Government of **Western Australia**
Department of **Water and Environmental Regulation**

CleanRun

Let's drive down emissions

CleanRun On-Road Vehicle Emissions Monitoring

2017

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Department of Water and Environmental Regulation

July 2018

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Acknowledgements

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Contents

Figures

Tables

Summary

What we did

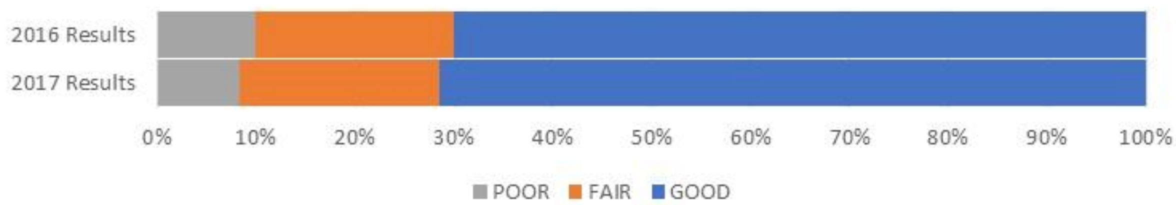
The Department of Water and Environmental Regulation (DWER) has completed a vehicle emissions monitoring campaign for 2017. The goal of monitoring was to assess the health of Perth's vehicle fleet.

Monitoring was completed using a Remote Sensing Device (RSD). The RSD measures emissions of carbon monoxide, nitrogen oxide, hydrocarbons and smoke as vehicle pass by. A smart sign provides simple and immediate feedback to drivers, advising them of their vehicle's performance.

Emissions were measured at six different locations between November and December 2017 with 19,000 valid samples collected for analysis. The monitoring campaign was planned to ensure the data collected was representative of the wider Perth fleet.

What we found

Overall, vehicle emissions measured in 2017 improved compared to 2016 and earlier monitoring. Gradual improvements in vehicle emissions have been observed each year as older vehicles are retired and replaced by vehicles using cleaner technologies.

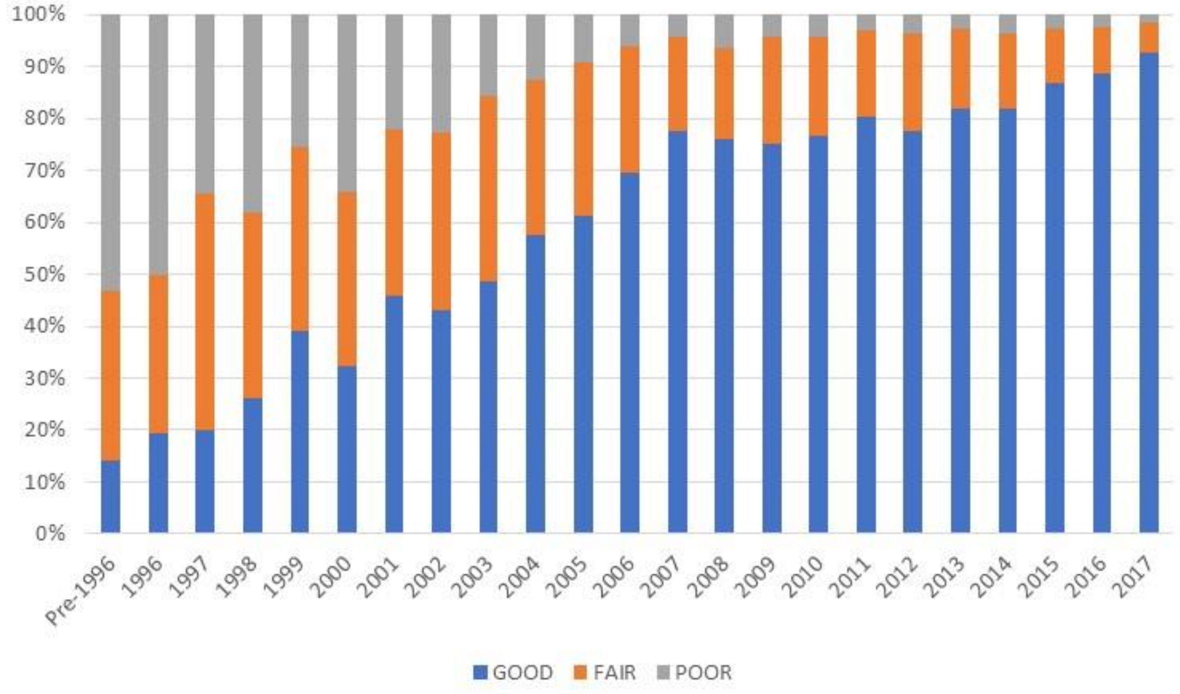


2017 Smart sign results. Improvement in fleet emissions can be seen with the proportion of vehicles rating GOOD being higher and the proportion of vehicles rating 'Poor' being lower in 2017 compared to 2016

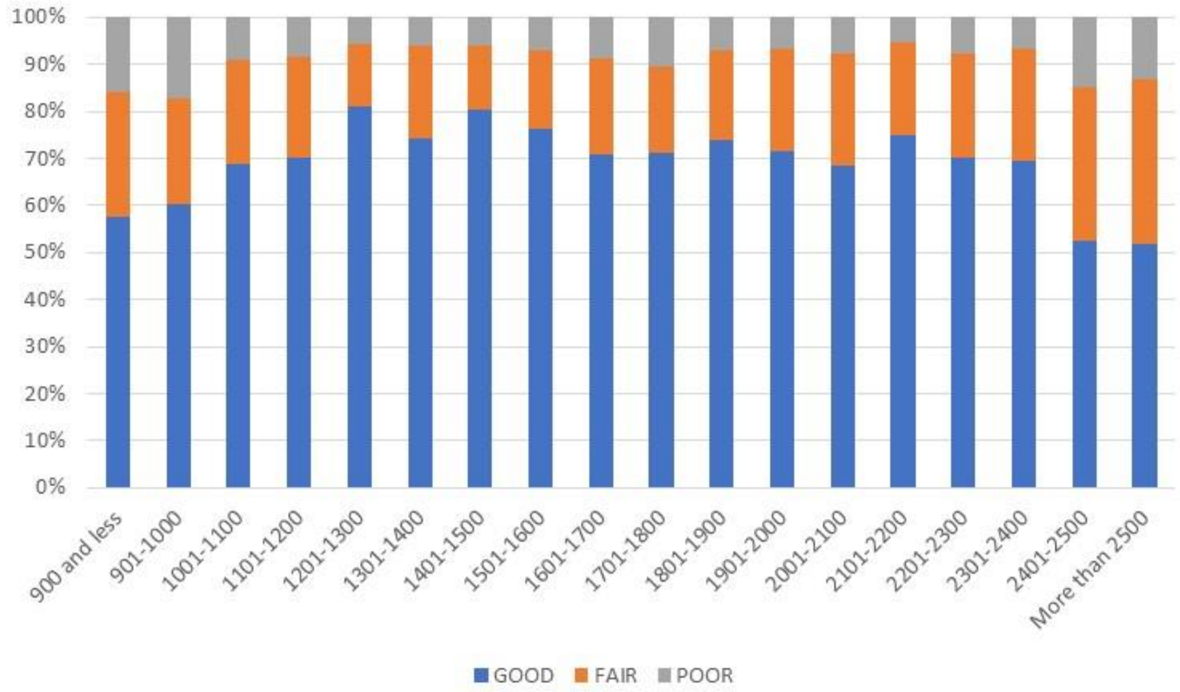
Of the pollutants measured, only hydrocarbons were found to be slightly higher than in 2016. Fuel companies are required to manage the Reid Vapour Pressure (RVP) of petrol to reduce evaporative emissions during summer months. The 2016 monitoring campaign was undertaken between March and April when fleet petrol is more likely to have a lower RVP compared to November and December.

Liquid petroleum gas (LPG) vehicles as a group show continual increases in emissions since 2014, which is likely due to the LPG fleet aging. Unlike petrol and diesel vehicles, there are few new LPG vehicles introduced to the market each year. LPG vehicles are the overall worst performing in the fleet for emissions, significantly more so than petrol or diesel vehicles.

The lightest vehicles in the fleet, notably vehicles weighing less than a tonne, were also observed to be producing higher emissions than expected. It is speculated that cheap entry level cars may be deteriorating more quickly than heavier cars with a higher build quality. Mechanical assessment data would be needed to test this assumption.



2017 Smart sign ratings for vehicles by year of manufacture



2017 Smart sign ratings for vehicles by tare weight (kg) range

1 Introduction

The Department of Water and Environmental Regulation's (DWER) CleanRun program operates an Accuscan 4600 Remote Sensing Device (RSD) that monitors the exhaust emissions of passing vehicles. The operation of this device forms part of the Department's commitments to the National Environment Protection (Diesel Vehicle Emissions) Measure (Diesel NEPM) and the Perth Air Quality Management Plan (Perth AQMP).

The Department deployed the RSD at six sites across the Perth metropolitan area in November and December 2017. During this time, each site was monitored over a two day period.

Remote sensing of vehicle emissions provides the Department with an efficient way to characterise the Perth vehicle fleet. The RSD is set up on a roadside and captures the emissions data of passing vehicles with no impact to traffic flow or typical vehicle performance. Photographs capture the vehicle registration number, allowing vehicle registration information to be extracted from the Department of Transport (DoT) database.

Analysis of emissions data together with vehicle information allows the Department to determine how vehicles are performing and how vehicle emission performance varies according to age, make, model and fuel type. This data can then be used to inform policy decisions on vehicle regulation.

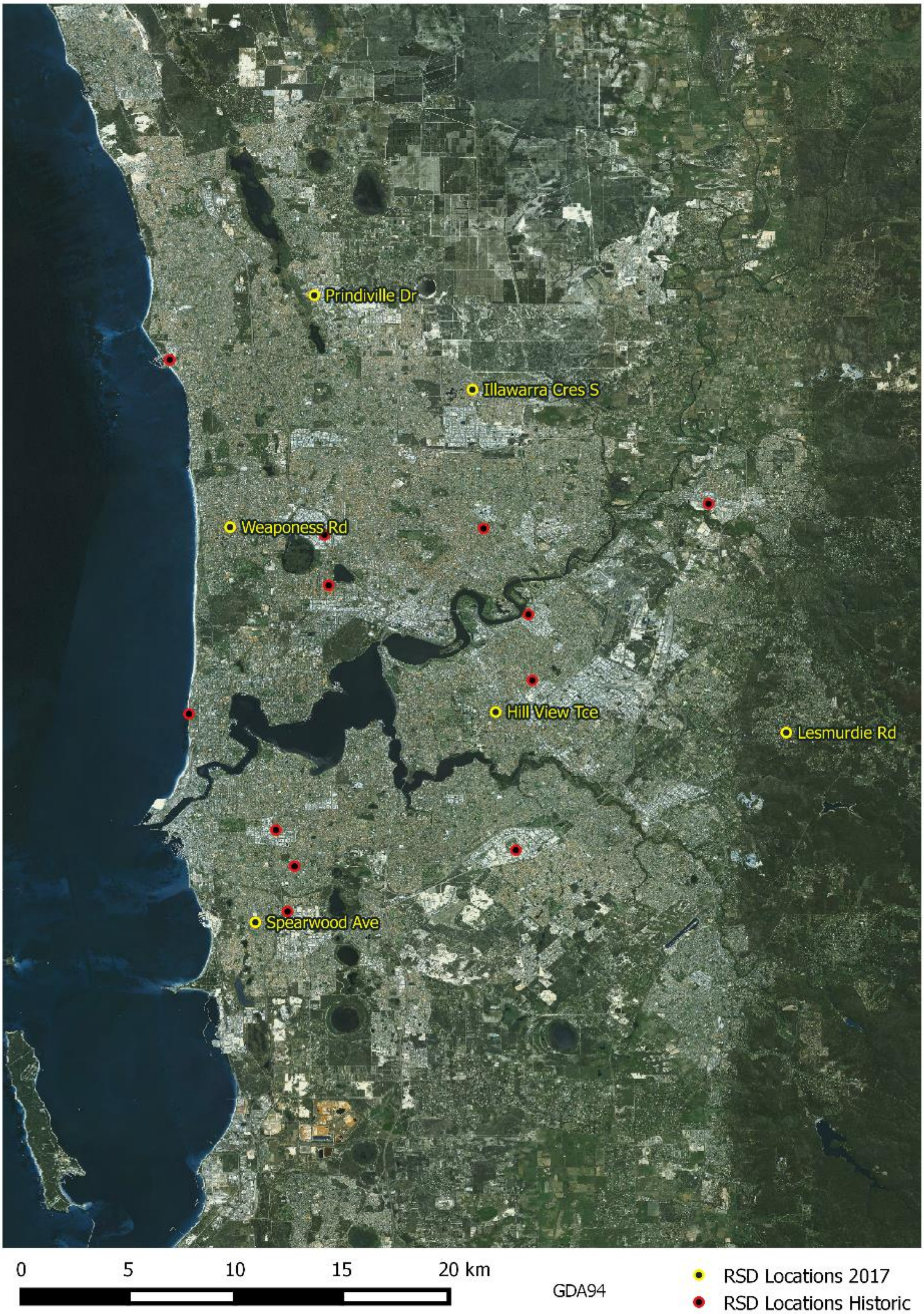


Figure 1: RSD monitoring locations

2 Equipment and method

2.1 Remote sensing device

The RSD measures the following exhaust pollutants:

- carbon monoxide (CO) as a percentage of exhaust volume
- nitrogen oxide (NO) as parts per million (ppm)
- hydrocarbons (HC) as parts per million (ppm)
- particulates (UV smoke) as a percentage of exhaust opacity.

The RSD measures exhaust gases by sampling gas conditions in the air in front of a vehicle (taken as the ambient condition or baseline) before sampling the gas conditions at the rear of a vehicle. The difference between the two conditions represents the emissions of the vehicle.

The RSD source/detector is set up on a roadside to project light (infrared and ultra violet) across the road to a reflector cube (Figure 2). The light reflected back to the RSD is partly absorbed by the vehicle exhaust and allows emissions to be calculated.

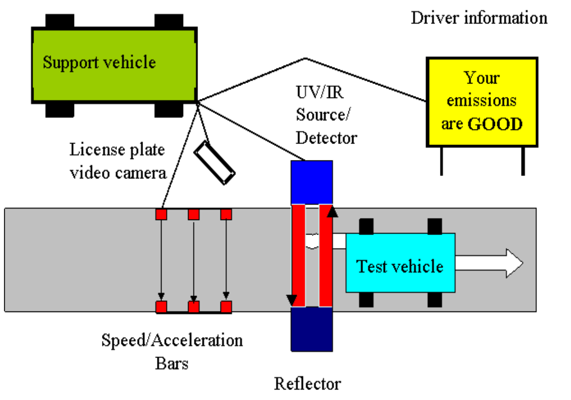


Figure 2: Schematic diagram of the RSD monitoring equipment[1] (left) and RSD source/detector and reflector in operation (right)

A sample is captured by the RSD when a vehicle passes the speed/accelerator bars triggering the source/detector to take the initial sample. To trigger sampling, vehicles must be under load when passing through the RSD, which is determined by calculating the vehicle specific power (VSP). VSP is calculated by the RSD using the:

- vehicle acceleration
- vehicle velocity
- road gradient.

