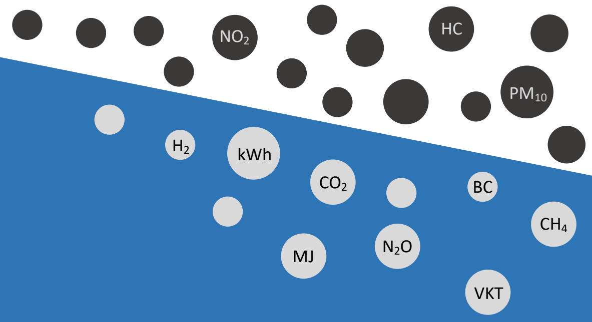

Real-World CO_2 Emissions Performance of the Australian New Passenger Vehicle Fleet 2008-2018 – Impacts of Trends in Vehicle/Engine Design

The research presented in this report is independent and has not been funded by an external organisation. This report has been prepared with all due diligence and care, based on the best available information at the time of publication. TER holds no responsibility for any errors or omissions within this document. Any decisions made by other parties based on this document are solely the responsibility of those parties.

Transport Emission Energy Research

TER (Transport Energy/Emission Research Pty Ltd)
https://www.transport-e-research.com/

Author: Robin Smit
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0. Glossary

Carbon dioxide equivalent (CO_2-e) emission – CO_2-e emissions are computed by multiplying emissions of a particular greenhouse gas with its Global Warming Potential (GWP), and taking the sum of these emissions.

Continuously Variable Transmission (CVT) – CVT is an automatic transmission system that can change seamlessly through a continuous range of effective gear ratios.

Light commercial vehicle (LCV) – LDV primarily constructed for the carriage of goods.

Light-duty vehicle (LDV) – Vehicle less than or equal to 3.5 tonnes Gross Vehicle Weight.

Greenhouse Gas (GHG) Emissions – GHG emissions are expressed as 'carbon dioxide equivalent' (CO_2-e) emissions.

Global Warming Potential (GWP) – GWP was developed to allow comparisons of the global warming impacts of different gases. GWP is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2), which has a GWP of 1. The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. The time period usually used for GWPs is 100 years. Methane (CH_4) is estimated to have a GWP of 28–36 over 100 years. Nitrous Oxide (N_2O) has a GWP 265–298 times that of CO_2 for a 100-year timescale. Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) are sometimes called high-GWP gases because, for a given amount of mass, they trap substantially more heat than CO_2. The GWPs for these gases can be in the thousands or tens of thousands.[1,2]

Gross vehicle weight/mass (GVW/GVM) – Maximum vehicle weight/mass when fully loaded as specified by the manufacturer.

Passenger Vehicle (PV) – LDV designed primarily for the carriage of people, such as cars, station wagons, SUVs and people movers.

Sports utility vehicle (SUVs) – LDV designed as an off road vehicle with two/four wheel drive capability, high ground clearance and a wagon body type.

Tare weight/mass – The weight/mass of an empty standard vehicle with all of its fluids (oils, coolants) but with only 10 litres of fuel in the tank.

1. Introduction

A recent TER study provided a historic review of vehicle fuel efficiency and CO_2 emission legislation in Australia.[3] The majority of state and territory governments across Australia have either announced or are developing zero emission and/or electric vehicle policy frameworks.[4] There are, however, no coordinated national policy measures in place in Australia that specifically mitigate CO_2 emissions – or rather greenhouse gas (GHG) emissions from road transport. For instance, Australia does not have mandatory fuel efficiency and/or CO_2 vehicle emission standards, which are internationally recognised as a key and fundamental policy measure to reduce GHG emissions. This is in contrast with e.g. the US, EU, Canada, Japan, China, South Korea and India.[5]

A historic analysis showed that Australia has attempted to impose CO_2 or fuel efficiency standards on light-duty vehicles a number of times over the past 20 years or so, but without success.[3] At this stage it is unclear if, and if so when, mandatory CO_2 emission standards will be adopted in Australia.

Fuel efficiency and CO_2 emissions are not the same as greenhouse gas (GHG) emissions. Greenhouse gases include CO_2 but other substances as well, such as water vapour, methane (CH_4), nitrous oxide (N_2O), ozone (O_3), chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs).

The available evidence suggests that CO_2 dominates GHG emissions from Australian road transport. For instance, a national motor vehicle emission inventory[1,2] estimated that road transport in Australia released 74.8 million tonnes of 'carbon dioxide equivalent' or CO_2-e emissions into the atmosphere per year. CO_2, CH_4 and N_2O made up 98.5%, 0.5% and 1.0%, respectively, of total CO_2-e emissions from Australian road transport.[6] In Australia, road transport contributed 16% to total CO_2 emissions in 2000 and this contribution has been growing to 17% in 2010 and 22% in 2017.[6,7,8,9] Total CO_2 emissions from road transport have increased by 31% in the period 2000-2017.[8] The situation is similar for total GHGs.[3] This trend is expected to continue, in line with expected population growth. For cost-effective policy action it is important to 1) properly understand what is driving this increase, and 2) to have accurate information on the CO_2 emissions performance of the on-road fleet in the real world.

Total CO_2 emissions for road transport (E, g) is computed as the sum of the products of total vehicle kilometres travelled (VKT_i, km) for vehicle class i and average on-road fleet CO_2 emission rate (e_i, g/km) for vehicle class i:

$$E = \sum VKT_i \times e_i \qquad \text{(Equation 1)}$$

[1] It is noted that CFC/HFC emissions were not estimated in the study. CFC/HFC emissions derive from mobile vehicle air conditioning systems, and are released by leakage and car accidents. They can potentially be significant given their high GWP values.

[2] Although, GHG emissions from road transport are dominated by CO_2, regulation of CH_4, N_2O and CFC/HFC emissions should be considered to prevent adverse policy impacts. For instance, omission of methane emission regulation, could indirectly promote CNG vehicles without taking into account the issue of 'methane slip' from this type of vehicles.[10] Similarly, modern emission control technology such as SCR may significantly increase nitrous oxide emissions.[11]

[3] Road transport contributed 12% to total CO_2-e emissions in 2000 and this contribution has been growing to 13% in 2010 and 16% in 2017. Total CO_2-e emissions from road transport have increased by 29% in the period 2000-2017.[8]

Equation 1 is important as reduction of **total** GHG emissions from road transport is – or rather should be – the actual objective. Total GHG emissions relate to international accords like the Paris Agreement, which aims to keep global warming within 1.5 °C. This objective requires transport to be zero CO_2-e emissions by 2050. Given the slow fleet turnover, this would require selling 100% zero emission vehicles by the early 2030s and by 2035 at the latest.[12]

Slow fleet-turnover implies that only a small portion of the on-road fleet can put downward pressure on *e*, i.e. new vehicles. Once a vehicle is purchased, its average (annual) real-world CO_2 emission rate is approximately fixed (ignoring the effects of e.g. engine ageing and changing driving conditions). New vehicles with significantly lower mean CO_2 emission rates, will penetrate the fleet, and over time will reduce *e,* as older vehicles are scrapped and exit the on-road fleet. It is thus important to understand the on-road and real-world CO_2 emissions performance of the new vehicle fleet in Australia.

Passenger vehicles, light commercial vehicles and heavy-duty vehicles (trucks, buses) contributed 54%, 19% and 27%, respectively, to total CO_2 emissions from road transport in 2017.[8] Given its dominant contribution to GHG emissions from road transport, this study focusses on CO_2 emissions for an important vehicle class: **passenger vehicles** (PVs), which include cars and SUVs.

The Australian Bureau of Statistics (ABS) reported that total travel by passenger vehicles (VKT_{PV}) in Australia was 142 billion kilometres in 2000. This has been growing to 176 billion kilometres in 2016, an increase of 24%.[13] This trend imposes increasing pressure on e_{PV}. It means that the average on-road CO_2 emission rate continually needs to reduce strongly to 1) offset the growth in kilometres travelled, and 2) reduce total GHG emission loads from road transport.

There is a general expectation and acceptance that mean CO_2 emission rates of the Australian new passenger vehicle (PV) fleet will autonomously reduce over time, due to technological improvements enforced by overseas vehicle emissions legislation.[14] The assumption of an autonomous reduction in fleet average CO_2 emissions underpins recent cost-benefit analysis studies conducted by the Australian Government.[5]

This report will show that this assumption is likely incorrect and that CO_2 emissions performance of new passenger vehicles has, in fact, stabilised, and increased in recent years. This creates a significant policy issue. As part of a global response to climate change, the Australian Government has internationally committed to reduce greenhouse gas emissions by 26-28% below 2005 levels by 2030.[5] As the key variables VKT_{PV} and e_{PV} in equation 1 are both increasing for passenger vehicles, growth in total CO_2 emissions from PVs is increasing at an accelerating rate, rather than decreasing.

