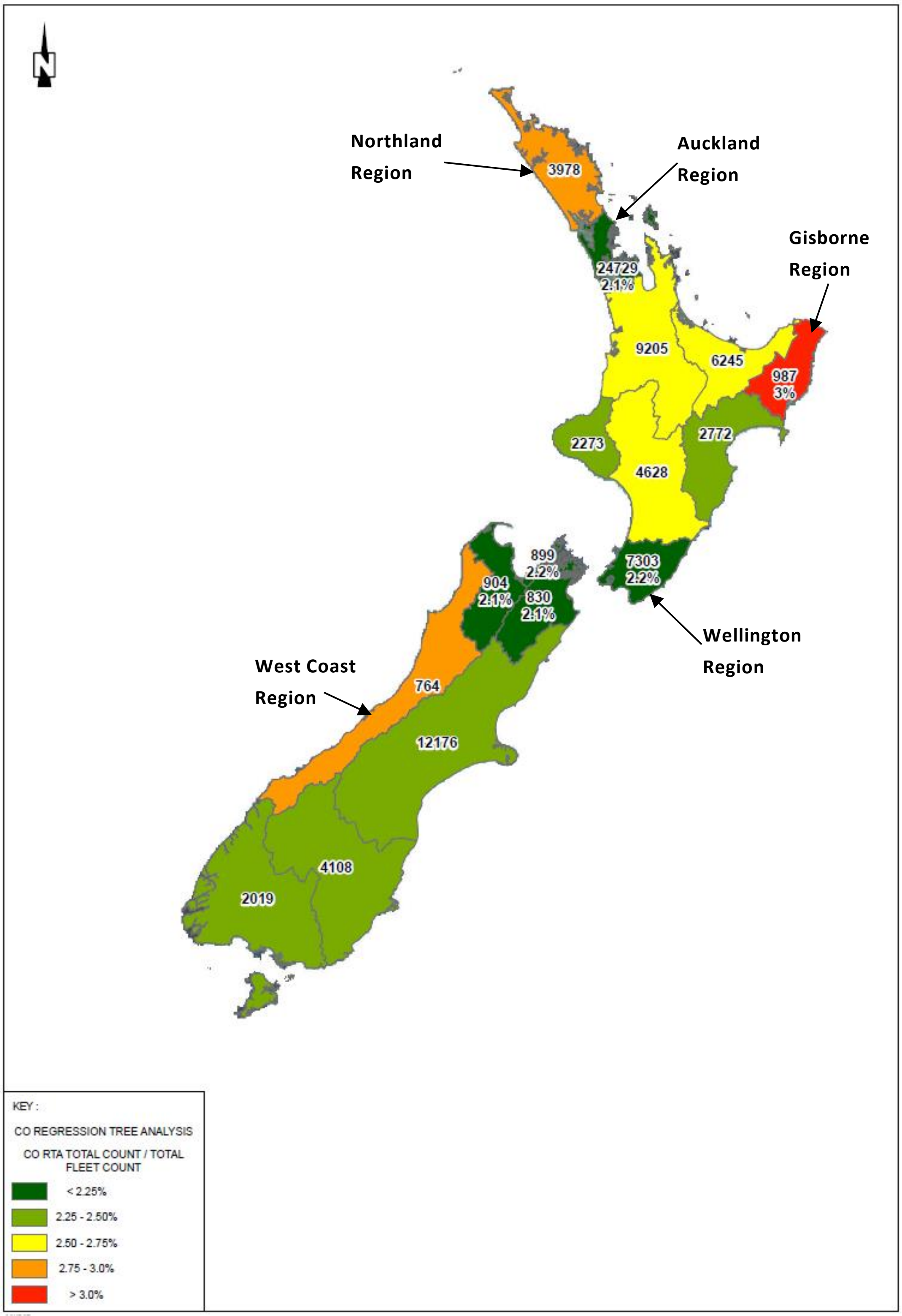

Figure 4: Number and proportion of potential CO GEVs by region

3.0 Stage 2: Impact of GEVs and Potential Emission Reduction Benefits

3.1 RSD Measurements of GEVs Compared to the Wider TEV Fleet

Emissions readings from vehicles classified as GEVs and TEVs were plotted alongside each other and showed a statistically significant difference between GEV and TEV subsets as shown for CO in Figure 5. The mean values are both higher than the median values. This indicates there are more vehicles with low emissions records than very high emissions records and that the frequency distributions for each of the data subsets are skewed to the right.