[1] Bluett, J., Dey, K., Fisher, G. (2008) *Assessing Vehicle Air Pollution Emissions*. Prepared for the Department of the Environment, Water, Heritage and the Arts by the National Institute of Water and Atmospheric Research Ltd (New Zealand).

As the vehicle is leaving the speed/accelerator bars, it will break the RSD light beam. The RSD will record the ‘front of vehicle’ gas concentrations just before the light beam is broken. Once the vehicle passes though the RSD, the light beam is re-established and the RSD records 50 ‘rear of vehicle’ samples over half a second (one every 10 milliseconds). If five or more samples are valid, the average is taken of all valid samples and logged.

Following the triggering of the RSD sample, a camera records the rear registration plate of the vehicle. This allows the vehicle specific data from the DoT database to be entered into the data log after the sampling.

If the sample speed, acceleration and VSP measurements are valid, and the RSD successfully measures the front and rear of vehicle gas conditions, the test is assigned a valid sample flag in the data log.

2.2 Smart sign

The CleanRun smart sign provides immediate feedback to the driver about their vehicle emissions performance. The display presents one of the three options:

Your vehicle emissions are **GOOD** ☺ = saving $$$

Your vehicle emissions are **FAIR** 😐 = costing $$$

Your vehicle emissions are **POOR** ☹ = costing $$$

Figure 3: CleanRun smart sign vehicle emissions performance feedback display

The score that appears on the smart sign is the lowest from all tested emissions. If any substance is rated as ‘Poor’, the vehicle receives a ‘Poor’. Similarly, if any substance is rated ‘Fair’, the vehicle gets a ‘Fair’. Only if all measured substances receive a ‘Good’ rating will the vehicle be rated as ‘Good’.

Cut points entered into the RSD are used to determine the ‘Good’, ‘Fair’ or ‘Poor’ results of the vehicle and are based on the emissions performance of the vehicle fleet from the previous deployment. The cut points for the 2017 campaign were based on the results from the 2016 campaign and are presented in Table 1.

Table 1: Smart sign cut points

Emission category	Good	Fair	Poor
Carbon monoxide (CO) %	<0.292	0.292–1.048	>1.048
Hydrocarbons (HC) ppm	<63	63–316	>316
Nitrogen oxide (NO) ppm	<840	840–1435	>1435
UV smoke (PM) %	<0.160	0.160–0.401	>0.401

A review of the smart sign cut points has been undertaken to account for changes in the vehicle fleet over time. New cut points for future monitoring are summarised in Appendix A.

3 Data collection

3.1 Site selection

The RSD requires specific conditions to operate effectively. An ideal monitoring location has the following characteristics:

- a single lane road
- a median strip for equipment placement
- a road gradient greater than two degrees (that is the road is sloped upwards)
- north-south alignment to minimise glare in number plate photographs
- adequate verge space for equipment trailer, camera, and the smart sign
- traffic flow of between 300 and 1,000 cars per hour.

Other important considerations include selecting sampling sites that:

- are representative of Perth's vehicle fleet
- provide for operator safety
- do not negatively impact on traffic flow and driver safety
- avoid sprinkler and bin collection days in residential areas.

The sites selected for the 2017 campaign were a mix of repeat and new sites. Weaponess Road, Illawarra Crescent South and Prindiville Drive were selected to collect data at the same location over multiple years. Hill View Terrace, Spearwood Avenue and Lesmurdie Road were new sites selected to improve the coverage of RSD sampling over the Perth metropolitan area.

Selected site characteristics are summarised in Appendix B.

3.2 RSD deployment

The RSD was deployed two days a week over six consecutive weeks. Deployments were scheduled for Tuesday and Wednesday.

The equipment was calibrated and operational by 7 am on most mornings. The RSD was re-calibrated between 10 am and 11 am depending on traffic conditions. Monitoring was completed around 2 pm on most days. This time range was sufficient to capture morning peak traffic as well as midday traffic movements.

A 40 kilometres per hour (km/h) speed limit and a traffic cone 'funnel' was established before the equipment to encourage vehicles to accelerate past the RSD source/detector unit.

3.3 RSD data capture

Each monitoring location performed differently according to local traffic flow and features of the site. Vehicles passing had to have both a positive VSP value and a valid gas sample taken for a sample to be accepted.

In addition to having a valid sample, each vehicle required a readable number plate in the photograph taken. Number plates were verified by the DoT vehicle database. Additional samples were lost because of transcription and readability errors.

Vehicle samples that met these checks were included in the analysis. Table 2 details data capture and attrition rates resulting from data validation checks at all sites. The totals from 2016 are also presented for comparison.

Table 2: Data capture and attrition rates

2017 Sites	Total samples	Valid VSP	Valid gas	Valid samples	Valid plates	Verified plates
Hill View Tce 14 and 15 November	3756	3670	2563	2504	2385	2297
		97.7%	68.2%	66.7%	63.5%	61.2%
Weaponess Rd 21 and 22 November	7127	6966	5564	5441	5138	4987
		97.7%	78.1%	76.3%	72.1%	70.0%
Spearwood Ave 28 and 29 November	4716	4559	3827	3713	3449	3366
		96.7%	81.1%	78.7%	73.1%	71.4%
Illawarra Cr S 5 and 6 December	3335	3293	2605	2572	2222	2113
		98.7%	78.1%	77.1%	66.6%	63.4%
Lesmurdie Rd 12 and 13 December	3308	3035	2658	2443	2255	2224
		91.7%	80.4%	73.9%	68.2%	67.2%
Prindiville Dr 19 and 20 December	5543	5457	4482	4411	4159	4060
		98.4%	80.9%	79.6%	75.0%	73.2%
Total (2017)	**27785**	**26980**	**21699**	**21084**	**19608**	**19047**
		97.1%	**78.1%**	**75.9%**	**70.6%**	**68.6%**
Total (2016)	**29725**	**29019**	**23619**	**23078**	**21136**	**20431**
		97.6%	**79.5%**	**77.6%**	**71.1%**	**68.7%**

VSP capture rate

Valid VSP measurements are reliant on vehicles having sufficient speed and acceleration relative to the road slope.

The high VSP capture rates at all locations confirm the sites selected had conditions that encouraged vehicles to accelerate through the RSD. However, a lower VSP capture rate at Lesmurdie Road was attributed to vehicles not slowing down sufficiently before passing the RSD and ‘coasting’ through rather than accelerating, as evidenced by average speed and acceleration data in Appendix B.

Gas capture rate

Valid gas measurements depend on environmental factors, equipment setup, and vehicle operation.

It is believed the primary cause of data loss was from plume variability. Vehicle exhaust release height varies depending on the type of vehicle, with exhaust plume dispersion influenced by the:

- exhaust temperature
- ambient temperature
- humidity
- winds.

The RSD beam is fixed at a height of approximately 30 cm above road surface to optimise capture of a range of vehicle exhaust release heights. It is noted the gas capture rate is broadly consistent with 2016 sampling (approximately 20 per cent loss).

While equipment setup may have contributed to some of the gas data loss, the equipment setup was calibrated within the required operational parameters, and is generally considered an insignificant influence. However, poor gas capture rate at Hill View Terrace is believed to have been influenced by an unbalanced reflector cube setup, resulting in poor signal quality.

Number plate capture rate

Number plate details are captured by a camera for each sample. RSD operators review photos and enter the number plate against each sample taken. Data loss occurs when:

- a number plate is unreadable due to glare, dirt and obstructions
- transcription errors from misreading photo or mistyping
- the number plate record is missing from the DoT database.

The lowest number plate capture rate occurred at Illawarra Crescent South. The number plates of 14 per cent of valid samples at this site were unreadable due to morning glare.

Data loss resulting from transcription errors and missing records in the DoT vehicle database ranged from 1 to 3.2 per cent.

3.4 Vehicle database query

Valid number plate samples were compiled and queried using the DoT vehicle database. Samples with valid number plates had the following vehicle data fields from DoT added to the RSD measurements:

- make

- model;
- body type
- tare weight
- year of manufacture
- fuel type
- number of cylinders
- transmission (automatic or manual)
- suburb of registration.

These fields, in conjunction with the emission data collected by the RSD, were used to undertake a vehicle fleet health check and identify any vehicle groupings that were producing significant emissions relative to the rest of the fleet.

4 Results

4.1 Fleet representation assessment

A comparison was made between the sampled fleet and the Perth metropolitan fleet to assess how representative the sampled vehicle fleet was of the wider Perth vehicle fleet.

DoT provided whole of state vehicle data which was filtered to meet the following criteria:

- vehicles registered to a postcode in the Perth metropolitan area
- vehicles that combust fuel as their primary power source
- vehicles with a body type that can be sampled by the RSD.

The postcodes and body types used to filter the entire fleet data for comparison with the sample data are presented in Appendix C.

Assessments of vehicle weight range, age, fuel type and body type are presented for all samples in Figure 4.

Site specific comparisons of sampled vehicles to the Perth fleet are presented in Appendix B.

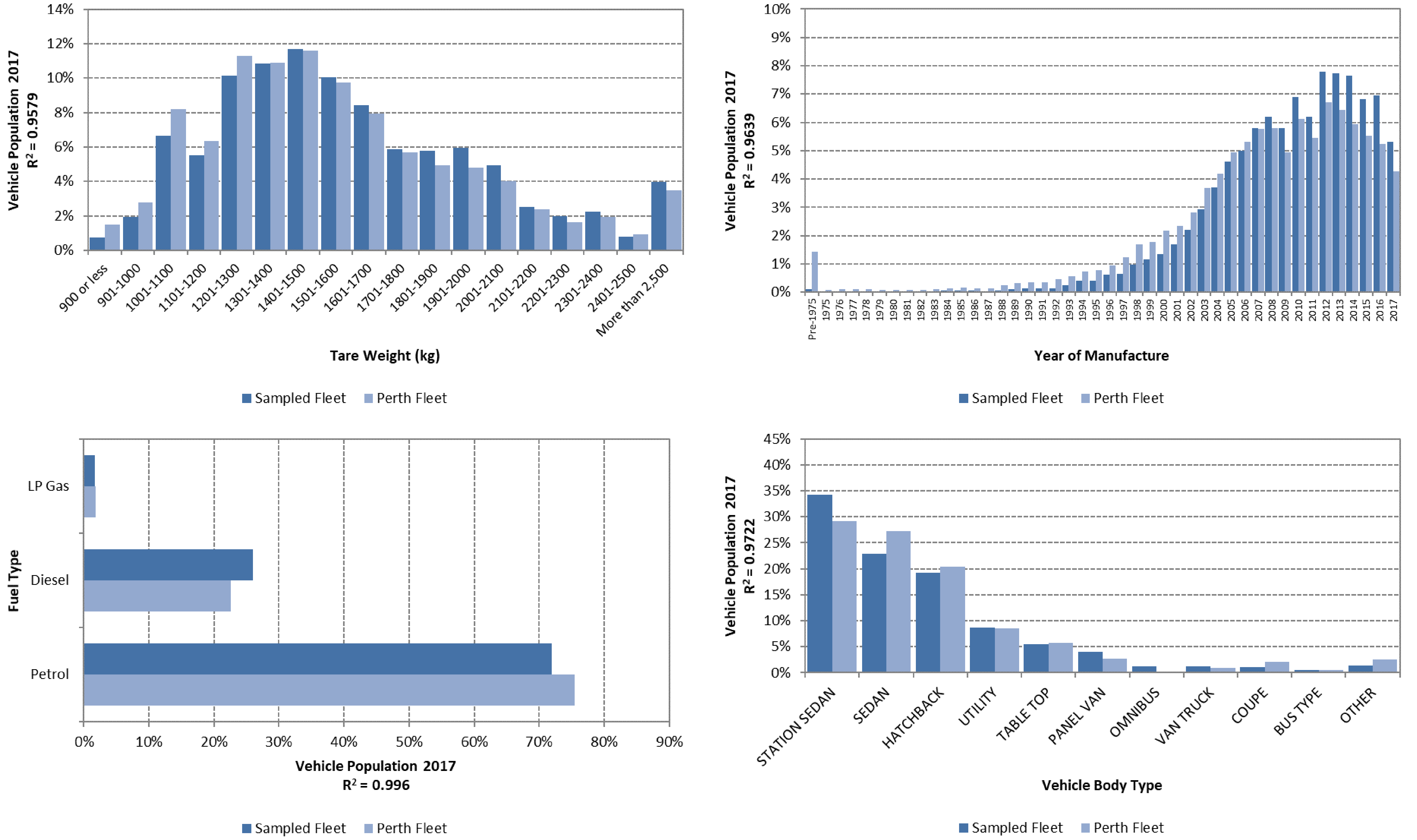


Figure 4: Sampled fleet vehicle data comparison to 2017 Perth fleet

Sampled vehicles had a comparable vehicle weight distribution to the Perth fleet.

On average sampled vehicles were two years younger than the Perth fleet. The Perth fleet had a significantly larger proportion of pre-1975 vehicles compare to sampled vehicles. The difference between sampled and fleet data is reduced to one year when pre-1975 vehicles are removed from the analysis. Several explanations exist for this but the most likely reasons are considered to be:

- Older vehicles registered by DoT but not active on the roads. Examples include racing and recreational vehicles, vintage and classic cars.
- Older vehicles generally spend significantly less time on the road and travel far less compared to newer vehicles.[2]
- Sampling site selection (see Appendix B for data):
    - Weaponess Road had substantially more vehicles represented in the 2009 and newer age groups than other sites. This was attributed to relative affluence of the area
    - Prindiville Drive were over-represented with 2010 and newer models. This was attributed to the proximity of several car sale yards in the vicinity of both sites
    - no sites demonstrated a significant over-representation of older vehicles.

Petrol vehicles were proportionally under-represented while diesel vehicles were under-represented in the sampled vehicle population.

Body type data shows ‘station sedan’ vehicles were over-represented, while ‘sedan’ vehicles were under-represented. No other significant differences were observed between the body types of sampled vehicles and the Perth fleet.

Overall, the sampled fleet was broadly representative of the Perth fleet. This is evidenced by high correlation values (between 0.9579 and 0.996). While there is a difference in the average fleet age, it is assumed sampling was representative of the Perth fleet that is routinely active. This is because all sites show bias towards new vehicles and also a bias away from older vehicles. The petrol and diesel variance may influence analysis of pollutants sensitive to the combustion of those fuel types. Care should be taken when interpreting data relative to station sedan and sedan body types.

[2] UniQuest (2014) *Australian Motor Vehicle Emission Inventory for the National Pollutant Inventory (NPI)*. Prepared for Department of Environment 2 August 2014: www.npi.gov.au/system/files/resources/e8311456-8a41-4473-9fa1-d2f9994ff8da/files/australian-motor-vehicle-emissions-inventory-2014_0.pdf

4.2 Vehicle speed assessment

The RSD setup had a speed control of 40 km/h. However, vehicles passing through were travelling at a range of speeds. The distribution of speed, presented in Figure 5, shows most vehicles were travelling between 30 and 45 km/h through the RSD.