2. Objective

The objectives of this study are 1) to perform a trend analysis of fleet average real-world CO_2 emissions performance of new passenger vehicles sold in Australia in the period 2008-2018, and 2) to examine the technological reasons for the observed trends.

3. Reported Fleet Average CO_2 Emission Rates in Australia

3.1 Official CO_2 emission rates for new vehicles

The National Transport Commission (NTC) has published official fleet average CO_2 emission rates for new Australian light-duty vehicles (LDVs) from 2005 onwards.[15] LDVs include cars, SUVs and light-commercial vehicles (LCVs). The Federal Chamber of Automotive Industries (FCAI) collects data from all manufacturers on new car sales and supplies these data to the NTC. The reported CO_2 emission rates for passenger vehicles (cars, SUVs) are about 90% of the reported CO_2 emission rate for LDVs.

Australia's performance is best understood when compared to international best practice. Figure 1 shows the official Australian passenger fleet average CO_2 emission rates by year of manufacture, together with those reported for the EU, USA and Japan. The overseas CO_2 data has been collected from a number of publications.[16,17,18,19]

It is clear that the Australian on-road fleet exhibits a distinct CO_2 emissions performance as compared with Europe, the USA and Japan.

New PVs in Australia have significantly higher mean CO_2 emission rates in grams per kilometre travelled (and thus fuel consumption). Moreover, the differences between Australia and the other jurisdictions have been increasing over time.

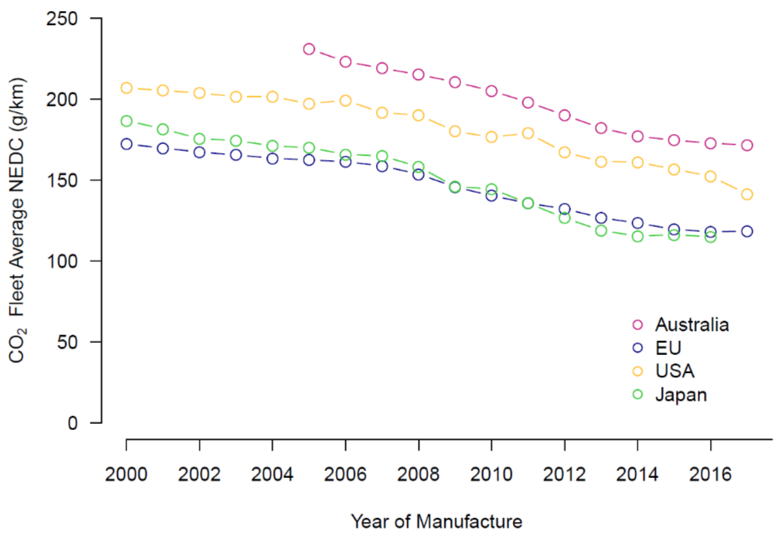

Figure 1 – Reported 'official' new PV fleet average CO_2 emission rates for major jurisdictions (NEDC).

Although the absolute difference over a twelve year time span is similar, Australia has increased its relative difference with:

- the EU from about 40% to 45%,
- the USA from about 15% to 20%, and
- Japan from about 35% to 50%.

These data confirm that new Australian PVs have not reduced CO_2 emission rates as fast as the other major jurisdictions in a relative sense. This is likely due to a number of factors, including a lack of mandatory GHG/CO_2 emissions and/or fuel efficiency standards, a strong and sustained growth in the sales of large and heavy vehicles, and a worse CO_2 emissions performance for diesel cars, combined with increased diesel PV sales. These factors are discussed in more detail later in subsequent sections.

3.2 The issue with officially reported CO_2 emission rates for new vehicles

Figure 1 shows the official PV fleet average CO_2 emission rates reported in several jurisdictions. There is, however, an issue with these data. It is well-known that **real-world** emissions and fuel consumption deviate substantially – and increasingly – from laboratory tests that are used to produce the officially reported CO_2 figures. This discrepancy is often referred to as 'the gap'.

For instance, international on-road emissions tests have consistently shown that the CO_2 emissions 'gap' for PVs has grown from about 10% in 2001 to more than 40% in 2015[4].[17,18] Similar results have been found in a 2017 study conducted by the AAA where limited Australian on-road emissions testing suggests that the CO_2 gap changed from 16% for Euro 4 PVs to 42% for Euro 6 PVs.[20]

So, in reality, the reduction in CO_2 emission rates (Figure 1) is not as large as one may be led to believe when examining the (official) laboratory results.

There are multiple reasons for this gap, such as the laboratory test protocol itself, and strategies used by car manufacturers (and allowed by the test) to achieve lower emissions in laboratory conditions. The official test uses the New European Drive Cycle (NEDC), which was developed in the early 1970s and consists of mild accelerations and constant speeds that do not reflect modern driving. In addition, the test procedure allows for several 'tolerances' and 'flexibilities' that have been increasingly used by car manufacturers to get favourable results in the laboratory. For instance, the EU regulation allows manufacturers to define resistances for the official test for a pre-production vehicle. Such a vehicle may be stripped from auxiliaries, use low-resistance and overinflated tires, use high-performance lubricants, and carefully select a favourable test track for coast down tests, among other options. This has led to unrealistically low fuel and emission test results in the laboratory.[21,22]

To address the gap issue, at least to some extent, the EU adopted a new test procedure in 2017 called the Worldwide Harmonized Light-duty Test Procedure (WLTP). However, CO_2 targets will still be assessed using the NEDC test up to 2020, after which new WLTP based targets will be developed and used. Although the USA uses different test procedures than Europe, they also suffer from an increasing gap between the official 2-cycle FTP test and real-world emissions.[23] The USA already uses a 5-cycle test to better estimate real-world fuel use and emissions. The 5-cycle test is expected to be a reasonable approximation of US real-world fuel efficiency and CO_2 emission rates, and may even be slightly conservative.[24]

If the reported 'official' CO_2 emission rates of new Australian PVs are increasingly inaccurate, and no real-world emission tests have been conducted in Australia since 2008 (refer to section 3.4), then the question is: *What are the actual CO_2 emission rates of new PVs on the road?*

This study has combined available data sources to estimate more realistic CO_2 emissions for new Australian PVs, and examine the impacts on total emissions, as well as the main factors behind the observed changes. The data, methods and results are discussed in the following sections.

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[4] It is noted that the situation is worse for air pollutants, as was demonstrated by the Volkswagen Scandal in 2015, which revealed a systemic issue with diesel cars of all brands. For instance, real world NO_x (nitrogen oxides) emissions have been shown to be 300% higher, on average.

4. Data sources and analysis

4.1 Australian CO_2 emission and vehicle sales data

An analysis of fleet-average CO_2 emission rates requires detailed information on vehicle sales and vehicle-specific CO_2 emission rates. These data are not publicly available in a single database. Therefore, two separate databases were acquired for further analysis.

- Green Vehicle Guide (GVG) CO_2 emissions data by the Commonwealth of Australia.[25]
- VFACTS[(5)] National Report by the Federal Chamber of Automotive Industries (FCAI).[26]

The GVG provides measured NEDC-equivalent CO_2 emission rates for specific vehicles by year of manufacture (2004-2018). These data are provided by the vehicle manufacturers to the Commonwealth. Detailed vehicle information are also provided, including fuel type (petrol, diesel, LPG, electric), drive train (ICEV, Hybrid, PHEV, EV)[6], brand, model, variant, engine capacity, number of cylinders, transmission (automatic, manual, CVT), number of gears and driven wheels (2WD, 4WD). The GVG provides this information for 949 brand-model combinations (car/SUV).

The VFACTS data provides detailed vehicle sales information for specific vehicles by year of manufacture (2008-2018). Detailed vehicle information are provided as well, including vehicle class (car, SUV, commercial), fuel type (petrol, diesel, LPG, electric), drive train (ICEV, Hybrid, PHEV, EV), brand, model, engine capacity, number of cylinders, rated engine power, transmission (automatic, manual, CVT), number of gears, driven wheels (2WD, 4WD), tare weight and gross vehicle weight. VFACTS provides this information for 494 brand-model combinations (car/SUV).

A combined car/SUV database was created using a fuzzy matching technique to stitch the databases together. Text strings were created in both databases that provide a unique description of each individual vehicle. The text strings include model, make, year of manufacture, drive train, fuel type, engine capacity, transmission and wheels driven. The agrep() function in R allows for approximate string matching, where the level of stringency is set with an 'edit distance parameter'. The results were subsequently checked to ensure accurate matching was achieved in the new database. The database contains information for 4,965 Australian vehicles regarding:

- the total number of vehicles sold in the years 2008 to 2018;
- reported CO_2 emission rate by year of manufacture (2008 to 2018); and
- relevant vehicle specifications.

The majority of vehicles were matched successfully. The percentage of total sales for which no CO_2 emissions information was available from the GVG database varied from 2% to 6%, depending on the year of manufacture. Therefore, regression modelling was conducted to fill in the data gaps for conventional vehicle types.