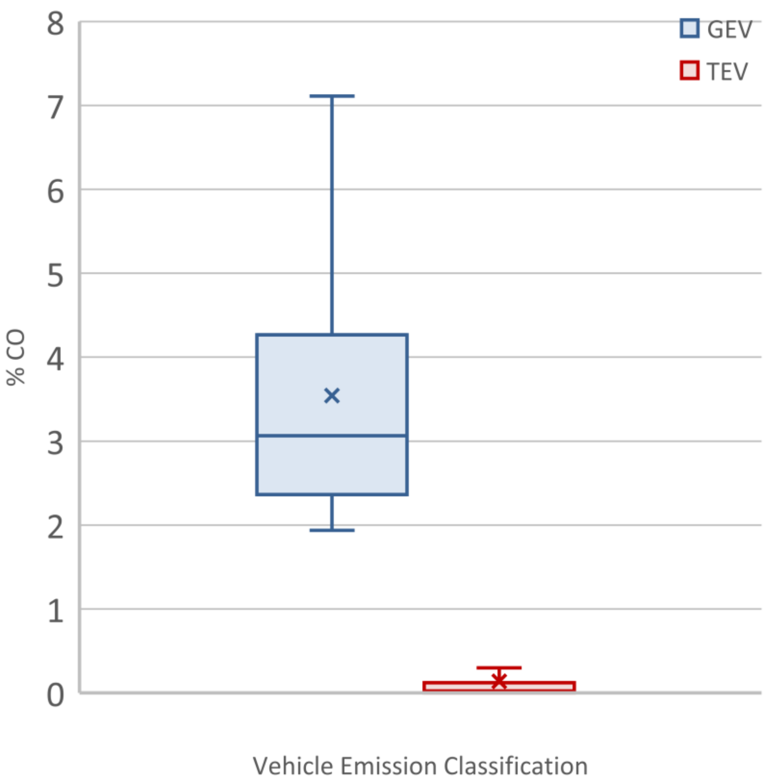

Figure 5: CO emissions from GEVs and TEVs (2015 RSD Data Set)

The HC, NO and PM emissions readings all show a statistically significant difference between GEV and TEV readings and all of the groups also display the same right-skewed behaviour with mean values higher than the respective median and a higher number of low emissions records than very high emissions records.

3.2 Potential Emission Reduction Benefits of GEV Replacement

RSD emissions measurements were used to assess the impact of GEV emissions. This involved the calculation of an emission factor in grams of pollutant per kilogram of fuel for each vehicle[3] from the RSD data. These emission factors were then combined with fuel efficiency data from the Vehicle Fleet Emissions Model (VFEM) and AADT values to estimate the annual emissions for each vehicle in grams of pollutant per year. Figure 6 shows the estimated annual CO emissions from CO GEVs and CO TEVs as recorded in the 2015 RSD data set.

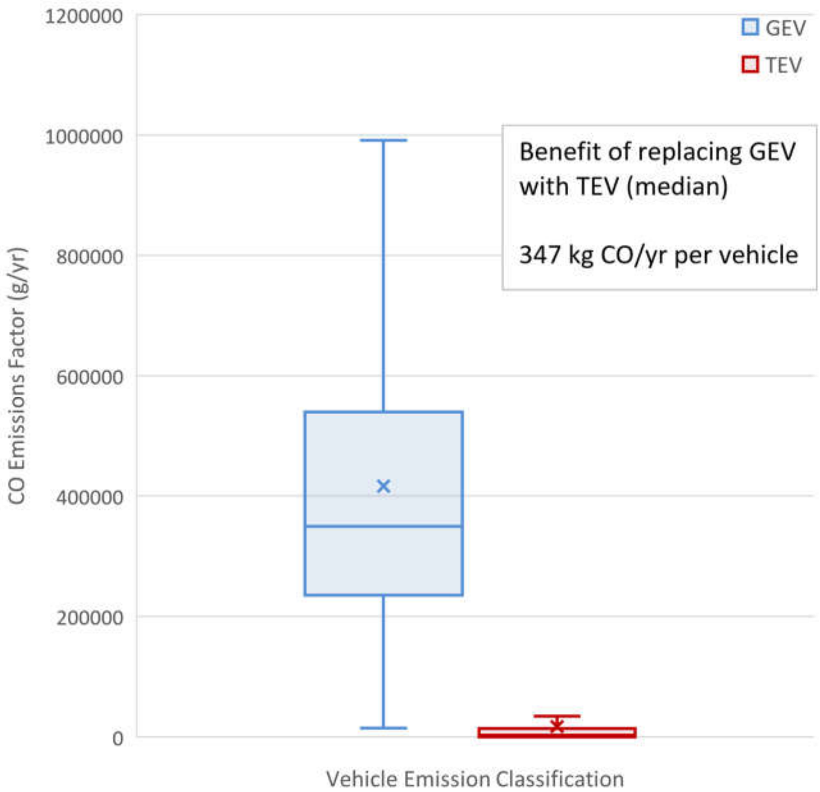

Figure 6: Estimated annual emissions of CO GEVs and TEVs

The average potential emission reduction benefit of removing a GEV from the fleet and replacing it with a TEV was calculated by the difference of the median value from each subset.