The 2017 vehicle speed distribution is comparable to the average distribution of all monitoring done to date. This is important as a significant difference between campaign vehicle sample speeds and historic vehicle sample speeds would limit comparisons to historic emissions data. If the sampling speed distribution is ‘faster’ than the norm then emissions will be skewed upwards.

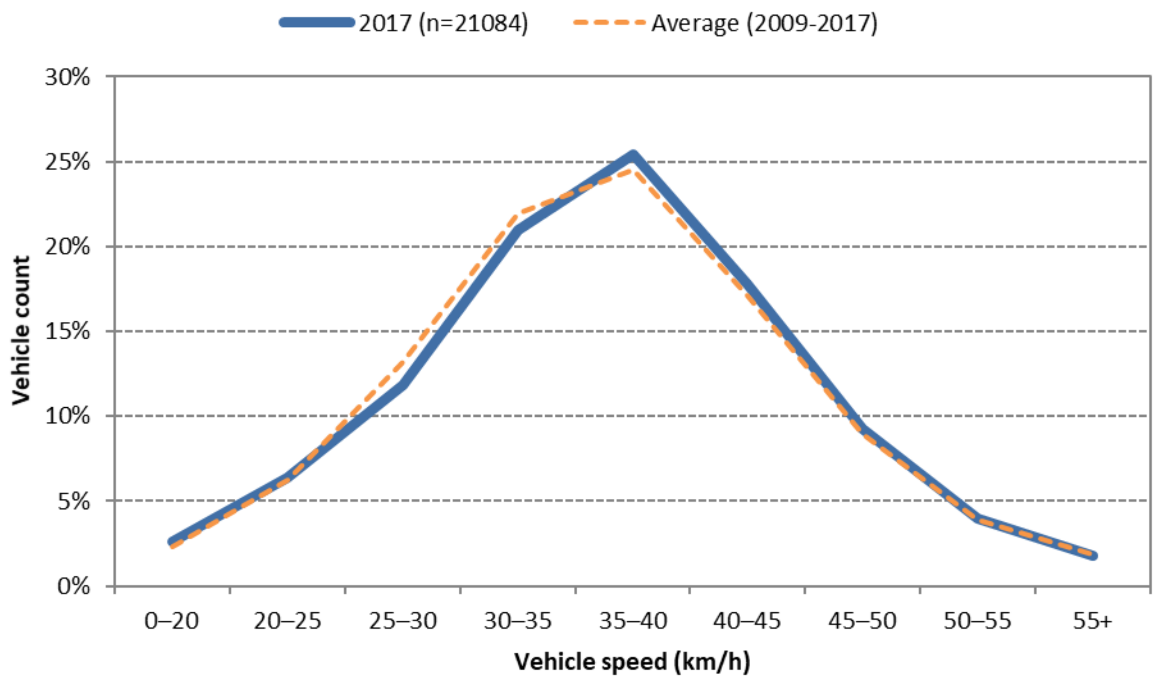


Figure 5: Vehicle counts by speed

Median emissions for CO, HC, NO and smoke are presented in Figure 6. Sampling data from the 2009–10, 2014, 2016 and 2017 RSD campaigns have been presented for comparative purposes.

The overall trend observed is emissions increase with speed.

Both CO and NO emissions from speed groups above 30 km/h are shown to be trending downwards since sampling began in 2009, with the only exception being NO at speeds above 55 km/h. HC and smoke emissions for 2017 are higher in nearly all speed groups compared to 2016.

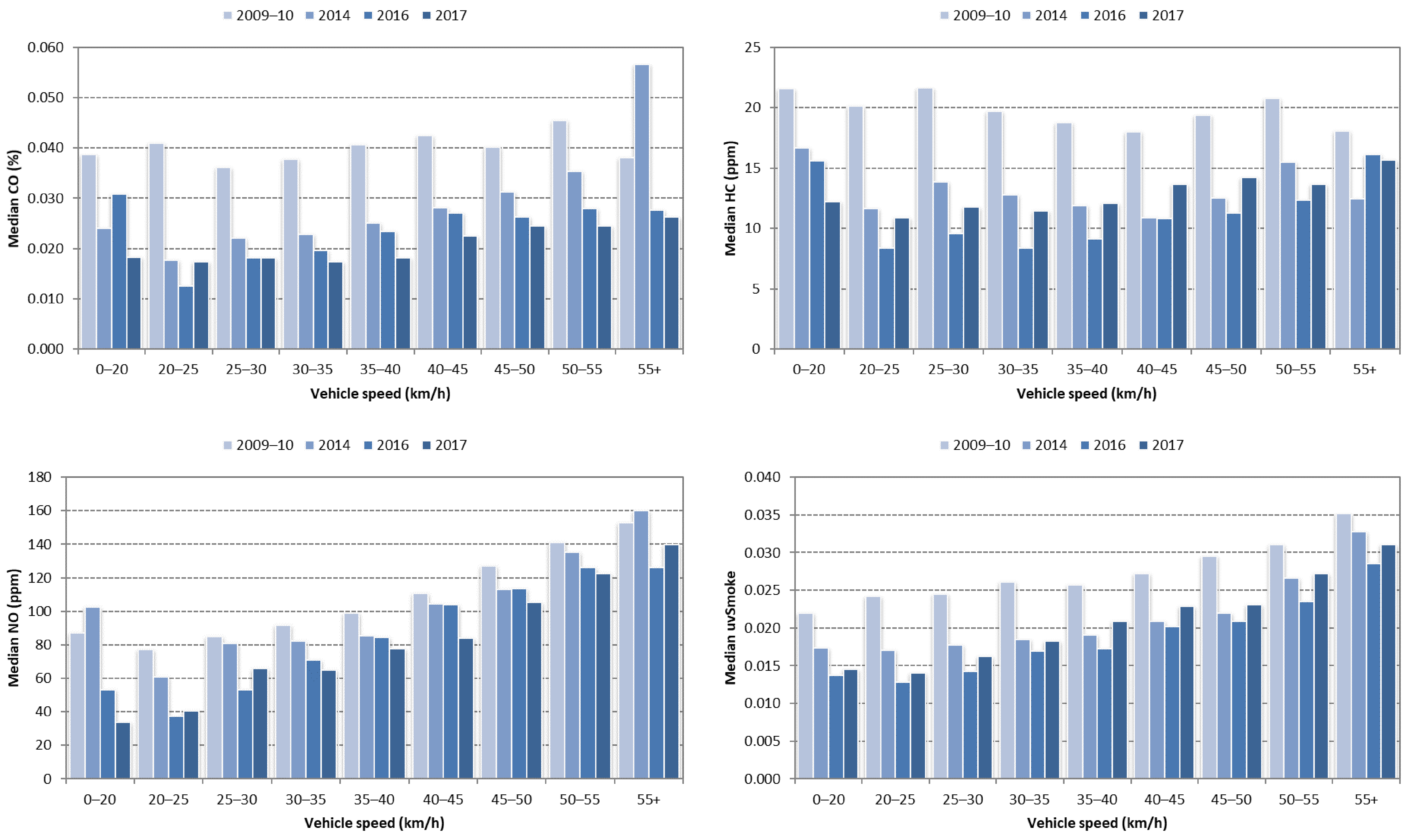


Figure 6: Median emissions over time per vehicle speed

4.3 Fuel assessment

Median emissions of all vehicles by fuel type are presented in Figure 7. Sampling data from the 2009–10, 2014, 2016 and 2017 RSD campaigns are presented for comparison.

CO emissions were highest from petrol and LPG vehicles. Measured emissions have been continually decreasing for petrol and diesel vehicles since 2009. In contrast, median LPG vehicles emissions are increasing over time which is attributed to the existing LPG fleet aging with few new LPG vehicles entering the fleet.

HC emissions are highest for LPG vehicles. Emissions from petrol and diesel vehicles are decreasing over time, though an increase was recorded in 2017. Similar to CO, median HC emissions from LPGs are observed to be increasing over time.

Diesel and LPG vehicles produce significantly more NO emissions than petrol vehicles. There is a downward trend in NO emissions from petrol and diesel vehicles. LPG vehicle NO emissions have increased since monitoring began in 2009, though there is variability year to year.

Smoke emissions are dominated by diesel vehicles, though the median emission trend is decreasing over time. Petrol and LPG vehicle smoke emissions are comparable with no change in trend observed since 2014.

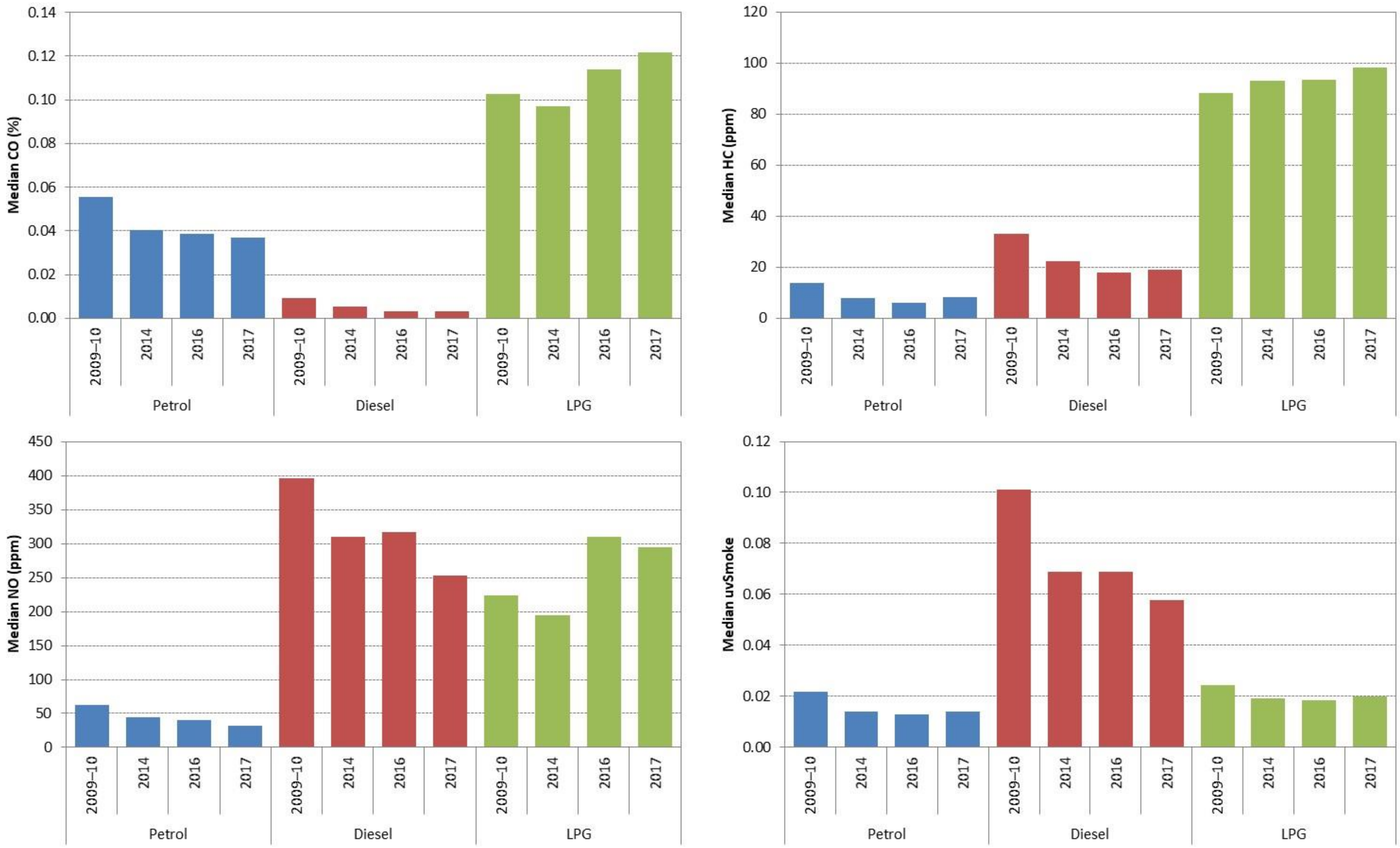


Figure 7: Median emissions over time per fuel type

4.4 Body type assessment

The median emissions of the 10 most common body types sampled were assessed and compared across 2009–10, 2014, 2016 and 2017 RSD campaigns.

The fuel type distribution of body types was considered when assessing recorded emissions. As observed earlier in Section 4.3, fuel type has a significant influence on the types of emissions from vehicles. The fuel type percentage breakdown for the most nine most common body types sampled in 2017 is presented in Figure 8.

Petrol is the dominant fuel type for several body types, particularly so for sedan, hatchback and coupe-style vehicles. Station sedans are petrol dominated, but with growing representation of diesel vehicles. Diesel dominates the van truck and omnibus body types and has become more popular than petrol in recent years for utility, table top and panel van body types.

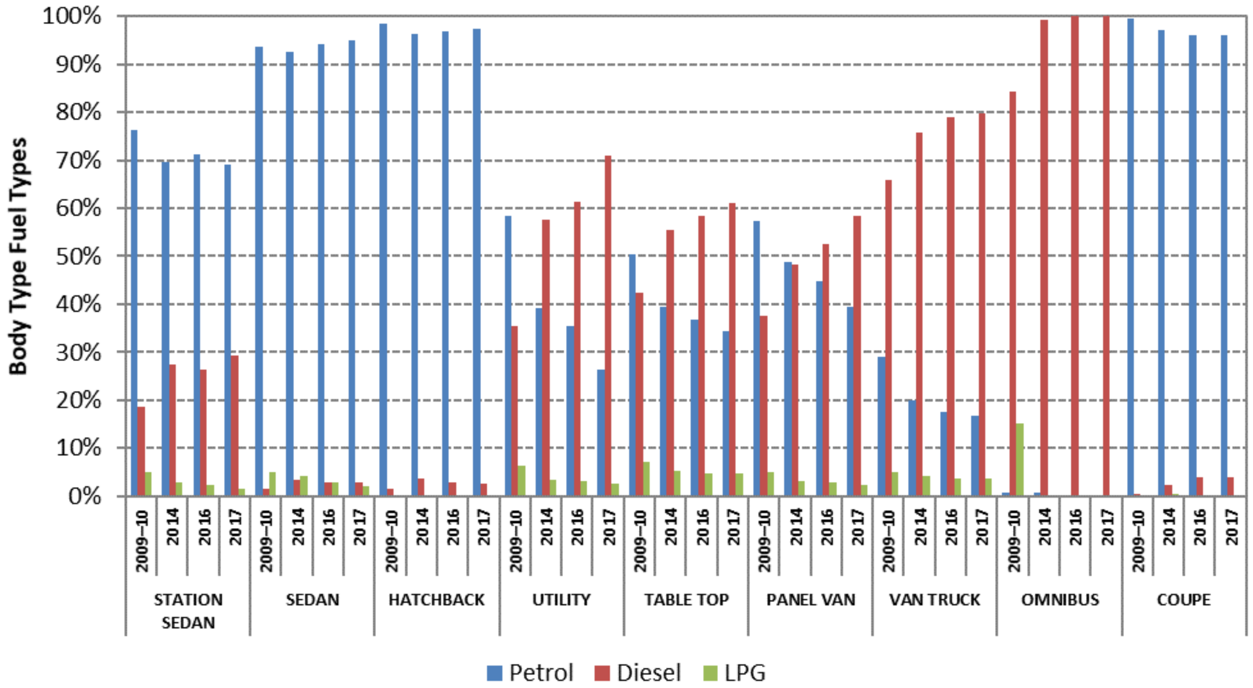


Figure 8: Sampled body type fuel type percentages

Median emissions for CO, HC, NO and smoke by body type are presented in Figure 9. Sampling data from the 2009–10, 2014, 2016 and 2017 RSD campaigns are presented for comparative purposes.