[5] © Federal Chamber of Automotive Industries (2019).
Based on information provided by and with the permission of the Federal Chamber of Automotive Industries.

[6] ICEV = Internal Combustion Engine Vehicle, PHEV = Plug-In Hybrid Electric Vehicle, EV = Electric Vehicle.

4.2 Regression modelling to fill the gaps in CO_2 information

To fill the gaps in the newly created car/SUV database, the statistical relationship between measured CO_2 (response variable) and various predictor variables was examined for two vehicle classes, ICEV-Petrol (ICEV-P) and ICEV-Diesel (ICEV-D). The predictor variables are engine capacity, number of cylinders, rated engine power, transmission, number of gears, driven wheels (2WD, 4WD), tare weight and gross vehicle weight. These variables are known to correlate well with fuel consumption and CO_2 emissions.[27]

Automatic stepwise variable selection was used to determine the appropriate model structure for the two regression models. The step() procedure in R works by iteratively adding or removing variables from the model to ensure that for each iteration the model's goodness-of-fit improves, continuing until no improvements can be made. Interaction terms were included in the model formulation. Residual analysis was conducted to verify normality of error terms, constant error variance and presence and effect of outlying observations (Cook's Distance).

Figure 2 shows the goodness-of-fit plots of the fitted regression models. Adjusted R^2 values are 0.88 for ICEV-P and 0.85 for ICEV-D, implying a reasonable fit. The ratio of maximum predicted to maximum observed CO_2 emission rate ($Ratio_{max}$) is 0.87 and 0.83, respectively. Model fit summaries including regression coefficients are included in Appendix I.

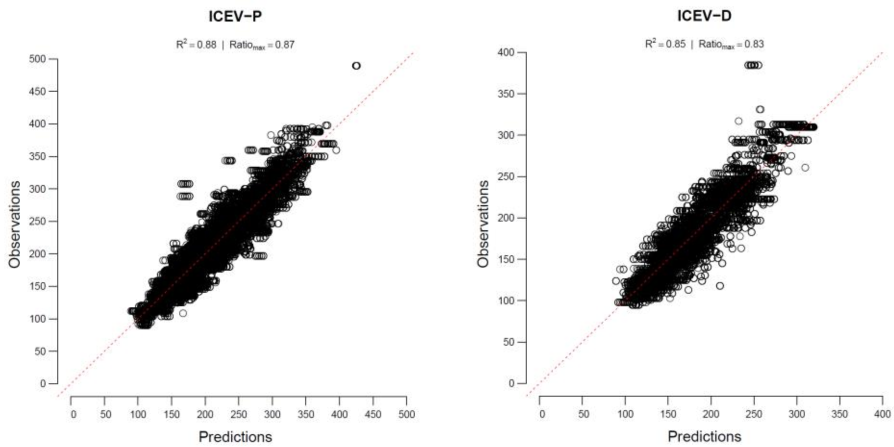

Figure 2 – Goodness-of-fit plots for two regression models to estimate CO_2 emissions (NEDC-eq).

The optimised models have 61 and 57 predictor variables for petrol and diesel ICEVs, respectively. It is noted that simple main effect linear models (without interaction variables) also provided a reasonable fit (ICEV-P adjusted R^2 = 0.85, $Ratio_{max}$ = 0.79; ICEV-D adjusted R^2 = 0.80, $Ratio_{max}$ = 0.88). Residual analysis suggested that more complex models with interaction variables are preferable.

Some predictor variables are correlated to other variables. Engine capacity has a moderate to strong (linear) correlation with number of cylinders (r = 0.92 petrol, r = 0.83 diesel) and rated engine power (r = 0.87 petrol, r = 0.69 diesel). Tare weight and gross vehicle weight are also strongly correlated (r = 0.94 petrol, r = 0.93 diesel). The high level of interdependence among (clusters of) variables (multicollinearity) means that care is needed in the interpretation of the fitted model, as will be discussed later.

The regression models with interaction terms were used to estimate CO_2 emission rates for ICEV-P/D vehicles for which no CO_2 emissions information was available from the GVG database. This last step completed the new car/SUV database for further analysis.

The percentage of total sales for which no CO_2 emissions information was available from the GVG database was reduced from 1.7% – 6.1% to 0.4% – 1.7%, depending on the year of manufacture. For the remaining data gaps there was either missing information on any of the vehicle parameters used in the regression models (e.g. GVM), or the vehicle was a hybrid or PHEV for which no regression models were developed (yet).

4.3 Computing PV fleet average CO_2 emission rates (NEDC)

The detailed Australian car/SUV database was used to compute sales-weighted fleet average CO_2 emission rates for each year of manufacture. As a first step the TER results were compared with the officially reported values by the NTC (Figure 3).

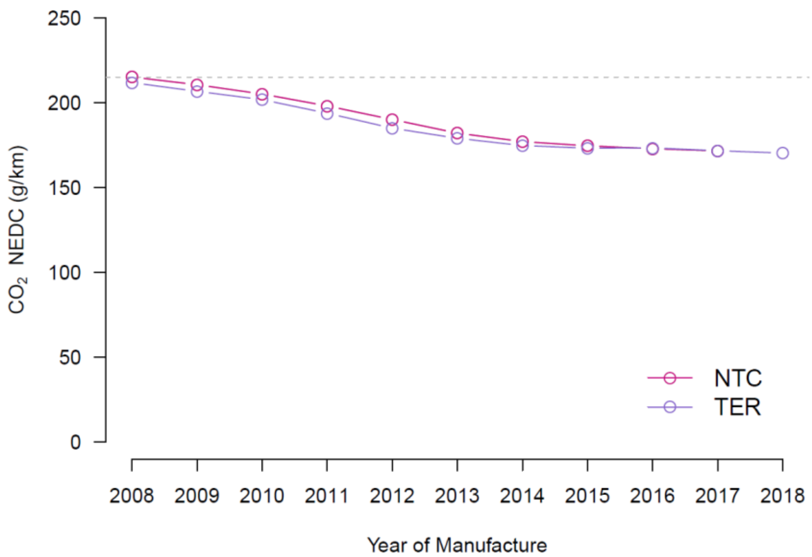

Figure 3 – Reported 'official' average CO_2 emission rates for the new PV fleet, TER vs. NTC (NEDC).

The computed sales-weighted CO_2 emission rates by TER are similar to those officially reported by NTC, but there are small differences. Figure 3 shows that the differences between the data sets vary -2.7% to +0.3% and converge to a 0.1% difference in 2018. The mean difference (2008-2017) between TER and NTC is 1.4%. The new TER database is verified and can now be used to estimate real-world CO_2 emission rates for the new Australian PV fleet.

4.4 Correcting official CO_2 emission rates for real-world driving impacts

Australia used to have an impressive track record regarding vehicle emissions testing. Large in-service vehicle emission testing programs were conducted in Australia in the 1990s up to 2008, surpassing similar programs in the EU and US. They involved chassis dynamometer testing of hundreds of Australian vehicles over different real-world Australian test cycles, generating large databases with raw vehicle measurements.[7] The data underpinned Australian policy design and evaluation work, and development of vehicle emission inventories and software.

Unexpectedly, this has not continued. No significant and publicly available vehicle emission measurement programs have been conducted in Australia since 2008.[28] Since then, only one small study was conducted by AAA in 2017, but these data are not publicly available.[20] So a fundamental issue in Australia is a lack of sufficient and publicly available real-world emissions data for Australian vehicles since 2008.

As a consequence, neither do we know how our on-road fleet is actually performing in terms real-world emissions, nor is Australia able to develop and evaluate evidence-based and cost-effective policy measures to mitigate greenhouse gas and air pollutant emissions from road transport.

This is particularly pressing in the light of 1) internationally lagging fuel quality and emissions legislation in Australia, and 2) clear overseas evidence that the official (laboratory) emission test increasingly and substantially underestimates what is happening in the real world.

In the absence of CO_2 measurements of Australian PVs in real-world conditions, an alternative approach is to review the available information and estimate the impact of real-world driving conditions on officially reported CO_2 emission rates. This has been done in this study.

There have been a number of recent studies that have reported measured gap values for petrol, diesel and hybrid vehicles by year of manufacture.[17,18,20,22] These data have been analysed and used to estimate gap correction factors for the Australian on-road fleet for each year of manufacture (Table 2). The year dependent gap correction factors include a plausible range (min-max).

Table 2 – Real-world CO_2 gap value for new Australian PVs by year of manufacture used in this study.