The difference between the median annual emissions for GEVs and TEVs is 347 kilograms of CO per year (kg CO/yr) per vehicle. This provides an estimated

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[3] Method used as described in Golder Associates (New Zealand) Limited. (2018). *Assessing the Impact of Gross Emitting Vehicles (Appendix A: RSD Measurements to Emission Factors).*

annual emissions reduction benefit for replacement of a single CO GEV in the fleet.

The calculated value for replacement of a single vehicle was scaled to provide an estimate of the potential emissions reduction benefit of replacing the top 3% of emitters from the national fleet. This was calculated as over 108,000 GEVs. It is noted that identification and immediate replacement of all of these vehicles would be very unlikely due to the difficulty in accurately identifying them all and the high associated replacement costs.

This analysis shows that placing a single GEV from the fleet with a TEV provides a significant emission reduction benefit and that this benefit would be amplified if all GEVs were removed from NZs vehicle fleet. The analysis of the regional distribution of GEVs suggests that there may be an argument to support geographically targeted approach to regulating GEVs.

The potential annual emissions reduction benefits for replacing a single vehicle and all GEVs nationally for each of the pollutants are shown in Table 4.

Table 4: Potential Annual Emissions Reduction Benefits

Pollutant	Annual Emissions Reduction Benefit	
	Per Vehicle	All GEVs in National Fleet[1]
CO	347 kg CO/yr	37,500 tonnes CO/yr
HC	22.7 kg HC/yr	2,500 tonnes HC/yr
NO	42.6 kg NO/yr	4,600 tonnes NO/yr
NO_2	4.8 kg NO_2/yr	520 tonnes NO_2/yr
Particulate Matter	485 g PM/yr	53 tonnes PM/yr

Notes:
1. *Based upon national fleet of 3.61 million and 3% GEVs totalling 108,300 vehicles*

4.0 Achievement of Project Objective and Completion of Tasks

The objective of this project was to determine the impact of GEVs on emissions of pollutants harmful to human health from the vehicle fleet across New Zealand. The following issues were investigated:

- Prevalence of GEVs:
  - What proportion of the fleet are potentially GEVs?
  - How long do GEVs remain in the fleet?
  - What distance do GEVs typically travel in a year?
  - What is the regional distribution (geographical spread) of GEVs?
- Determination of replicability of GEV results;

- Determination of the potential impact of GEVs compared to emissions from the wider light duty vehicle (LDV) fleet; and
- Estimation of the emission reduction benefit of removing GEVs from the fleet.

The project was undertaken in two stages. A summary of findings from these is provided in the preceding sections of this report. The summary of findings from the study demonstrates that the objective of this project has been met and the investigation of targeted issues successfully completed.

5.0 Recommendations for Future Work

During this project, PDP and the external peer reviewer identified a number of questions which, if investigated, would provide additional insight into the impacts and management of GEVs and therefore add value to the outcomes of this study. Using this experience, PDP recommend that future work programmes consider the following tasks:

- Analyse the impact on emissions of vehicle age, odometer reading and emission standards separately for petrol and diesel vehicles. This could confirm and refine some of the findings of the current project;
- Develop a method for characterisation of GEVs/vehicle emissions that addresses the potential for non-independence of predictor variables. For example, if using vehicle age and emission standards as separate predictor variables, allowance should be made for the relationship between older emission standards and higher vehicle ages. A similar relationship is likely between high vehicle ages and high odometer readings;
- Conduct a more detailed investigation to confirm the finding that GEVs travel further each year than TEVs;
- Consider the impact of vehicle specific power (VSP) as measured by the RSD on GEVs;
- Assess the relative health benefits of GEV removal programmes which would target GEVs of specific pollutants, i.e. CO vs HC vs NO vs PM;
- Undertake a cost benefit analysis of replacing GEVs with TEVs;
- Review the Vehicle Emission Prediction Model to check that the model appropriately considers the impacts of GEVs on fleet average emissions;
- Investigate the potential benefits of a geographically targeted approach to regulating GEVs which considers, for example, the impact of districts with a relatively high proportion but a low number of GEVs;

- Engage policy analysts to assess if managing 3% of the LDV fleet as GEVs is practical and enforceable;
- Review vehicle inspection and maintenance (I/M) programmes (e.g. Warrant of Fitness) in NZ to identify if these could be potentially used to confirm and enhance the findings of this project;
- Consider the potential implications of the findings of this project on the heavy-duty vehicle fleet;
- Investigate any trends in GEVs by repeating and comparing the GEVs analyses undertaken in this report on an earlier RSD data set, e.g. 2009 vs 2015;
- Compare the findings of this study with international investigations on GEVs; and
- Consider if the RSD database may potentially be useful in assessing the impacts of GEVs on emissions of greenhouse gases from LDVs.