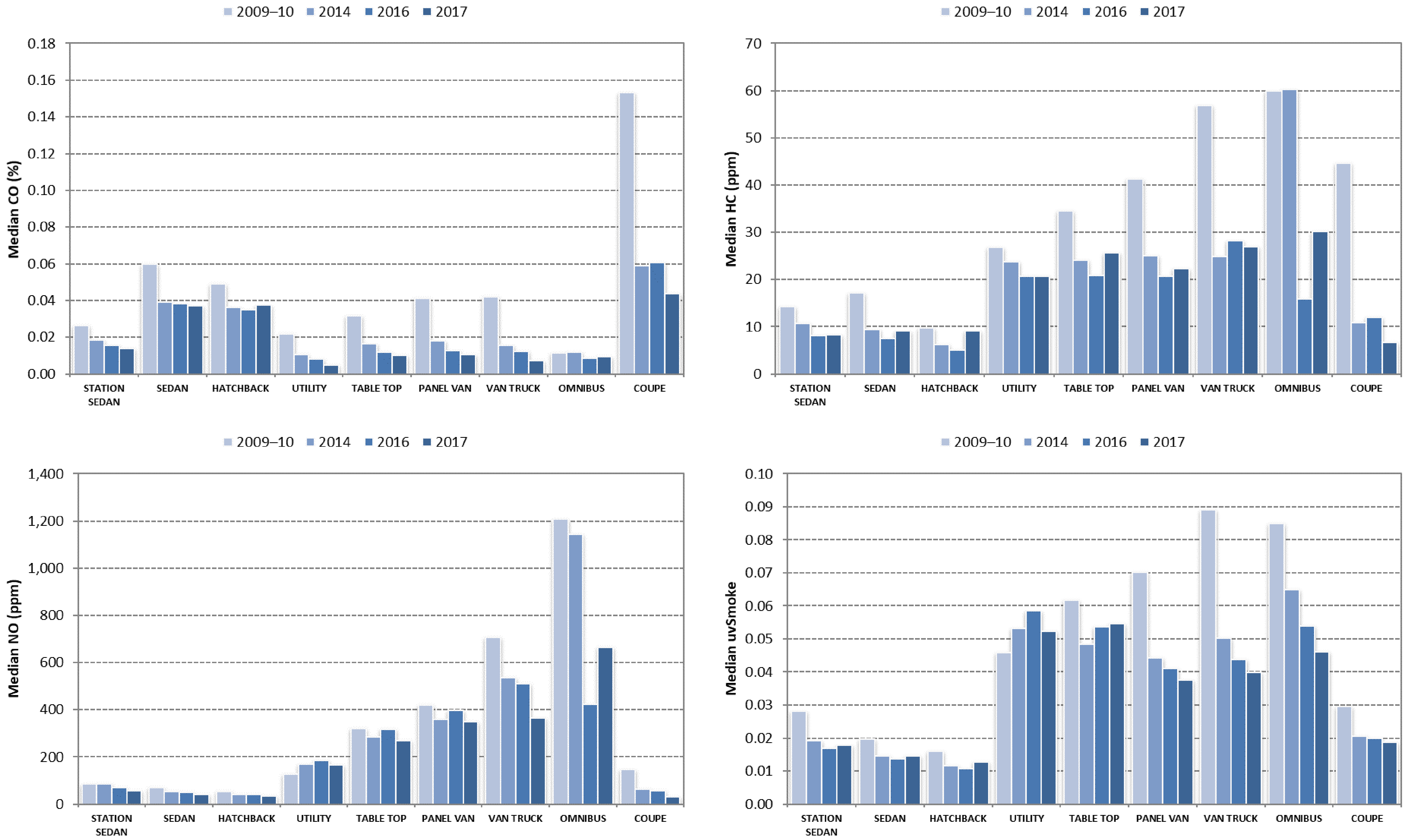


Figure 9: Median emissions over time per body type

CO emissions from all body types have decreased since the 2009–10 sampling campaign. A slight increase in CO emissions from hatchback and omnibus body types was observed compared to 2016. Coupe type vehicles are the highest emitters of CO. A review of the model types classified as coupes, indicates more are likely to be ‘sports’ models with larger engine size, however, engine capacity data for vehicles is required to test this relationship.

HC emissions have been improving for all body types since the 2009–10 sampling campaign. However, HC emissions measured in the 2017 campaign are higher for most body types compared to 2016. Body types with significant diesel populations have higher HC emissions compared to predominantly petrol body types.

Body types with significant diesel populations have higher NO emissions compared to body types dominated by petrol. NO emissions from utilities, table tops and panel vans show little improvement since 2009, while emissions from petrol dominated body types are continually decreasing over time.

Similar to NO, smoke emissions are higher from body types dominated by diesel vehicles. Smoke emissions from most body types have been decreasing since 2009. Emissions from utility and table top body types are not improving over time. Smoke emissions in 2017 are higher than 2016 for the three most common body types sampled (station sedan, sedan and hatchback).

4.5 Vehicle weight assessment

The heavier a vehicle, the more energy (fuel) is required to move it and keep it in motion, compared to a lighter vehicle.

The fuel type distribution of vehicle weight ranges were assessed as fuel type has a significant influence on emissions performance. The fuel type percentage breakdown for weight ranges considered in this assessment is presented in Figure 10.

Lighter vehicles are more likely to be petrol powered, while heavier vehicles are mostly diesel. There is also an increasing representation of diesel vehicles in the heavier weight ranges since the 2009–10 sampling campaign, with a corresponding decrease in petrol vehicle representation.

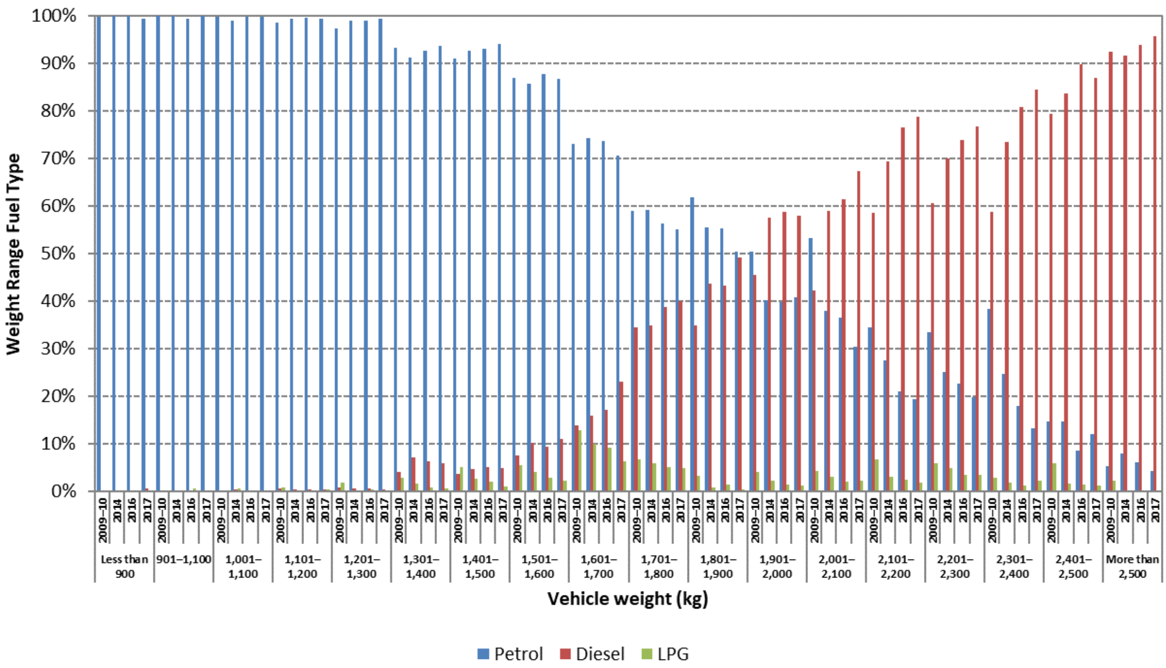


Figure 10: Vehicle weight range fuel type percentages

Emissions for CO, HC, NO and smoke by vehicle weight range are presented in Figure 11. Sampling data from the 2009–10, 2014 and 2016 RSD campaigns are presented for comparative purposes.

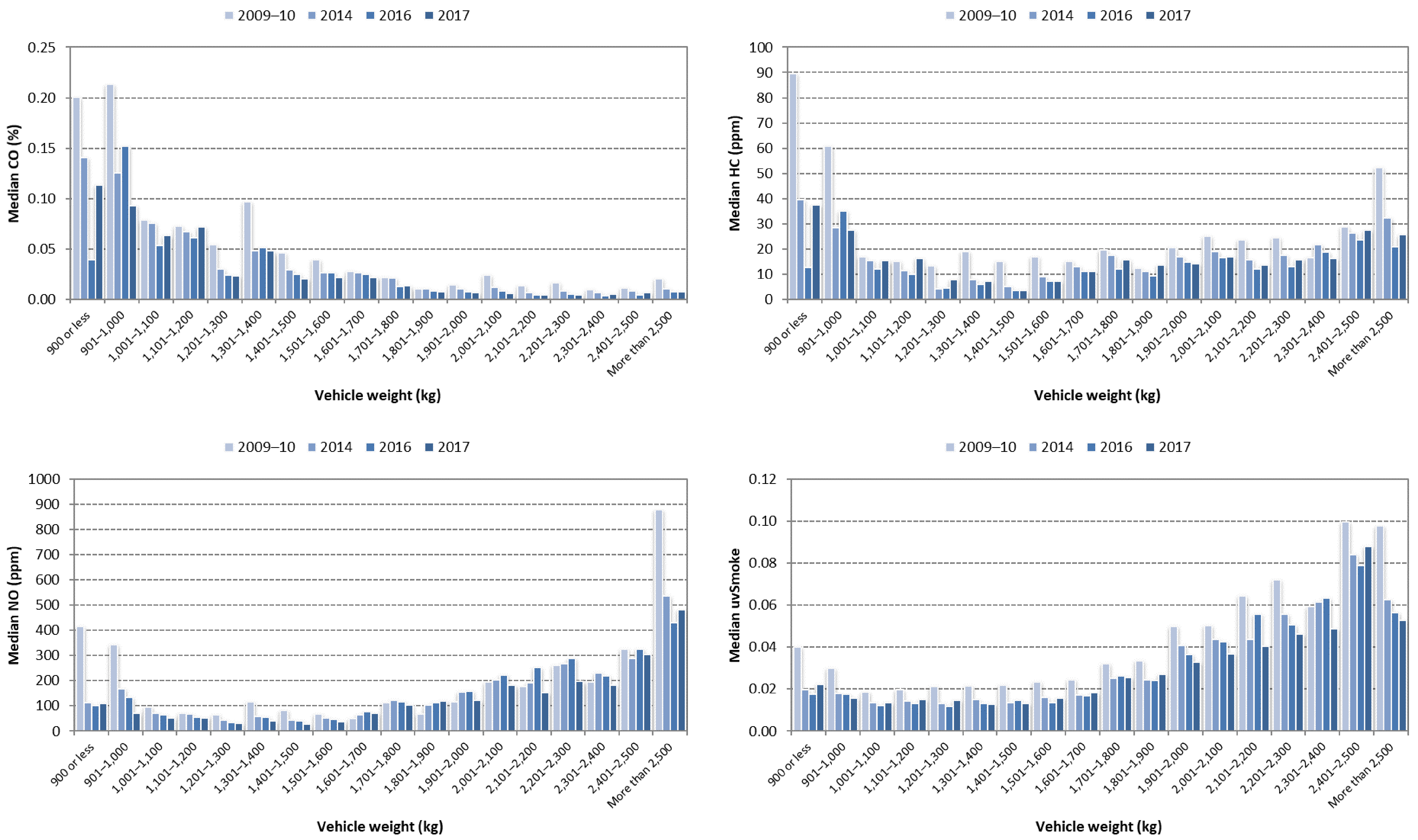


Figure 11: Median emissions over time per vehicle weight range

Higher CO and HC emissions were recorded for vehicles in the ‘less than 900 kg’ weight range than any other weight range. NO and smoke emissions in the ‘less than 900 kg’ weight range were only exceeded by vehicles weighing more than 1,700 kg.

Higher CO and HC emissions in lighter vehicles reflect the dominance of petrol vehicles in these ranges. Conversely, NO and smoke emissions in heavier vehicles reflect the dominance of diesel vehicles in these ranges.

There is no clear trend in CO emissions over the years. Emissions from the lightest vehicles vary each sampling period, though CO emissions from most groups have increased in 2017 from 2016. CO emissions from mid-range vehicles have reduced, while emissions from heavier vehicles are mostly consistent with previous years.

HC emissions were lowest in the 1201–1500 kg weight range in 2017 and gradually increased as vehicle weight increased. HC emissions have increased for most vehicle weight ranges in 2017 compared to 2016, but are generally better than when monitoring began in 2009.

NO emissions can be seen to increase as vehicle weight increases, with emissions from the ‘greater than 2500 kg’ range notably higher than all other weight ranges. NO emissions have improved for most weight ranges since monitoring began in 2009.

Smoke emissions were higher from heavier vehicles in the fleet. Emissions from lighter vehicles have remained stable since 2014, while emissions from heavier vehicles have generally been improving since 2009.

4.6 Year of manufacture assessment

Year of manufacture is a proxy for vehicle technology. Vehicles in Australia are built in accordance with Australian Design Rules (ADRs), with a number of ADRs dedicated to emission standards for vehicles. Emission standards exist with respect to:

- vehicle weight (3.5 tonnes being the cut-off between ‘light’ and ‘heavy’ vehicles)
- engine type (spark ignition or compression ignition).

Emission standards have been gradually tightened over the years with ADRs aligning with European emission standards since the early 2000s.

RSD data can be used to assess the impact of changes to emission standards on vehicle emissions. The RSD equipment does not directly measure exhaust emissions, so direct comparison to ADR standards is not possible. Instead, step changes in the data should be apparent in years where improved emissions standards for a pollutant were introduced.