Year of Manufacture	ADR Standard	Euro Standard	Proportion Diesel	Real-World Gap Minimum	Real-World Gap Mean	Real-World Gap Maximum
2008	ADR79-01	E3	12%	9.2%	9.6%	10.1%
2009	ADR79-01	E3	13%	11.2%	11.8%	12.4%
2010	ADR79-02	E4	15%	10.6%	12.4%	14.2%
2011	ADR79-02	E4	16%	13.7%	15.1%	16.5%
2012	ADR79-02	E4	19%	16.3%	18.1%	19.8%
2013	ADR79-02	E4	18%	18.4%	20.4%	22.4%
2014	ADR79-03	E5	18%	17.2%	19.9%	22.7%
2015	ADR79-03	E5	17%	19.8%	23.0%	26.1%
2016	ADR79-03	E5	18%	21.9%	25.5%	29.2%
2017	ADR79-04	E5	17%	26.1%	30.4%	34.7%
2018	ADR79-04	E5	17%	28.8%	34.0%	39.2%

[7] See for instance https://www.infrastructure.gov.au/vehicles/environment/emission/index.aspx.

The estimated gap corrections consider:

- The proportion of petrol/diesel vehicles in the sales data. This proportion can be readily computed with the detailed vehicles sales data included in the new PV database.
- The difference in vehicle emissions legislation between the EU and Australia. Australia does not have mandatory vehicle CO_2 emission or fuel efficiency standards in place. However, Australia does have emission standards for air pollutants (Australian Design Rules or ADRs) and follows the EU emission regulations since 2003. Adoption of these EU vehicle emission standards has historically been lagging behind the European Union, varying from 2-7 years. Euro standards were matched with corresponding years of manufacture in order to properly allocate overseas gap data to the Australian PV fleet.

The gap values in Table 2 have been used to correct the officially reported CO_2 emission rates and estimate real-world sales weighted CO_2 emission rates for the new Australian PV fleet. Both officially reported NTC and computed TER (NEDC-equivalent) values (Figure 3) have been used. The results are shown in Figure 4. The officially reported (NEDC-equivalent) values (Figure 3) are also included again.

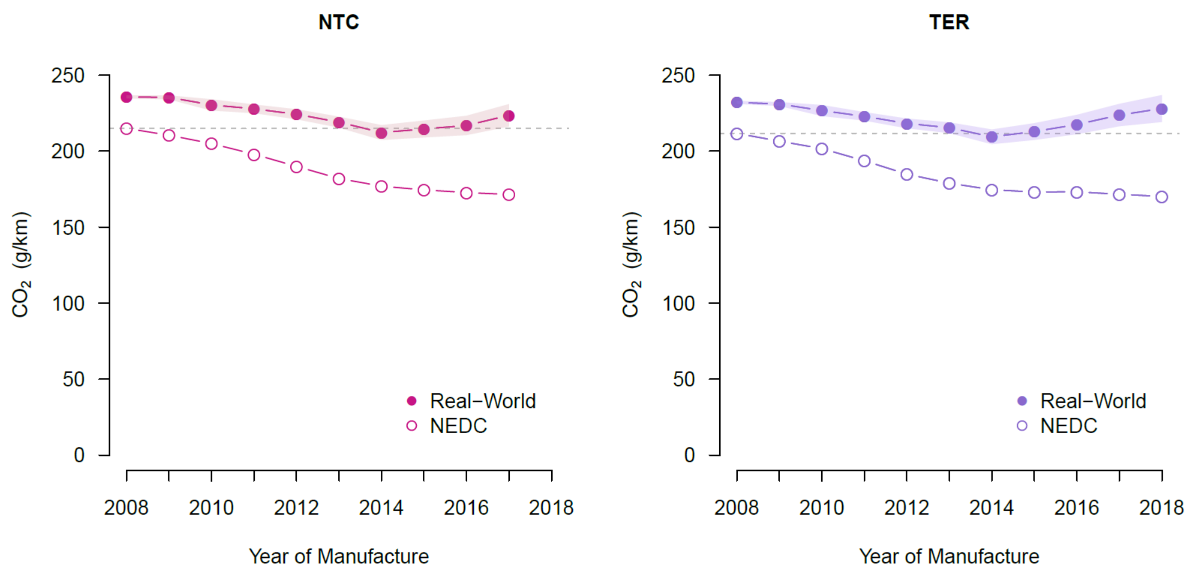

Figure 4 – Average real-world CO_2 emission rates for the Australian new PV fleet.

The values presented in Figure 4 (solid dots) provide the best estimate of the actual on-road average CO_2 emission rates for new Australian passenger vehicles. The solid dot points show the gap-corrected values using the mean gap values in Table 2, whereas the colour shaded area shows the plausible range in which the actual mean CO_2 emission rate is expected to fall. The grey dashed lines show the emission rate in 2008. It can be used to assess the difference with subsequent years.

The officially reported (NEDC) figures (clear dots) suggest a consistent downward trend in fleet average CO_2 emission rates in the order of a 2-4% reduction per annum in the period 2008-2014, slowing down to about 1% per annum, for recent years.

In contrast, the data corrected for real-world driving suggest a different story for new Australian PVs. In 2008, the average real-world CO_2 emission rate was 10% higher than the officially reported value (Table 2). This real-world emission rate then also reduced, but at a lower rate in the period 2008-2014, on average by 1.5% per annum. However, the real-world emission rate has been increasing with +2% to +3% since 2015.

The downward trend has changed into an upward trend since 2015. As a consequence, little to no progress has been made regarding mean real-world CO_2 emission rates for PVs in the period 2008-2018. In fact, the mean real-world fleet emission rate e_{PV} in 2018 is estimated to be similar or exceed the rate in 2008. If the trend continues, mean real-world fleet emission rate in 2019 and beyond will exceed emission rates in previous years.

The discrepancy between official and real-world driving has increased in the 2008-2018 period (Table 2). Figure 5 shows the discrepancy in absolute terms as (fleet average) excess CO_2 emission rates, including the plausible range in coloured shading.

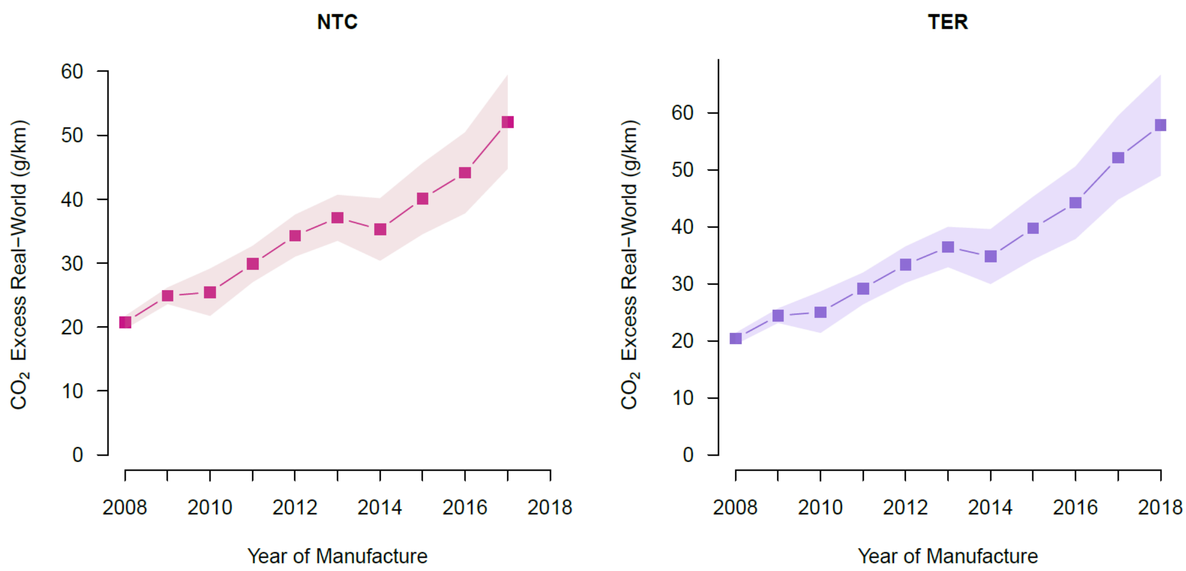

Figure 5 – Real-world mean excess CO_2 emission rates for new Australian PVs.

4.5 Assessing the relevance of the gap in relation to total CO_2 emissions

According to the Federal Department of Environment and Energy (Australian Greenhouse Emissions Information System - AGEIS) total CO_2 emissions from Australian road transport was 82,151,130 tonne/annum in 2017, of which 44,169,770 tonne/annum (54%) was emitted by a vehicle class defined as ‘cars’.[7] This is the latest year for which the information is available at the time of writing the report.

The Australian Bureau of Statistics (ABS) reported that total VKT for passenger cars was 175,899 million kilometres in 2016 and 179,761 kilometres in 2018.[13]. Total annual excess emissions can be estimated by making assumptions on the proportion of VKT by model year and using the mean gap values presented in Figure 5.

Table 3 shows the calculation and assumptions for one base year (2018). Note that excess CO_2 emissions for vehicles older than 2008 are assumed to be the same as those for 2008.

Table 3 – Total real-world CO_2 gap emissions for base year 2018.

Year of Manufacture	Vehicle Age	Proportion VKT 2018	VKT in 2018 (million km)	Mean Real-World CO_2 Gap (g/km)	Total Excess CO_2 Emissions (tonne)
< 2008	10+	23.2%	41,794	(20)	835,889
2008	10	5.0%	8,988	20	183,359
2009	9	5.5%	9,887	24	241,546
2010	8	6.0%	10,786	25	270,085
2011	7	6.5%	11,684	29	341,294
2012	6	7.0%	12,583	33	420,000
2013	5	7.5%	13,482	36	491,747
2014	4	8.0%	14,381	35	500,389
2015	3	8.5%	15,280	40	607,806
2016	2	8.8%	15,729	44	696,122
2017	1	9.0%	16,178	52	843,630
2018	0	5.0%	8,988	58	519,716
Total	-	100.0%	179,761	-	5,951,581

The total estimated excess CO_2 emission for base year 2018 is estimated to be 5,952 ktonne, which is a significant portion (13%) of total reported CO_2 emission from cars.

It is noted that the assumed proportions in VKT by year of manufacture/age (Table 3) are initial estimates that only roughly capture the expected reduction in vehicle travel with vehicle age. A detailed fleet model that accounts for differences in vehicle type (e.g. small passenger car, compact SUV), fuel type and vehicle age would provide a more accurate picture. TER has developed a fleet model that can do this (AFM, Australian Fleet Model, Appendix II). The tool estimates the on-road vehicle population and total (vehicle) kilometres travelled (VKT) for 1,240 vehicle categories for different base years. The tool explicitly simulates changes in vehicle population, and uses relationships between vehicle age, vehicle type and annual mileage or scrappage rates. Use of this tool is outside the scope of this study.

The approximate and generic age-dependent VKT proportions in Table 3 were subsequently combined with total VKT data for previous base years (ABS) to estimate total VKT for each year of manufacture for a particular base year. These VKT estimates can then be multiplied with the official and real-world CO_2 emission rates by year of manufacture, and finally summed, to estimate total CO_2 emissions for the on-road passenger vehicle fleet (cars, SUVs). The results are shown in Figure 6.

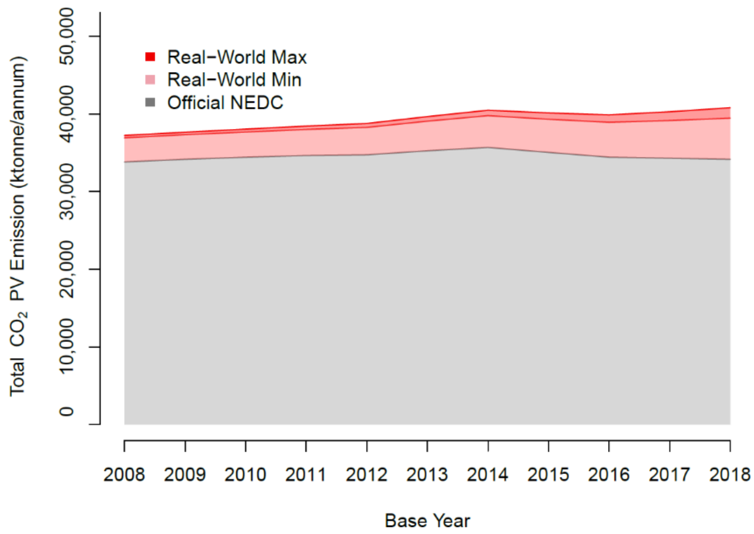

Figure 6 – Total CO_2 emissions by base year for the on-road Australian **new** passenger vehicle fleet.

The bottom up calculation shown in Figure 6 suggests that total real-world CO_2 emissions have increased with about 10% in the period 2008-2018, which is roughly in line with the increase in total VKT. Total real-world CO_2 emissions for PVs is estimated to have changed from 36.9 – 37.2 million tonnes of CO_2 in 2008 to 39.5 – 40.8 million tonnes in 2018 (plausible range). If the officially reported NEDC based values are used, total CO_2 emissions do not change in this period.

The total CO_2 emission estimate for passenger vehicles (Figure 6) is 89 – 91% of the figure reported by AEGIS in 2017 for 'cars' (44,170 ktonne). The reasons for this difference could include:

- unaccounted factors (ageing, increased congestion)
- uncertainty in total (ABS) VKT estimates,
- uncertainty in VKT proportions (Table 3),
- a potential difference in vehicle class definitions (different data sources),
- uncertainty in the estimated real-world gap value, and
- uncertainty in reported AEGIS emissions.

If VKT, ageing, congestion and vehicle definition are minor factors, and AEGIS is assumed to be accurate, then the results suggest that the real-world gap may be even larger then was conservatively assumed in this study.

AEGIS reports a lower increase of 6% in CO_2 emissions from cars for the slightly shorter period 2008-2017.[8] It is noted that AEGIS reports a substantially higher increase in total CO_2 emissions from LCVs (27%) and trucks/buses (21%) in the same period, which suggests that a similar research study into these vehicle classes would be useful.

The largest difference between official and real-world emission estimates occurs in 2018, as expected. For this base year it leads to an additional total CO_2 emission between 5.3 and 6.6 million tonnes (plausible range).

4.6 Trends in fleet-averaged vehicle specifications

Overseas studies that have found that vehicle design parameters such as weight, power and size strongly influence CO_2 emissions.[23] The sales-emission-vehicle parameter database created in this study was used to compute sales-weighted mean values for each available design parameter and each year of manufacture. It is noted that 'transmission' is a factor variable with three levels (manual, automatic, CVT), so instead of the mean value, the proportion of total sales for each level was computed for each year of manufacture.

Figure 7 shows the trends in mean (sales weighted) vehicle parameters in the period 2008-2018.

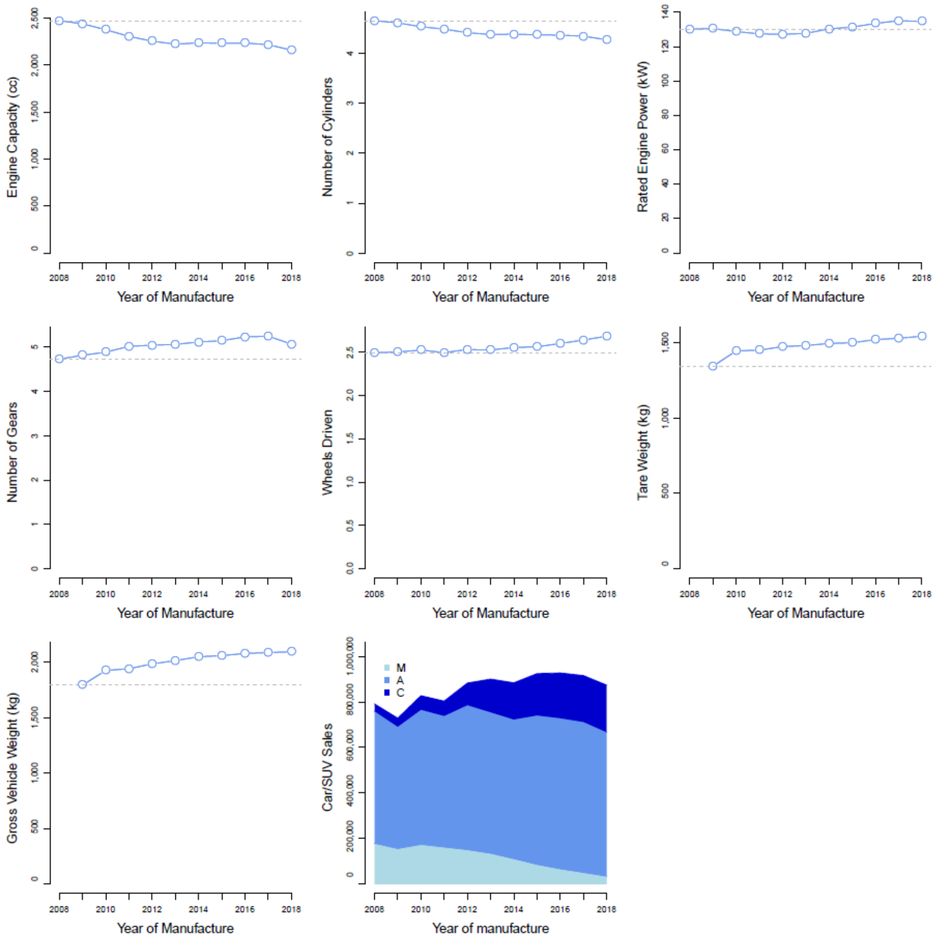

Figure 7 – Time-series of mean passenger vehicle design parameters by year of manufacture.

It is clear that there have been some significant changes in sales weighted mean values for the eight vehicle parameters for passenger vehicles.