Median emissions for light (equal to or less than 3.5 tonnes) petrol and diesel vehicles are presented in Figure 12 to Figure 15. The relevant ADR standard is overlain for reference. Sampling data from the 2009–10, 2014, 2016 and 2017 RSD campaigns are presented for comparative purposes. The year of manufacture range assessed for petrol and diesel vehicles is based on having at least 100 samples from each campaign year for each year of manufacture. LPG and heavy vehicles were not assessed due to insufficient sample sizes.

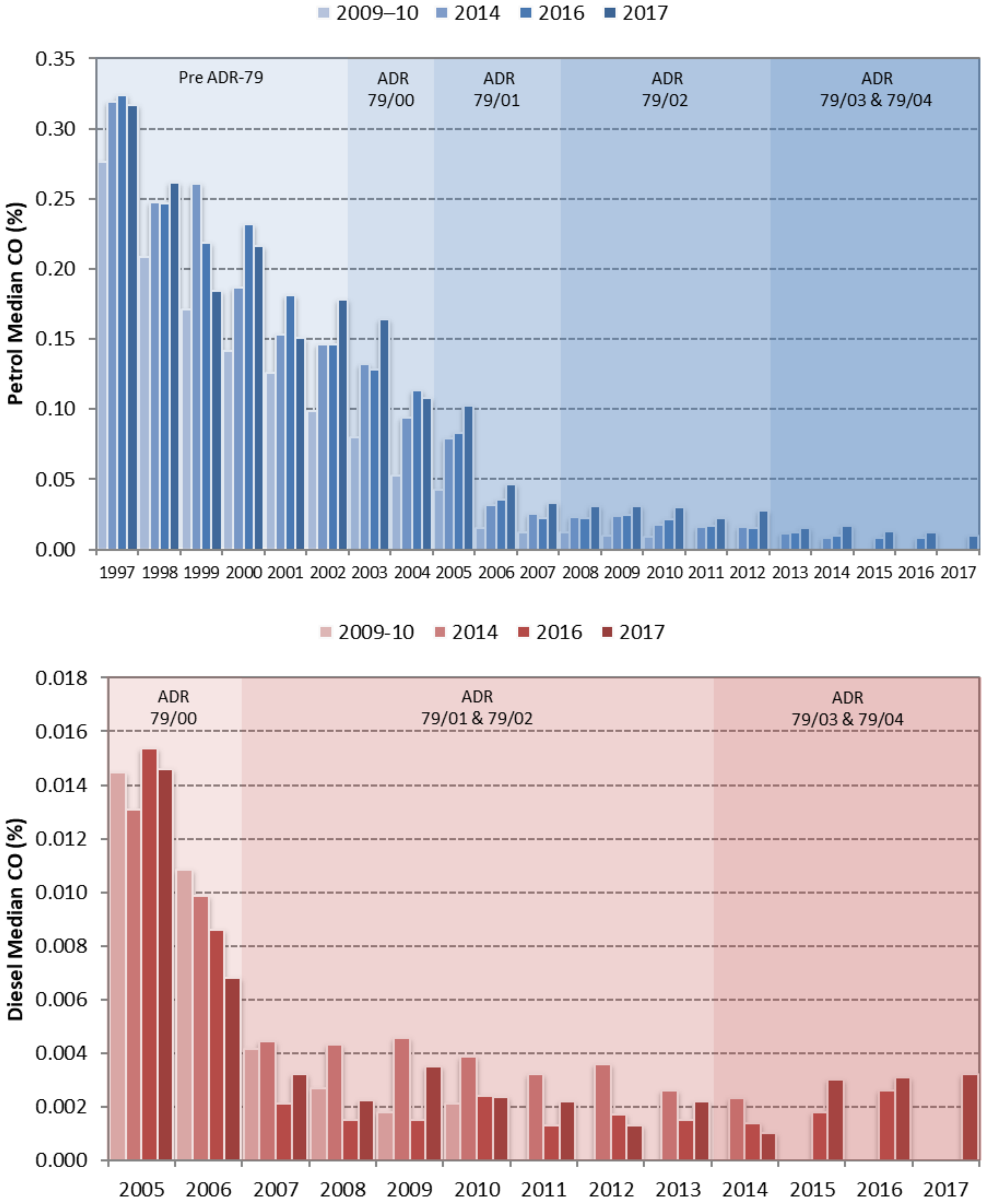


Figure 12: Median CO emissions over time per year of manufacture

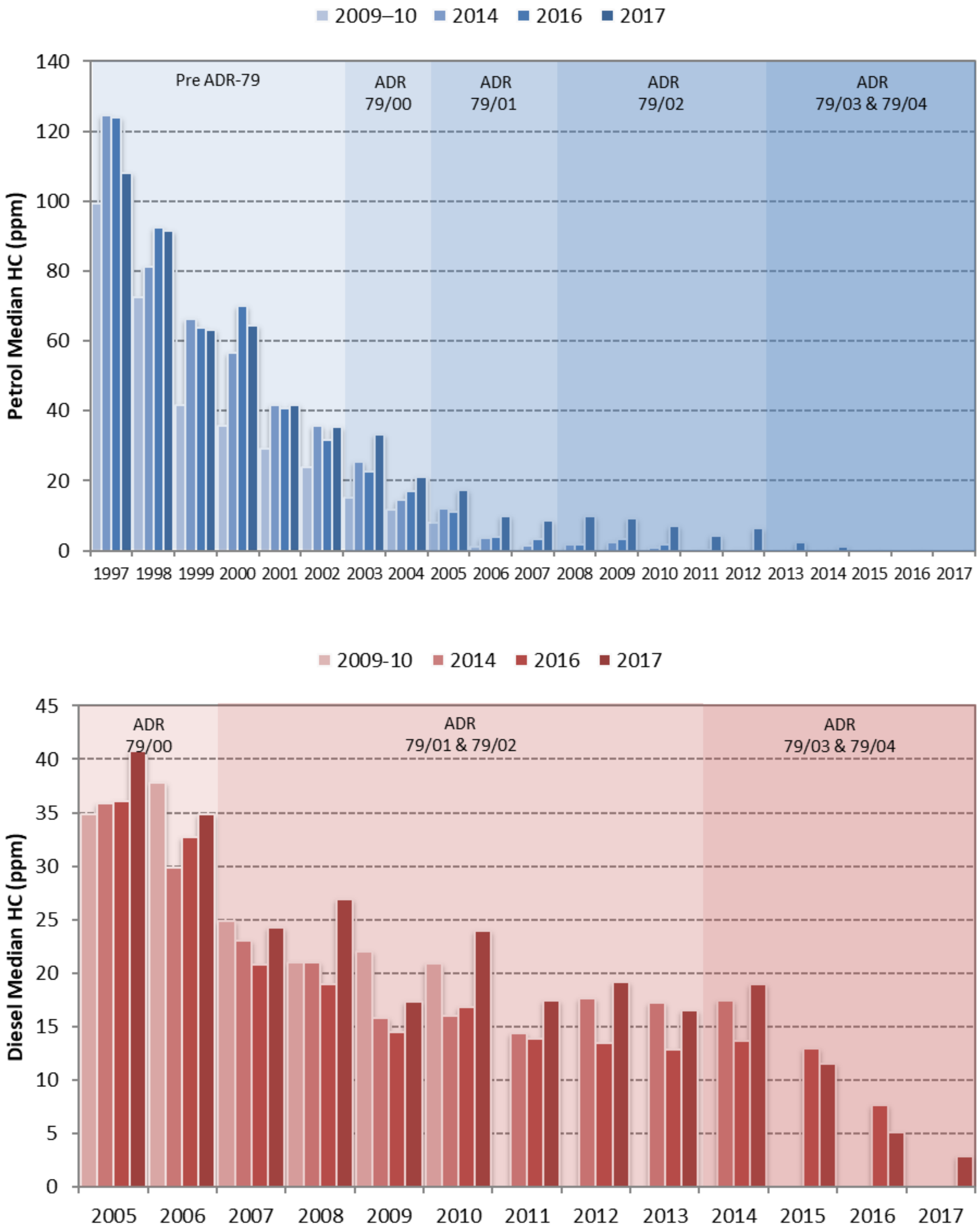


Figure 13: Median HC emissions over time per year of manufacture

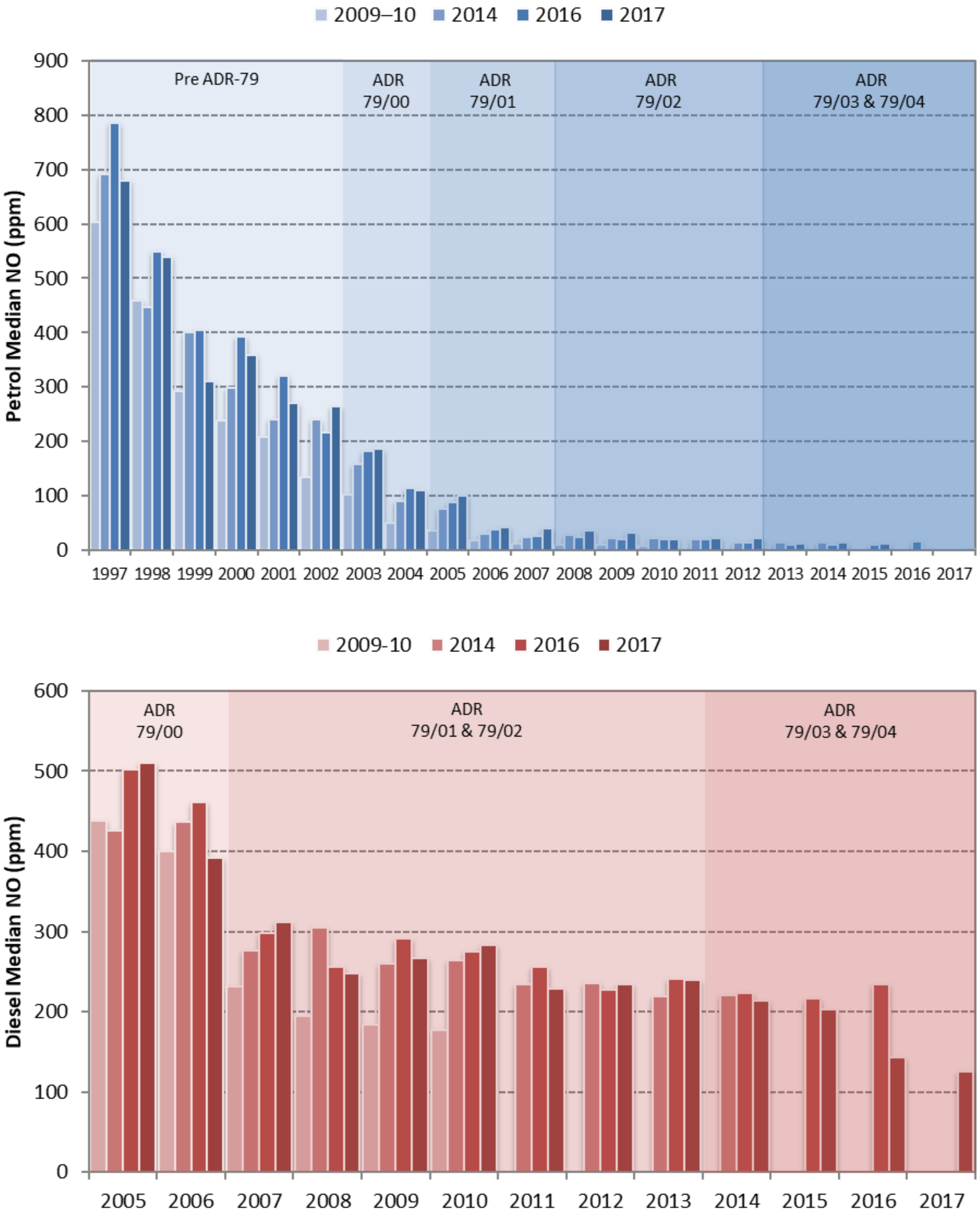


Figure 14: Median NO emissions over time per year of manufacture

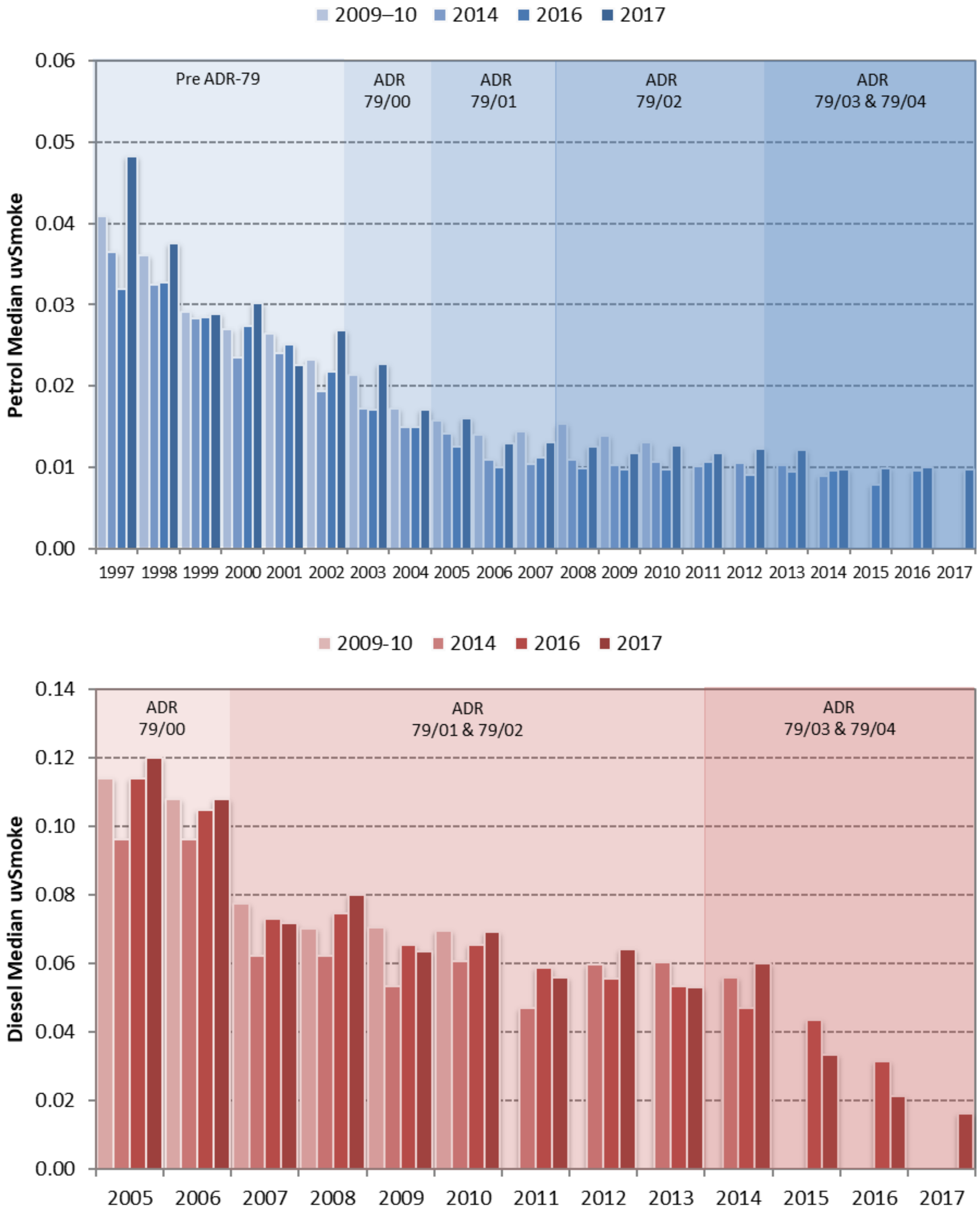


Figure 15: Median smoke emissions over time per year of manufacture

Vehicle aging

For petrol vehicles, emissions are observed generally to increase between sampling years as they age; i.e. a vehicle sampled in 2014 will likely be producing more emissions when sampled again in 2016. This trend of emissions increasing as a vehicle ages is better observed in newer models, with more variability in the trend for pre-ADR79 models.

Diesel vehicle data also shows signs of vehicle aging between sampling years, particularly for HC and smoke emissions, though the trend is much weaker compared to petrol vehicles.

Emission standards

All datasets show improvements in emissions between manufacturing years. This trend has been less significant in recent years.

Petrol vehicles

The largest step change is noticeable in vehicles manufactured in 2006 or later. This change occurs in advance of the ADR79/02 standards introduced in 2008, which effectively halved the emission limits of CO, HC and oxides of nitrogen (NO_X), which includes NO, for petrol vehicles[3].

The transition from ADR79/00 to ADR79/01 introduced tighter standards for HC and NO and shows a similar step change at least a year in advance, with notable differences in emissions for CO, HC and NO between 2003 and 2004 manufactured vehicles.

ADR79/03 and ADR79/04 maintained the same CO and HC standards, slightly tightened the NO_X standard, and introduced a particulate standard. A step change is observed for all substances, though the smoke emission step change appears later, which is consistent with the relaxed particulate standard in ADR79/03 compared to ADR79/04.

It was also observed that emissions of HC from 2015 and newer vehicles were below detection for most vehicles sampled in the 2017 RSD campaign. A similar observation was made for 2012 and newer vehicles during the 2016 campaign, 2011 and newer vehicles in the 2014 campaign, and 2007 and newer vehicles during the 2009-10 campaign. These data suggests vehicle degradation is the main driver of HC emissions, but further investigation is required to properly establish the cause of these observations.

Diesel vehicles

The biggest step change appears in 2007 or later vehicles and coincides with the complete introduction of ADR79/01 emission standards. These standards effectively

[3] Current and historic Australian Design Rule (ADR) standards for petrol vehicles are published on the Department of Infrastructure, Regional Development and Cities website: https://infrastructure.gov.au/vehicles/environment/emission/files/Emission_Standards_for_Petrol_Cars.pdf

halved the emission limits of HC, oxides of nitrogen (NO_X), which includes NO, and particulates. The CO limit was also reduced by approximately 20 per cent.[4]

The transition from ADR79/02 to ADR79/03 improved HC and NO_X standards and significantly limited particulate emissions. The data shows that CO emissions have increased compared as a result of the standard change. HC, NO and smoke emissions all show signs of improvement, albeit only in the last 2-3 years rather than when the standard changed. Future testing will determine if this measured drop is a function of vehicle age or a genuine step change in emission levels.

[4] Current and historic Australian Design Rule (ADR) standards for diesel vehicles are published on the Department of Infrastructure, Regional Development and Cities website: https://infrastructure.gov.au/vehicles/environment/emission/files/Final_Emission_Limits_for_Light_Vehicles_Euro_2-Euro_6.pdf

5 Key findings

Based on the observations made on emissions with respect to vehicle speeds, fuel types, body types, vehicle weights and year of manufacture, the 2017 RSD campaign found:

- The sampled fleet was representative of Perth’s vehicle fleet. Conclusions about the sampled fleet apply to the wider Perth fleet.
- The 2017 vehicle speed distribution was comparable to the average distribution of historic monitoring data. 2017 sampling can be reasonably assessed against historic sampling.
- CO emissions in 2017 have mostly decreased compared to 2016 and earlier monitoring.
- HC emissions in 2017 have increased compared to 2016, though are comparable or better than emissions measured in 2014 and earlier. 2016 monitoring was undertaken between March and April when fleet petrol is more likely to have a lower RVP compared to November and December. Lower RVP fuel results in fewer HC evaporative emissions. Fleet fuel quality data would need to be sourced and reviewed to test if this is the actual cause of the increase.
- NO emissions in 2017 are comparable to, or slightly less than 2016 measured emissions.
- Overall smoke emissions in 2017 were lower than 2016 and earlier measurements. Smoke emissions from petrol vehicles were slightly higher than 2016, but this was offset by improvements in diesel smoke emissions.
- Continual increases in emissions since 2014 have been observed for LPG vehicles, which is likely due to the LPG fleet aging. Unlike petrol and diesel vehicles, there are few new LPG vehicles with lower emissions introduced to the market each year.
- 2017 data suggests the lightest vehicles in the fleet may be producing more emissions than mid-range vehicles. This is evident in observed NO and smoke emissions, where the lightest vehicles are dominated by petrol (which have lower NO and smoke emissions compared to diesel) but have higher emissions than mid-range vehicles where diesel vehicles start to compete with petrol vehicles. This may be due to a lower build quality in entry level budget models compared to heavier vehicles.

Appendices

Appendix A – Smart sign cut point review

Average fleet emissions change over time as vehicle technology improves and preferences for the use of petrol and diesel fuels change. The smart sign cut points need to be reviewed and adjusted regularly to ensure vehicles with comparatively poor emissions receive appropriate feedback.

Smart sign cut points are set based on the historic performance of the fleet, meaning the rating drivers see when passing through is how their car emissions compare to the fleet average. This is done because there are no in-service standards available to make objective comparisons to. The use of a historic benchmark is the next best option and can facilitate fleet comparisons year to year. A 70/20/10 ratio to divide the fleet into ‘Good’/’Fair’/‘Poor’ groups is used for the Department’s RSD program.

It is understood anecdotally from RSD programs globally that more than 50 per cent of vehicle emissions come from the worst 10 per cent of vehicles. The ‘Poor’ cut point reflects this. The ‘Fair’ cut point is selected to reach vehicles most likely to become ‘Poor’ without intervention and to minimise the risk of drivers undertaking expensive servicing that would be unlikely to produce a worthwhile reduction in emissions.

The ‘Good’/’Fair’/’Poor’ metrics from the 2017 campaign are presented in Table 3. This data represents what drivers saw and includes samples that did not have a valid or verified number plate recorded (i.e. no corresponding vehicle data).

Table 3: SmartSign ratings for 2017

Emission category	Good	Fair	Poor
Carbon monoxide (CO) %	87.90%	9.32%	2.79%
Hydrocarbons (HC) ppm	82.85%	14.19%	2.96%
Nitrogen oxide (NO) ppm	89.84%	5.98%	4.18%
UV smoke (PM) %	93.87%	5.07%	1.06%
Totals 2017	**71.44%**	**20.29%**	**8.28%**
Totals 2016	**71.04%**	**19.01%**	**9.95%**

The 71.44/20.29/8.28 ratio for 2017 tells us that the vehicle fleet overall is producing lower emissions than it was in 2016. If the good or fair results were below 70 or 20 aspect of the ratio respectively then the opposite would be true.

The data is consistent with 2016 metrics which used cut points developed during 2014 RSD campaign. The updated cut points used for the 2017 campaign, which were developed from 2016 campaign data, have maintained the ‘Good’/‘Fair’/‘Poor’ ratio established over previous monitoring campaigns.

A detailed breakdown of ‘Good’/‘Fair’/‘Poor’ ratings by fuel type is presented in Figure 16. Fuel type analysis shows compressed natural gas (CNG) and LPG vehicles produce significantly worse emissions than their petrol and diesel counterparts – the exception being smoke emissions which were comparable to petrol vehicles.

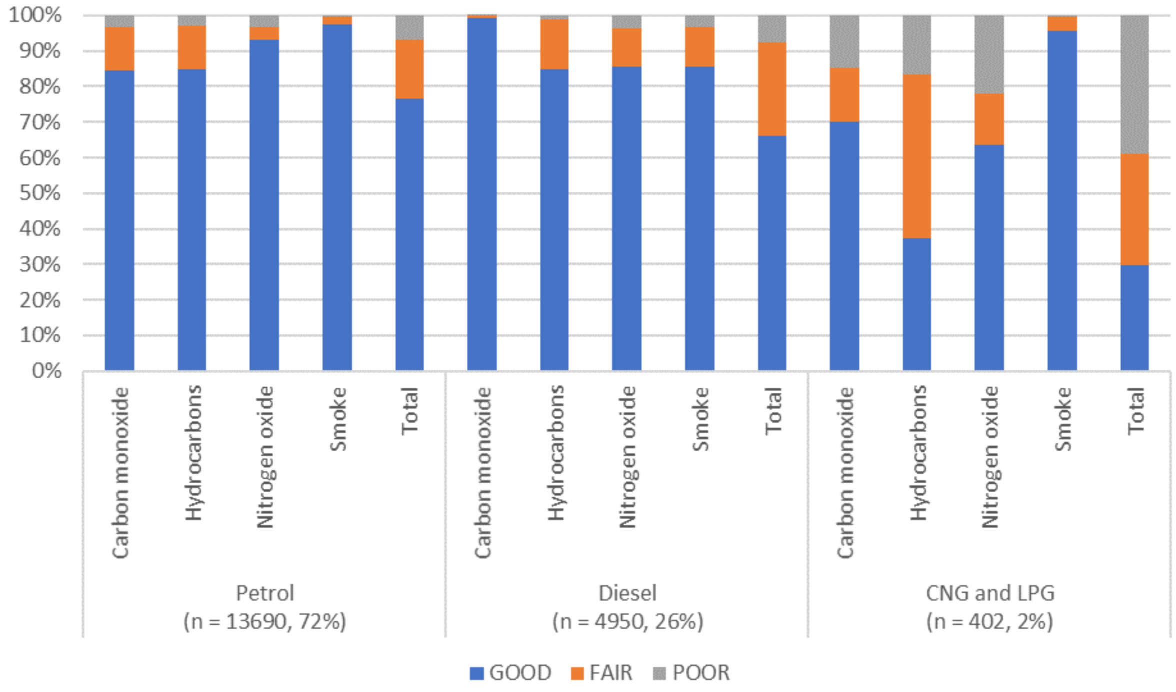


Figure 16: Smart sign ratings by fuel type

Petrol cars were more likely to trigger worse ratings as a result of carbon monoxide or hydrocarbon emissions, while diesel car ratings were influenced by hydrocarbon, nitrogen oxide and smoke emissions.

Analysis of 'Good'/'Fair'/'Poor' ratings were undertaken for year of manufacture, and tare weight groups. These results are presented in Figure 17, Figure 18, and Figure 19.