- **Engine downsizing** – in the period 2008-2018, mean engine capacity and the mean number of cylinders have reduced with 13% and 8%, respectively. As a consequence, there is a clear and consistent trend of engine downsizing in the new Australian PV fleet.
- **Engine performance** – average rated engine power for PVs has increased slightly with 3% in the 2008-2018 period.
- **Drive train** – both (mean) number of gears and wheels driven have increased with 7% and 8%, respectively, in the 2008-2018 period. The proportion of automatic transmissions has remained rather constant over time (~70%), but there has been a significant shift from manual transmissions to CVT. In 2008, 23% of sold PVs had manual transmissions and 4% had CVT. In 2018 the proportions have reversed with 4% of sold PVs having manual transmissions and 24% having CVT.
- **Vehicle weight** – both tare weight and gross vehicle weight have consistently increased over the period 2009-2018[8], i.e. tare weight by 15% and GVM 17%. Vehicle weight is well known to strongly affect fuel use and CO_2 emission rates, as heavier vehicles require more energy to move.[29,30] So this parameter is expected to be an important factor.

4.7 Impacts of vehicle specification trends on fleet average CO_2 emissions

The analysis in the previous section demonstrated that vehicle manufacturers have made significant changes in vehicle specification of Australian PVs over the 2008-2018 time period. The next step is to examine the **relevance** of each vehicle design parameter in relation to the observed trend in mean CO_2 emission rates.

This will assist with:

1) understanding which developments in the vehicle market have had beneficial, adverse or immaterial impacts on fleet average CO_2 emission rates, and
2) provide useful information for the development of cost-effective mitigation policies

The regression analysis showed that the average sales weighted fleet CO_2 emission rate e_{PV} is a complex function of various vehicle parameters, including interactions between these parameters. The emission rate is also dependent on vehicle design parameters that were not available from the VFACTS/GVG data. These would include, for instance, increased use of engine technologies such as Gasoline Direct Injection (GDI), Variable Valve Timing (VVT), turbocharging and cylinder de-activation. The latter is captured, to some extent, by the time variable 'year of manufacture', which is included in the regression models.

[8] The weight data for 2008 were excluded as the sales-weighted proportion of missing values was high (34%).

As was discussed before, vehicle parameters are often correlated and complex interactions exist, which means that analysis of (standardised) regression coefficients is not possible. Quantifying the actual impacts of individual parameters would require more advanced statistical analysis (e.g. principal component analysis).

As an alternative approach, the regression models have been used to compute the impact of individual variables, or clusters of variables, for a set of predefined scenarios. Variables that are highly correlated are clustered and they describe a particular aspect of vehicle design. Trends in tare weight and GVM are assessed together. Similarly, engine capacity, number of cylinders and rated engine power are clustered to describe the impacts of changes in engine size and performance.

The base scenario reflects the mean vehicle design parameters for a particular vehicle type (ICEV-P or ICEV-D), year of manufacture 2009 and automatic transmission. Individual variables, or clusters of variables, are then varied to reflect mean vehicle design parameters for year of manufacture 2018, creating alternative scenarios that describe particular vehicle design aspects. For transmission, the impact of shifting from manual to CVT was quantified using the base scenario definition.

The scenarios are then input into the respective ICEV-P and ICEV-D regression models to quantify the impact or each vehicle design aspect. Table 4 shows the results.

Table 4 – Impact of vehicle parameter trends in the period 2009-2018 on mean (NEDC) CO_2 emission rates by vehicle type.

Category	Vehicle Parameter	ICEV-P	ICEV-D
Engine size/performance	Engine capacity	– 6.5%	– 2.3%
	Number of Cylinders		
	Rated engine power		
Drive train	Number of Gears	– 0.3%	– 9.5%
	Wheels Driven	+ 0.3%	+ 1.6%
	Transmission shift manual → CVT	– 2.6%	– 11.3%
Weight	Tare weight	+ 2.5%	+ 15.2%
	Gross vehicle weight		

\+ = adverse impact (increase emissions)
– = beneficial impact (reduce emissions)

The results from this study show that the net result of changes in vehicle design in the period 2008-2018 (Figure 4) has likely led to little improvement in fleet average real-world emission rates for new PVs, with a trend reversal since 2015, i.e. an expected increase of 2-3% per annum since 2015. This is in contrast with the general view that CO_2 emission rates are autonomously reducing, based on the officially reported NEDC based figures.

Table 4 suggests that some developments have reduced CO_2 emission rates, but that others have had the opposite effect. Changes in engine design (reduction in both engine capacity and number of cylinders) and transmission (increase in number of gears, shift to CVT) have had a beneficial impact. In contrast, an increase in vehicle weight has had an adverse impact on CO_2 emission rates, which is particularly strong for diesel PVs. The observed shift from 2WD to 4WD vehicles (increase in wheels driven) also has an adverse impact.

This study shows that vehicle manufacturers have not applied changes in vehicle specifications in a way that would have consistently improved fuel efficiency and reduced CO_2 emissions. This is likely caused – to some extent – by a lack of nationally coordinated policy measures and incentives in Australia, such as mandatory GHG emission or fuel efficiency standards for new motor vehicles.

The results in Table 4 suggest that the increase in vehicle weight is likely to be the most important factor that have led to stable and recently increasing CO_2 emission rates.

An underlying trend is the increase in diesel PV sales. Diesel PV sales made up 12% in 2008, which then increased to 19% in 2012. It has been more or less stable in the period 2013-2018, fluctuating between 17-18%. Further analysis shows that diesel PVs are, on average about 40% heavier than petrol PVs. Other diesel vehicle design parameters also adversely affect CO_2 emission rates, including a higher proportion of 4WD vehicles, 15% higher engine capacity and a low portion of CVT transmissions (few percent).

As a consequence, mean CO_2 emission rates for diesel PVs are higher as compared with petrol PVs (about 10% in recent years). The impact on real-world emissions is expected to be significantly larger as diesel cars generally drive more kilometres than petrol cars.

A climate friendly and low greenhouse gas emission image is incorrect for Australian diesel cars.

It is noted that the results in Table 4 are based on NEDC emissions data, not real-world Australian emissions data, which are not available. Therefore, the inherent assumption is that vehicle design parameters impact real-world and NEDC emission rates in a similar fashion. This is a reasonable assumption, as evidenced by other research studies[31]. Nevertheless, real-world emissions data should be used to verify this assumption when they become available.

The result of consistently increasing total travel VKT_{PV} and recently increasing fleet average emission rates e_{PV} is an accelerated increase in total CO_2 emissions from passenger vehicles (cars and SUVs).

5. Conclusions and concluding remarks

This study has pulled together detailed Australian data on vehicle sales, vehicle specification and measured CO_2 emission rates for passenger vehicles (cars, SUVs) for the period 2008-218. A statistical analysis was conducted to 1) fill in data gaps and 2) examine the relationships between observed CO_2 emission rates and vehicle specification parameters. In addition, an international literature review was conducted to develop plausible correction factors to quantify the impact of real-world conditions on measured CO_2 emission rates. The main conclusions from this work are:

- The generally accepted assumption of an autonomous reduction in average CO_2 emission rates (g/km) for passenger vehicles is likely incorrect.
- Official CO_2 emission rates are based on an increasingly unrealistic laboratory test procedure that underestimates real-world fuel consumption and associated CO_2 emission rates (g/km).
- This study finds that these fleet-average CO_2 emissions rates (g/km) for new passenger vehicles have actually stabilised, and are likely increasing since 2015.
- A continuous increase in vehicle weight and a shift to the sale of more 4WD vehicles, in particular for diesel cars/SUVs, are likely factors that have contributed to this.
- Other changes in engine design (reduction in both engine capacity and number of cylinders) and transmission (increase in number of gears, shift to CVT) have had a beneficial impact and have likely offset (to some extent) an increase in fleet-average CO_2 emissions rates (g/km) for new passenger vehicles.
- Nevertheless, total travel (kilometres) is consistently growing, in line with population growth.
- This study estimates that total real-world CO_2 emissions from passenger vehicles have increased with about 10% in the period 2008-2018, from about 37 million tonnes in 2008 to 40 million tonnes in 2018.
- A comparison with the EU, USA and Japan confirms that new Australian passenger vehicles are underperforming in relation to CO_2 emissions (and fuel economy).
- In addition, the difference between Australia and these regions is increasing, which means that the relative performance of Australian passenger vehicle is getting worse.
- A climate friendly image for Australian diesel cars is incorrect, as they have, on average, significantly higher CO_2 emission rates (g/km) than Australian petrol cars.
- A fundamental issue in Australia is a lack of publicly available real-world emissions data for Australian vehicles since 2008.
- Road transport CO_2 emissions increasingly acts as a drag on achieving a reduction in total GHG emissions from Australia.

The available evidence suggests that measures are required to arrest the growth in total CO_2 emissions from passenger vehicles, and ensure that, over time, emissions are actually reduced. Although state, territory and local governments are developing zero emission and/or electric vehicle policy frameworks[4], Australia is currently lacking a coordinated national policy or strategy to mitigate CO_2 emissions from road transport, despite overseas experience that shows that a range of policy options are available. These include, but are not limited to, introduction of mandatory vehicle fuel efficiency and/or CO_2 vehicle emission standards. An integrated policy approach will be required to ensure cost-effective reduction of total CO_2 emissions from the on road fleet.

6. Recommendations for further work

Since this work was unfunded, the scope was restricted. However given the size of the combined vehicle sales, CO_2 emission and vehicle parameter database, there are avenues in which the research can be expanded and refined. Below are some suggestions for further work.

- Refine the analysis with a further breakdown by vehicle type, e.g. petrol vs. diesel PVs.
- Develop CO_2 regression models for hybrid diesel and hybrid petrol vehicles
- Conduct detailed fleet modelling to estimate total travel for individual vehicle classes.
- Expand the analysis to include light-commercial vehicles (LCVs).
- Expand the analysis to include heavy-duty vehicles (trucks/buses).
- Expand the analysis to assess the impact of increased uptake of electric vehicles.
- Correct real world emission factors such as ageing and changes in driving conditions.

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Appendix I – CO_2 regression models (NEDC- equivalent)

Petrol ICEV

predictor variable	estimate	std.error	statistic	p.value
(Intercept)	5.48E+03	4.44E+02	12.3	< 0.01
ec	1.77E+00	1.32E-01	13.4	< 0.01
my	-2.70E+00	2.21E-01	-12.2	< 0.01
tare	-5.04E+00	6.04E-01	-8.3	< 0.01
wdve	1.01E+03	7.13E+01	14.2	< 0.01
gears	-3.85E+02	4.83E+01	-8.0	< 0.01
tCVT	-2.13E+03	2.74E+02	-7.8	< 0.01
tMAN	-6.93E+02	1.29E+02	-5.4	< 0.01
rpow	-4.11E+00	1.58E+00	-2.6	< 0.01
ec^2	-5.88E-06	5.01E-07	-11.7	< 0.01
cyl	-1.14E+03	9.73E+01	-11.7	< 0.01
gvm	5.00E+00	4.45E-01	11.2	< 0.01
gears * tCVT	8.05E+00	1.80E-01	44.8	< 0.01
gears * tMAN	3.21E+00	3.31E-01	9.7	< 0.01
ec * wdve	-2.38E-03	5.05E-04	-4.7	< 0.01
wdve * tCVT	-6.93E+00	4.69E-01	-14.8	< 0.01
wdve * tMAN	1.87E+00	2.63E-01	7.1	< 0.01
my * wdve	-5.05E-01	3.54E-02	-14.3	< 0.01
ec * tCVT	2.20E-02	4.35E-03	5.1	< 0.01
ec * tMAN	1.35E-02	9.90E-04	13.6	< 0.01
tare * tCVT	-2.10E-02	4.62E-03	-4.5	< 0.01
tare * tMAN	-1.02E-02	2.09E-03	-4.9	< 0.01
tCVT * rpow	9.58E-02	2.16E-02	4.4	< 0.01
tMAN * rpow	1.07E-01	5.89E-03	18.2	< 0.01
tare * rpow	-1.91E-04	1.92E-05	-9.9	< 0.01
tCVT * ec^2	-6.91E-06	9.11E-07	-7.6	< 0.01
tMAN * ec^2	-2.18E-06	1.17E-07	-18.6	< 0.01
tare * wdve	6.57E-03	9.36E-04	7.0	< 0.01
wdve * rpow	1.78E-02	2.63E-03	6.8	< 0.01
wdve * ec^2	-3.10E-07	7.17E-08	-4.3	< 0.01
ec * ec^2	-9.69E-10	5.31E-11	-18.2	< 0.01
rpow * ec^2	4.46E-09	4.37E-10	10.2	< 0.01
wdve * gears	-6.98E-01	8.73E-02	-8.0	< 0.01
my * gears	1.91E-01	2.39E-02	8.0	< 0.01
ec * my	-8.54E-04	6.56E-05	-13.0	< 0.01
my * tare	2.57E-03	3.00E-04	8.5	< 0.01
gears * rpow	-2.44E-02	2.41E-03	-10.1	< 0.01
my * tCVT	1.03E+00	1.36E-01	7.6	< 0.01
my * tMAN	3.27E-01	6.41E-02	5.1	< 0.01
gears * ec^2	7.28E-07	5.05E-08	14.4	< 0.01
ec * gears	-3.06E-03	3.85E-04	-7.9	< 0.01
tare * cyl	-3.21E-02	1.45E-03	-22.2	< 0.01
wdve * cyl	3.02E+00	1.94E-01	15.6	< 0.01
gears * cyl	-1.13E+00	1.52E-01	-7.4	< 0.01
my * cyl	5.73E-01	4.84E-02	11.8	< 0.01
ec * cyl	6.42E-03	2.03E-04	31.7	< 0.01
rpow * cyl	-1.01E-02	2.56E-03	-3.9	< 0.01
tCVT * cyl	5.76E+00	1.25E+00	4.6	< 0.01
tMAN * cyl	1.02E+00	3.75E-01	2.7	< 0.01
tare * ec^2	4.35E-09	2.94E-10	14.8	< 0.01
my * rpow	2.15E-03	7.85E-04	2.7	< 0.01
tare * gvm	3.09E-05	9.92E-07	31.1	< 0.01
my * gvm	-2.53E-03	2.22E-04	-11.4	< 0.01
gears * gvm	2.66E-03	2.99E-04	8.9	< 0.01
rpow * gvm	9.30E-05	1.41E-05	6.6	< 0.01
ec^2 * gvm	-1.49E-09	2.79E-10	-5.4	< 0.01
cyl * gvm	6.47E-03	1.06E-03	6.1	< 0.01
wdve * gvm	-1.65E-03	6.39E-04	-2.6	0.03
tCVT * gvm	7.98E-03	3.62E-03	2.2	0.02
tMAN * gvm	-3.30E-03	1.37E-03	-2.4	< 0.01
ec * gvm	-5.24E-06	1.43E-06	-3.7	< 0.01

Diesel ICEV

predictor variable	estimate	std.error	statistic	p.value
(Intercept)	-1.21E+04	1.64E+03	-7.4	< 0.01
ec	1.89E+01	1.25E+00	15.1	< 0.01
gvm	-1.24E+01	7.28E-01	-17.1	< 0.01
gears	3.53E-01	2.68E+00	0.1	0.90
my	6.01E+00	8.17E-01	7.4	< 0.01
wdve	-4.78E+01	6.44E+00	-7.4	< 0.01
tCVT	-4.45E+03	1.51E+03	-2.9	< 0.01
tMAN	-1.51E+02	2.80E+02	-0.5	0.59
rpow	-5.01E+01	5.44E+00	-9.2	< 0.01
tare	1.17E+01	9.67E-01	12.1	< 0.01
cyl	1.94E+03	1.89E+02	10.3	< 0.01
ec^2	-3.17E-03	2.11E-04	-15.0	< 0.01
gvm * rpow	-8.68E-04	4.71E-05	-18.4	< 0.01
ec * tare	1.37E-04	9.17E-06	15.0	< 0.01
tCVT * rpow	3.43E-01	2.31E-01	1.5	0.14
tMAN * rpow	-2.32E-01	2.56E-02	-9.1	< 0.01
gears * tCVT	1.31E+01	1.76E+01	0.7	0.46
gears * tMAN	1.09E+01	8.08E-01	13.4	< 0.01
ec * wdve	4.18E-02	5.19E-03	8.1	< 0.01
wdve * tare	6.28E-03	1.41E-03	4.5	< 0.01
wdve * tCVT	-1.71E+01	3.55E+00	-4.8	< 0.01
wdve * tMAN	2.52E+00	4.72E-01	5.3	< 0.01
rpow * cyl	-6.77E-02	1.87E-02	-3.6	< 0.01
gvm * cyl	1.64E-02	1.41E-03	11.6	< 0.01
gears * rpow	1.29E-01	8.23E-03	15.7	< 0.01
ec * cyl	-7.62E-02	6.03E-03	-12.6	< 0.01
tare * ec^2	-2.18E-08	1.55E-09	-14.0	< 0.01
rpow * ec^2	3.69E-08	6.41E-09	5.8	< 0.01
ec * gears	-2.40E-02	2.22E-03	-10.8	< 0.01
gvm * gears	2.38E-02	1.16E-03	20.5	< 0.01
gears * tare	-2.42E-02	1.60E-03	-15.1	< 0.01
cyl * ec^2	1.69E-05	1.07E-06	15.9	< 0.01
gears * ec^2	2.62E-06	4.07E-07	6.4	< 0.01
gvm * tCVT	1.26E-01	2.90E-02	4.3	< 0.01
gvm * tMAN	3.64E-02	2.81E-03	13.0	< 0.01
tCVT * tare	-1.72E-01	3.19E-02	-5.4	< 0.01
tMAN * tare	-4.03E-02	3.91E-03	-10.3	< 0.01
wdve * ec^2	-9.65E-06	1.06E-06	-9.1	< 0.01
ec * ec^2	-1.30E-08	1.80E-09	-7.2	< 0.01
rpow * tare	5.53E-04	7.07E-05	7.8	< 0.01
tare * cyl	-1.71E-02	2.22E-03	-7.7	< 0.01
gvm * my	6.15E-03	3.63E-04	16.9	< 0.01
my * tare	-5.82E-03	4.81E-04	-12.1	< 0.01
tCVT * ec^2	8.04E-06	6.97E-06	1.2	0.25
tMAN * ec^2	2.17E-06	3.35E-07	6.5	< 0.01
wdve * rpow	3.04E-02	9.58E-03	3.2	< 0.01
gvm * wdve	-2.78E-03	1.02E-03	-2.7	< 0.01
my * tCVT	2.33E+00	7.62E-01	3.1	< 0.01
my * tMAN	4.11E-02	1.39E-01	0.3	0.77
ec * my	-9.35E-03	6.24E-04	-15.0	< 0.01
my * ec^2	1.59E-06	1.05E-07	15.1	< 0.01
my * rpow	2.49E-02	2.71E-03	9.2	< 0.01
my * cyl	-9.26E-01	9.38E-02	-9.9	< 0.01
gvm * tare	-8.77E-06	1.85E-06	-4.7	< 0.01
wdve * cyl	1.16E+00	3.87E-01	3.0	< 0.01
gears * wdve	-5.23E-01	1.88E-01	-2.8	< 0.01
tCVT * cyl	-7.98E+01	1.60E+01	-5.0	< 0.01
tMAN * cyl	-2.43E+00	1.13E+00	-2.1	0.03