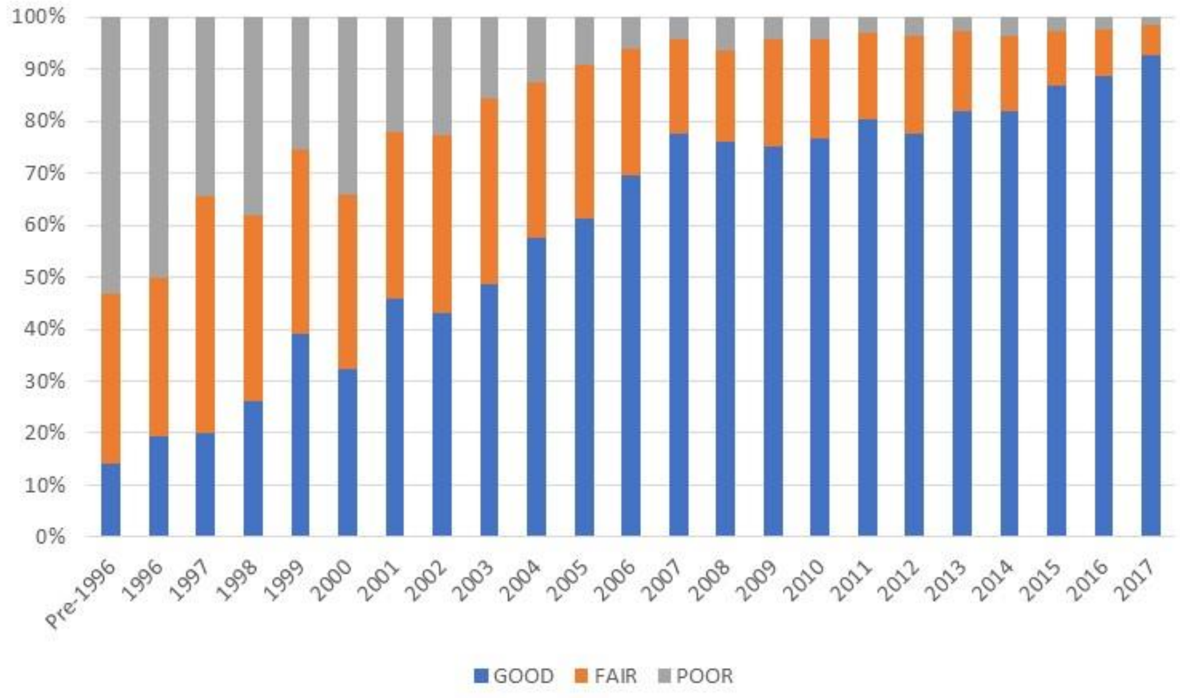


Figure 17: Smart sign ratings by year of manufacture

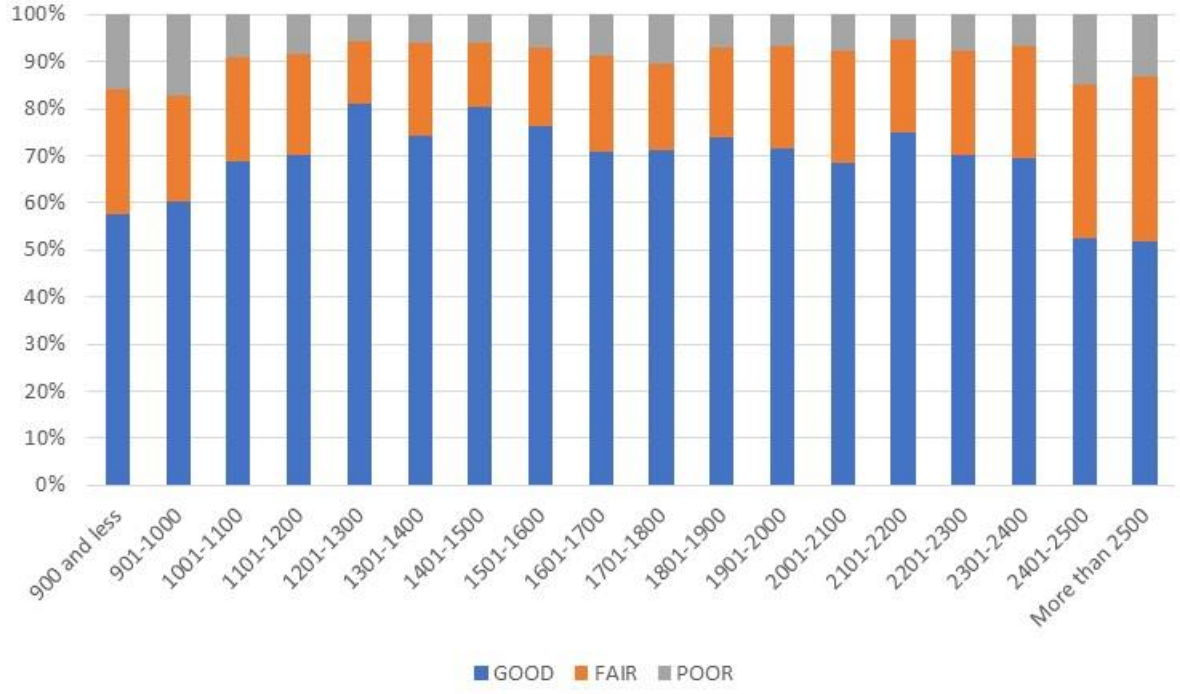


Figure 18: Smart sign ratings by tare weight (kg) range

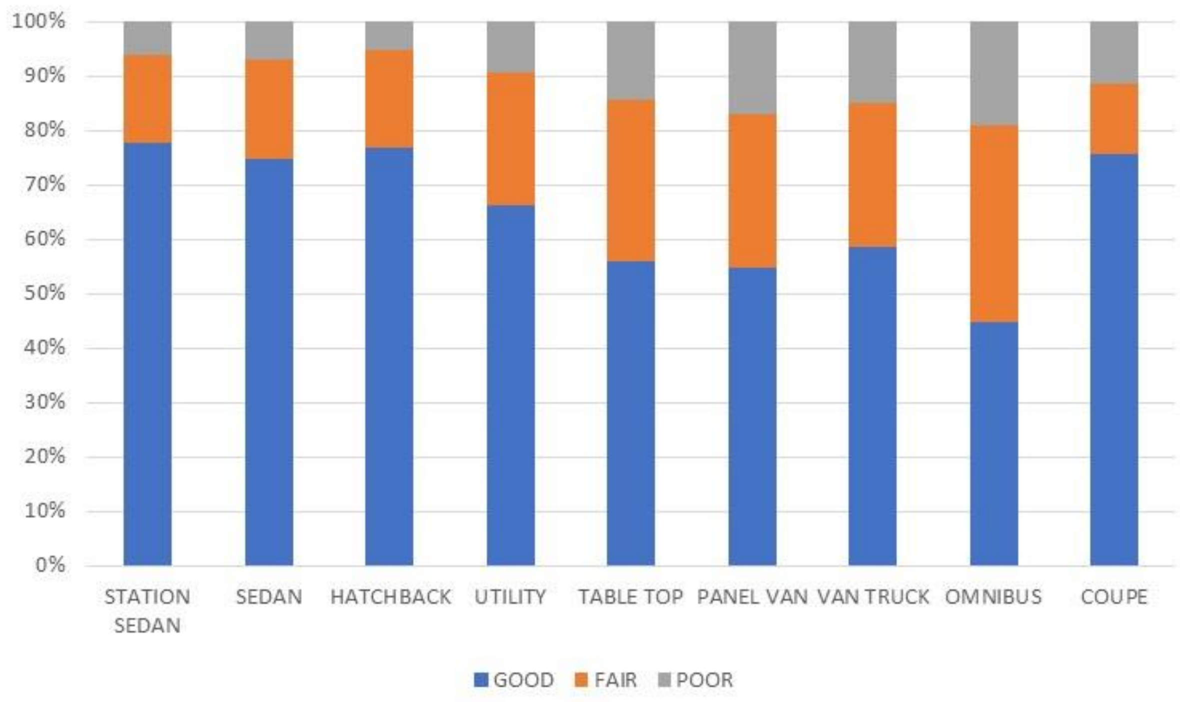


Figure 19: Smart sign ratings by body type

While interesting in their own merit, only fuel parameters were found useful for the Smart sign cut point review.

The following principles were considered in reviewing the smart sign cut points:

- the percentile ranges considered for 'Good'/ 'Fair'/'Poor' ratings should appear reasonable and consistent with the 70/20/10 principle
- the number of drivers that see 'Good', 'Fair' and 'Poor' ratings should reflect a vehicle's overall performance relative to the whole of fleet
- the use of diesel and petrol (but not LPG or CNG) fuel should be considered in setting criteria where significant differences in emissions exist (for example, smoke emissions from diesel versus petrol)
- cut points should not increase.

Alternative cut points have been considered for adoption, taking the above points into consideration. Six scenarios were tested to update the Smart sign cut points. These scenarios are presented in Table 4.

Table 4: Alternate smart sign cut points based on 2017 data

Emission category	Good	Fair	Poor
Scenario 1: 90% 'Good', 9% 'Fair', 1% 'Poor'			
Carbon monoxide (CO) %	90.00%	9.00%	1.00%
Hydrocarbons (HC) ppm	90.00%	9.00%	1.00%
Nitrogen oxide (NO) ppm	90.00%	9.00%	1.00%
UV smoke (PM) %	90.00%	9.00%	1.00%
Scenario 1 Totals	**74.39%**	**22.23%**	**3.37%**
Scenario 2: Current criteria (90% 'Good', 9% 'Fair', 1% 'Poor') using petrol vehicle data for CO and HC, and diesel vehicle data for HC, NO and uvSmoke			
Carbon monoxide (CO) %	92.03%	7.08%	0.89%
Hydrocarbons (HC) ppm	90.00%	9.00%	1.00%
Nitrogen oxide (NO) ppm	92.36%	5.57%	2.06%
UV smoke (PM) %	95.96%	3.70%	0.33%
Scenario 2 Totals	**80.80%**	**15.48%**	**3.73%**
Scenario 3: 'Above average = 'Good' criteria (50% 'Good' , 40% 'Fair', 10% 'Poor')			
Carbon monoxide (CO) %	50.00%	40.00%	10.00%
Hydrocarbons (HC) ppm	50.00%	40.00%	10.00%
Nitrogen oxide (NO) ppm	50.00%	40.00%	10.00%
UV smoke (PM) %	50.00%	40.00%	10.00%
Scenario 3 Totals	**15.23%**	**59.16%**	**25.61%**
Scenario 4: 'Above average = 'Good' criteria (50% 'Good', 40% 'Fair', 10% 'Poor') using petrol vehicle data for CO and HC, and diesel vehicle data for HC, NO and uvSmoke			
Carbon monoxide (CO) %	60.33%	31.70%	7.97%
Hydrocarbons (HC) ppm	50.00%	40.00%	10.00%
Nitrogen oxide (NO) ppm	71.40%	20.96%	7.64%
UV smoke (PM) %	78.81%	17.18%	4.01%
Scenario 4 Totals	**30.19%**	**50.62%**	**19.19%**
Scenario 5: 'Nudged' criteria (88% 'Good', 8% 'Fair', 4% 'Poor')			
Carbon monoxide (CO) %	88.00%	9.00%	3.00%
Hydrocarbons (HC) ppm	88.00%	9.00%	3.00%
Nitrogen oxide (NO) ppm	88.00%	9.00%	3.00%
UV smoke (PM) %	88.00%	9.00%	3.00%
Scenario 5 Totals	**69.63%**	**19.12%**	**11.25%**
Scenario 6: 'Nudged' criteria (83% 'Good', 13% 'Fair', 4% 'Poor') using petrol vehicle data for CO and HC, and diesel vehicle data for HC, NO and uvSmoke			
Carbon monoxide (CO) %	86.91%	9.71%	3.38%
Hydrocarbons (HC) ppm	83.00%	13.00%	4.00%
Nitrogen oxide (NO) ppm	88.65%	6.88%	4.47%
UV smoke (PM) %	92.88%	5.74%	1.38%
Scenario 6 Totals	**69.80%**	**20.60%**	**9.60%**

Scenario 1 and 2 criteria explores setting cut-offs to only give the worst 10 per cent of emissions fleet a 'Fair' or 'Poor'. When applied to the 2017 dataset, the 70 per cent 'Good' target is nearly met, but only a limited number of vehicles received a 'Poor' rating for both scenarios.

Scenario 3 and 4 criteria present the case of emissions only receiving a 'Good' if they're in the top 50 per cent. The 'Poor' cut point is set to the worst 10 per cent. These scenarios show more than 50 per cent of vehicles received a 'Fair' rating. The 'Good' and 'Poor' rating varied between the two scenarios, but either option represents a significant divergence from the 70/20/10 distribution of feedback from the smart sign.

Scenario 5 and 6 cut points were based on a more arbitrary percentile range compared to the other scenarios. These scenarios were focused on producing a 'Good'/'Fair'/'Poor' percentage distribution of 70/20/10. While nudging the percentile ranges could produce the desired 70/20/10 ratio, without accounting for fuel type (scenario 5), diesel vehicles had a 54/32/14 'Good'/'Fair'/'Poor' percentage distribution. Accounting for fuel type (scenario 6) improved this ratio to 63/28/9, removing an unreasonable bias that diesel vehicles would experience driving through the RSD.

With respect to the four principles outlined above for selecting cut points, the cut points from scenario 6 appear the most reasonable to apply for future sampling.

The recommended cut points to be applied for future sampling are presented in Table 5. The calculated new cut points are lower than the current cut points, except for the 'Good' cut point for hydrocarbons (<64). The current cut point of <63 was instead retained.

Table 5: New smart sign cut points

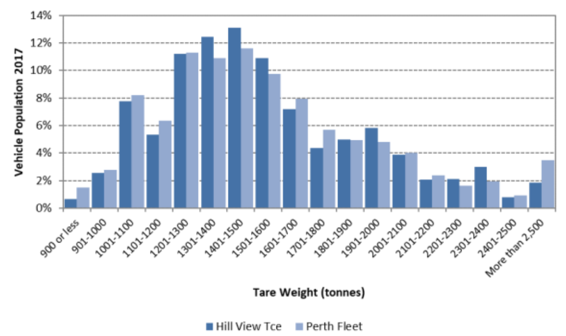
Emission category	Good	Fair	Poor
Carbon monoxide (CO) %	<0.267	0.267–0.922	>0.922
Hydrocarbons (HC) ppm	<63	63–254	>254
Nitrogen oxide (NO) ppm	<767	767–1380	>1380
UV smoke (PM) %	<0.145	0.145–0.347	>0.347

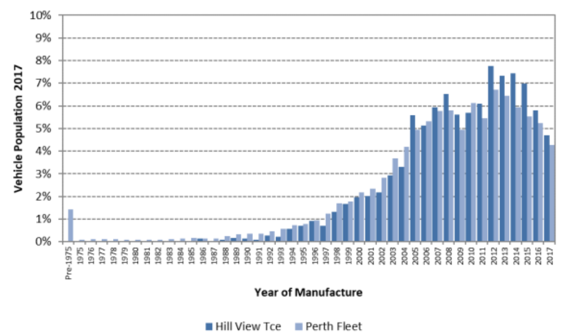
Appendix B — Site characteristics

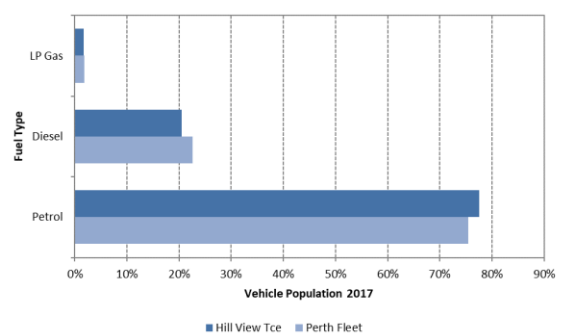
Hill View Tce, St. James

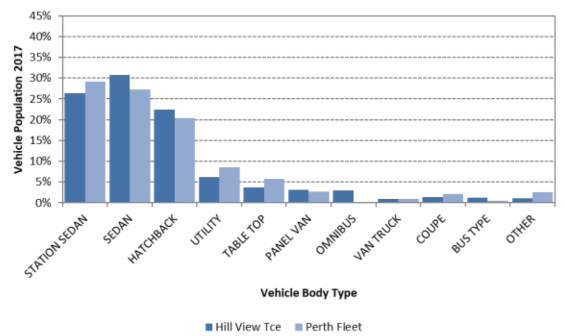
Median strip: Narrow, painted/kerbed
Slope: 2.6°
Traffic direction: North
7am-2pm traffic flow: 273 cars/hour
Average speed: 36.5 km/h
Average acceleration: 0.48 km/h/s
Fleet composition: Residential

Fleet Representation (tare weight, year of manufacture, fuel type, body type)







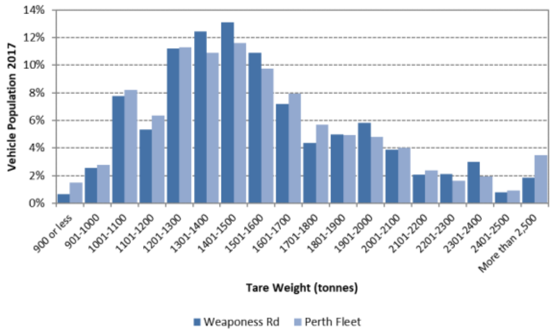


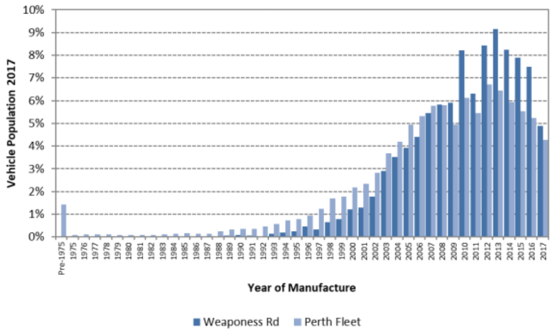
Hill View Tce Fleet Representation (tare weight, year of manufacture, fuel type, body type)

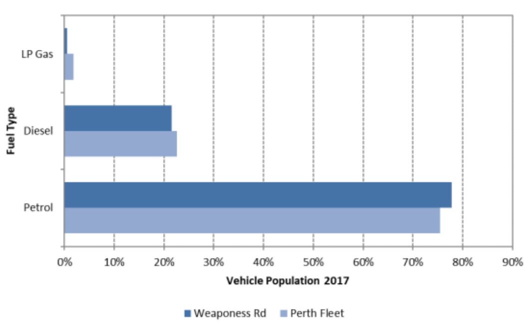
Weaponess Rd, Wembley Downs

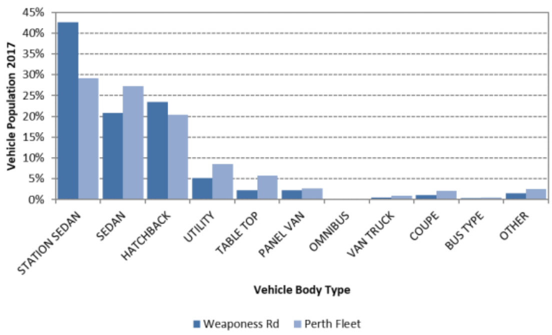
Median strip: Narrow, painted
Slope: 2.7°
Traffic direction: South
7am-2pm traffic flow: 515 cars/hour
Average speed: 34.1 km/h
Average acceleration: 0.41 km/h/s
Fleet composition: Residential