Appendix II – AFM (Australian Fleet Model)

Various engine and vehicle design factors impact on vehicle emissions and fuel consumption. Emission simulation therefore requires a detailed breakdown of the on-road fleet. For instance, in the vehicle emissions software 'COPERT Australia' the fleet mix (on-road population, annual mileage, accumulated mileage) needs to be estimated for 226 vehicle classes.

Fleet mix modelling at this level of detail poses certain challenges and requires various assumptions. Published fleet data are often too aggregated to be useful for the high level of detail required for vehicle emissions modelling. In addition, available fleet data sets often apply different vehicle class definitions.

TER developed a fleet mix model called **AFM** (Australian Fleet Model). The tool estimates the on-road vehicle population and total (vehicle) kilometres travelled (VKT) for **1,240 vehicle categories** for different base years. The estimated kilometres travelled for a particular vehicle category (e.g. small ADR79-4 petrol passenger car) are then used to compute weighting factors for all vehicle categories that fall within a composite vehicle class (e.g. petrol car). Figure II.1 shows a schematic of the fleet mix modelling process.

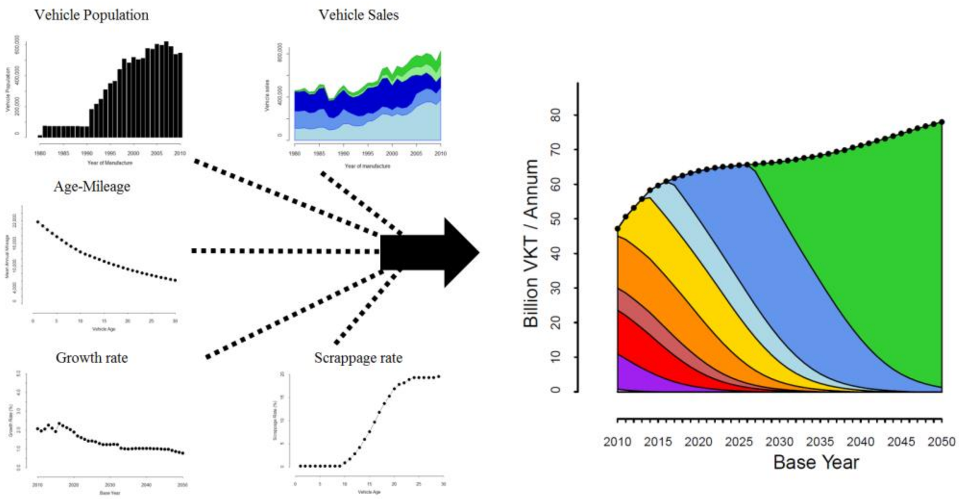

Figure II.1 – AFM fleet mix modelling process.

The first step creates a detailed on-road vehicle population table for current and/or past base years, using various data sets. The next step is to estimate total travel for each vehicle class, which is expressed as total vehicle kilometres travelled per year (VKT/annum). At a more detailed level, vehicle usage is reflected in mathematical relationships between vehicle age and mean annual mileage and between vehicle age and accumulated mileage.

For future years information regarding on-road vehicle population and vehicle sales is not available. Therefore, assumptions need to be made regarding the on-road fleet population and vehicle use. Fleet growth rate and fleet turnover (scrappage) are considered for each vehicle class (40 in total) to simulate the progressive changes in fleet composition over time.

The simulation generates a detailed (future) vehicle population and travel (VKT) data table for 40 vehicle classes and 31 vintage/age categories (i.e. 1,240 model classes) for each base year. The data tables are compressed to 40 vehicle classes and 19 ADR categories. Each ADR category spans a predefined range of vehicle model years. For instance, small ADR79/02 petrol cars include model years 2010-2013. Since not all combinations of vehicle class and ADR exist (e.g. some ADRs apply only to heavy-duty vehicles), the results are compressed VKT tables with a total of 360 model classes for each base year. These data provide a detailed breakdown of the fleet mix population and travel (VKT), which is subsequently used for vehicle emissions modelling.

As a final step, the vehicle population, annual mileage and accumulated mileage data can be converted to, for instance, the COPERT Australia input file format, where an input file for is created for each base year.

Fleet averaged vehicle emission factors can now be computed. In order to do this, estimated total travel for each vehicle class is used to create weighting factors for each vehicle class that belongs to a particular composite vehicle category.

Figure II.2 illustrates the process with an example. The middle chart visualises the detailed fleet mix simulation for a particular Australian vehicle class for base years 2010-2050. The different colours represent ADR categories relevant for this vehicle class. The dotted black line represents total travel (VKT) for this vehicle class for each base year. The two dashed vertical lines represent the VKT distributions across ADR categories for 2010 and 2025. These VKT distributions are normalised by dividing by total VKT (adding up to 100%), and shown on either side as VKT percentage bar plots.

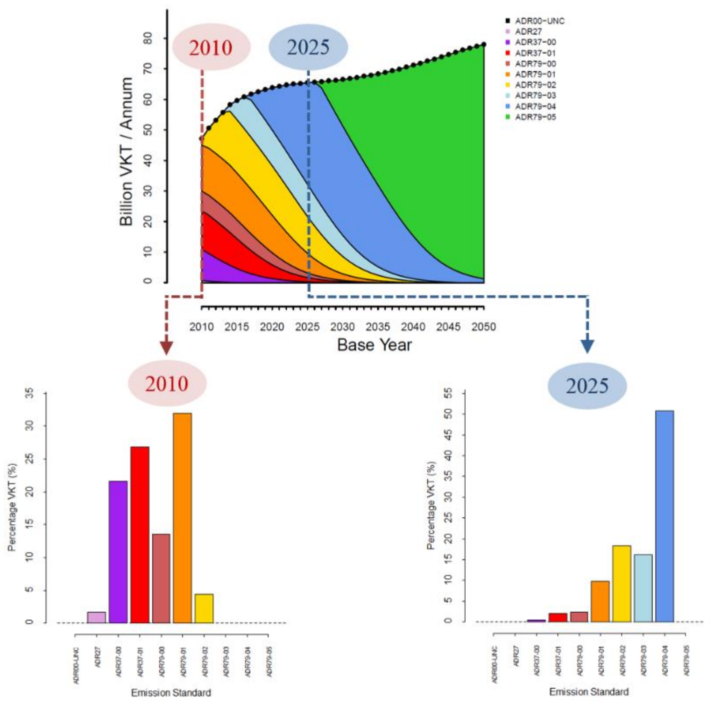

Figure II.2 – Example of weighting factor calculations.

These VKT percentages are subsequently combined with vehicle/ADR category specific emission factors, expressed as grams per km (g/VKT), to compute a fleet average emission factors for this vehicle class. It is noted that different assumptions on e.g. age-mileage or age-scrappage relationships will lead to different estimates of future on-road vehicle population, VKT and accumulated mileage. Therefore, a sensitivity analysis is generally recommended to quantify the uncertainty in predictions.