Fleet Representation (tare weight, year of manufacture, fuel type, body type)







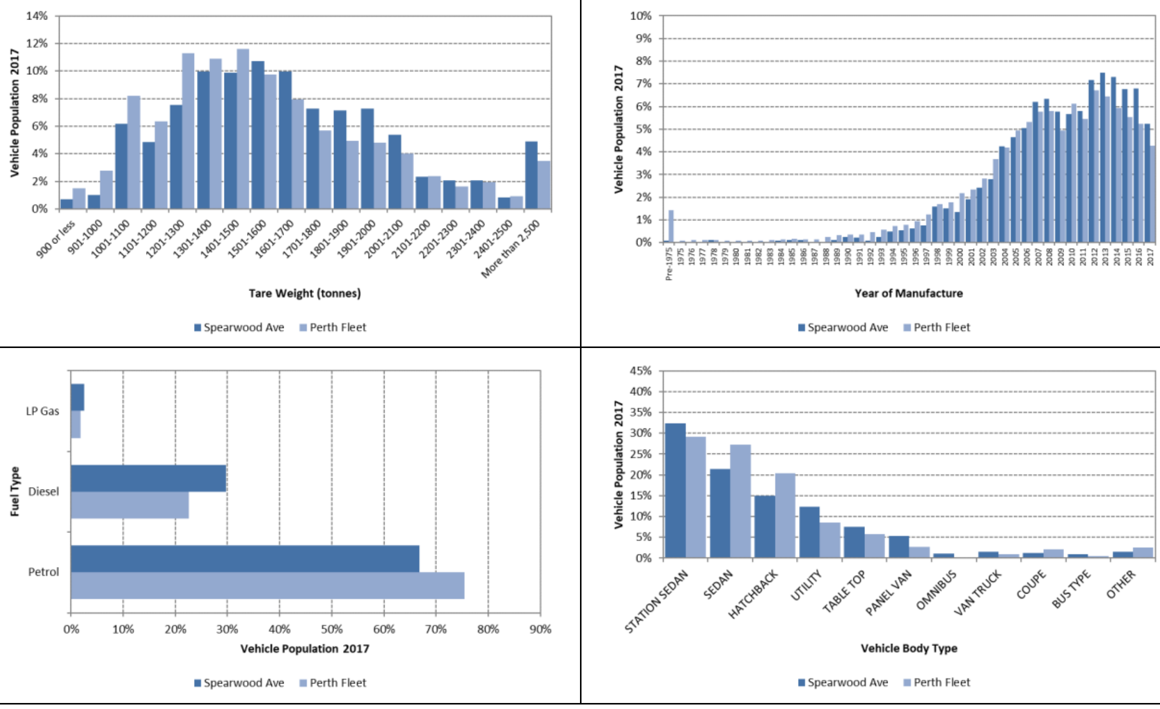


Weaponess Rd Fleet Representation (tare weight, year of manufacture, fuel type, body type)

Spearwood Ave, Spearwood

Median strip: Wide, kerbed
Slope: 1.9°
Traffic direction: East
7am-2pm traffic flow: 335 cars/hour
Average speed: 37.2 km/h
Average acceleration: -0.02 km/h/s
Fleet composition: Residential

Fleet Representation (tare weight, year of manufacture, fuel type, body type)

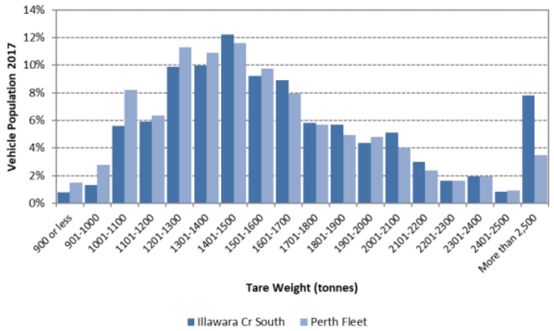


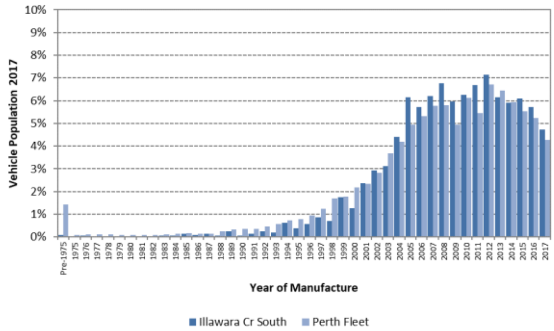
Spearwood Ave Fleet Representation (tare weight, year of manufacture, fuel type, body type)

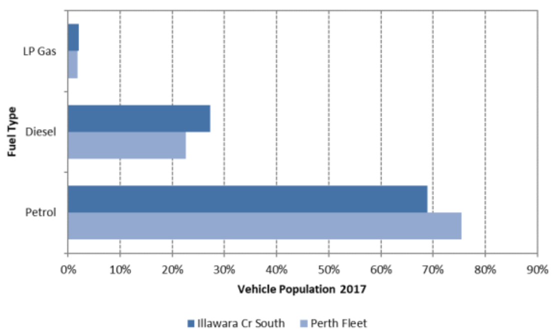
Illawarra Cr S, Malaga

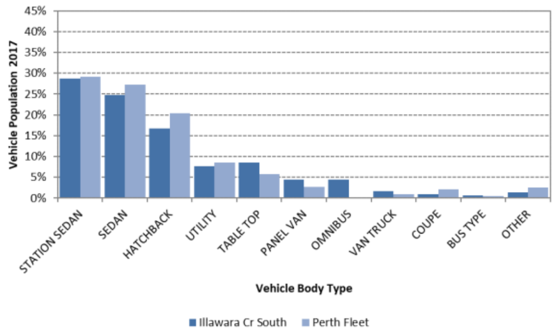
Median strip: Narrow, painted
Slope: 1.5°
Traffic direction: West
7am-2pm traffic flow: 234 cars/hour
Average speed: 39.5 km/h
Average acceleration: 1.16 km/h/s
Fleet composition: Commercial and residential

Fleet Representation (tare weight, year of manufacture, fuel type, body type)







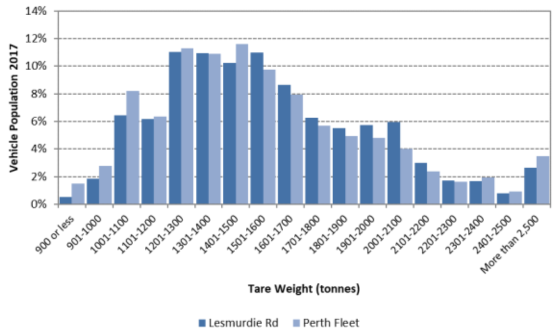


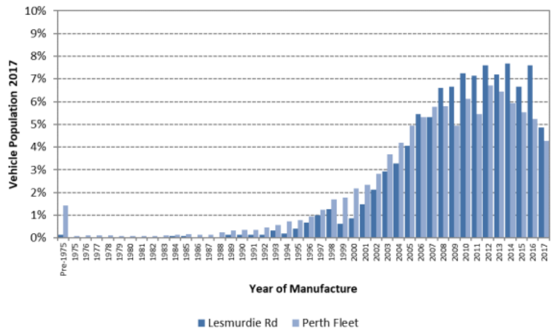
Illawarra Cr S Fleet Representation (tare weight, year of manufacture, fuel type, body type)

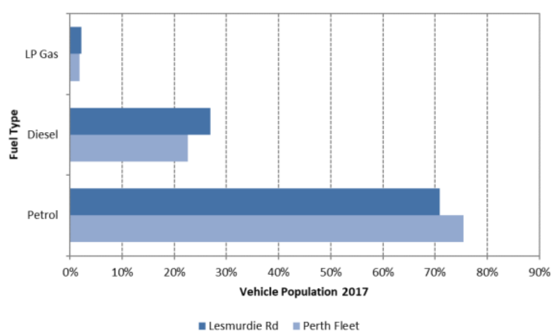
Lesmurdie Rd, Lesmurdie

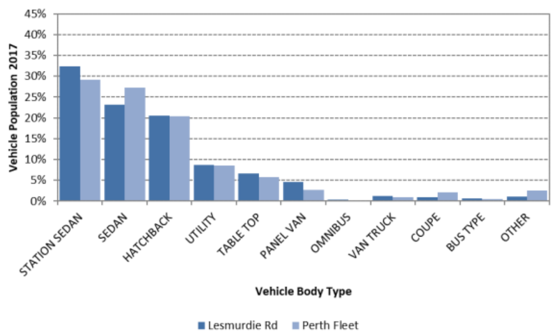
Median strip: Narrow, painted
Slope: 1.4°
Traffic direction: North
7am-2pm traffic flow: 234 cars/hour
Average speed: 40.9 km/h
Average acceleration: -0.07 km/h/s
Fleet composition: Commercial and residential

Fleet Representation (tare weight, year of manufacture, fuel type, body type)



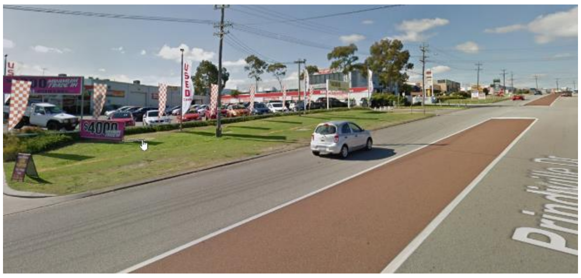






Lesmurdie Rd Fleet Representation (tare weight, year of manufacture, fuel type, body type)

Prindiville Dr, Wangara



Median strip: Wide, painted

Slope: 3.4°

Traffic direction: East

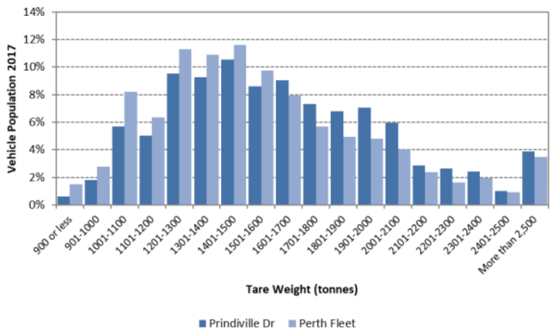
7am-2pm traffic flow: 402 cars/hour

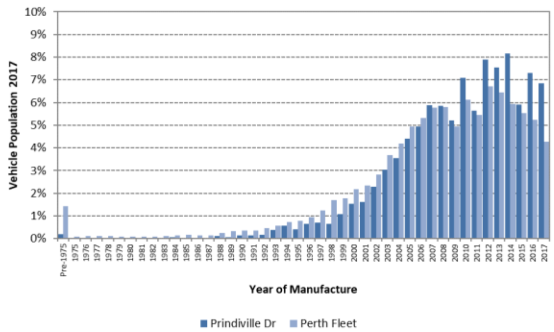
Average speed: 36.2 km/h

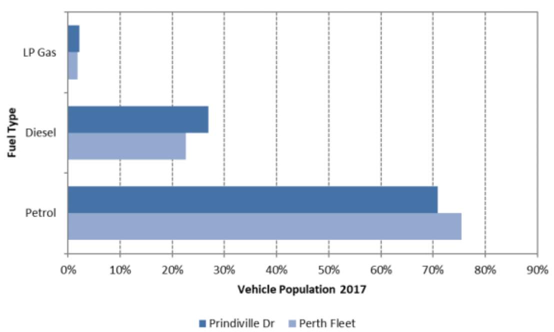
Average acceleration: 0.12 km/h/s

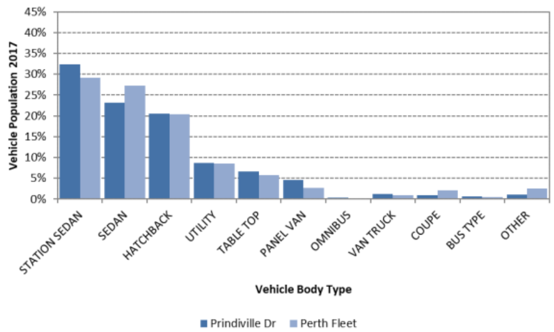
Fleet composition: Commercial

Fleet Representation (tare weight, year of manufacture, fuel type, body type)









Prindiville Dr Fleet Representation (tare weight, year of manufacture, fuel type, body type)

Appendix C — Data used for fleet representation assessment

Postcodes representing the Perth metro area

Postcodes									
6000	6018	6033	6058	6073	6104	6147	6162	6180	6503
6003	6019	6034	6059	6074	6105	6148	6163	6181	6556
6004	6020	6035	6060	6076	6106	6149	6164	6182	6558
6005	6021	6036	6061	6077	6107	6150	6165	6207	6560
6006	6022	6037	6062	6078	6108	6151	6166	6208	6562
6007	6023	6038	6063	6079	6109	6152	6167	6209	6566
6008	6024	6041	6064	6081	6110	6153	6168	6210	6567
6009	6025	6050	6065	6082	6111	6154	6169	6211	
6010	6026	6051	6066	6083	6112	6155	6170	6213	
6011	6027	6052	6067	6084	6121	6156	6171	6214	
6012	6028	6053	6068	6090	6122	6157	6172	6215	
6014	6029	6054	6069	6100	6123	6158	6173	6302	
6015	6030	6055	6070	6101	6124	6159	6174	6390	
6016	6031	6056	6071	6102	6125	6160	6175	6501	
6017	6032	6057	6072	6103	6126	6161	6176	6502	

Vehicle body types measurable by RSD

Measurable
AMBULANCE
ARMOURED TRUCK
BUS TYPE
CONVERTIBLE
COUPE
DOUBLE CAB
FIRE TENDER
GARBAGE WAGON
HATCHBACK
HEARSE
INVITATION VEHICLE
JEEP
KITCHEN TRUCK
MOBILE CARAVAN
MOTOR WAGON
MOURNING COACH
OMNIBUS
PANEL VAN

Measurable
POST VINTAGE VEHICLE
REFRIGERATED VAN
ROADSTER
SCHOOL BUS
SEDAN
STATION SEDAN
STATION WAGON
STREET ROD
STRETCH LIMOUSINE
TABLE TOP
THREE-WHEEL CAR
TOW TRUCK CL 1
TOW TRUCK CL 2
UTILITY
VAN TRUCK
VETERAN VEHICLE
VINTAGE VEHICLE
WORK VAN

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