Real world energy use projections for VFEM

Report prepared for

Ministry of Transport

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Glossary

Term	Definition
BEV	A **battery electric vehicle** uses electric motors instead of internal combustion engines (ICEs) for propulsion using power provided by rechargeable battery packs.
CO_2	**Carbon dioxide** is a greenhouse gas
GVM	**Gross vehicle mass** is the maximum allowed weight of the vehicle when loaded. Light vehicles have a GVM of 4 tonnes or less. Heavy vehicles have a GVM of more than 4 tonnes.
HCV	**Heavy commercial vehicles**
HEV	A **hybrid electric vehicle** integrates a small battery and an electric motor to enhance the energy to distance efficiency of the internal combustion engine. The battery's charge is maintained by the internal combustion engine and regenerative braking - it cannot be charged by plugging into an electrical supply. Hybrids can offer greater fuel economy than a traditional internal combustion engine but can only travel very short distances on electric power only.
ICCT	**International Council on Clean Transportation**
ICE	An **internal combustion engine** is an engine powered through the burning of fossil fuels. The term 'ICE' is often used as shorthand for any vehicle powered by an internal combustion engine, whether petrol or diesel or any other flammable medium.
IEA	**International Energy Agency**
kWh	A **kilowatt hour** is the amount of energy released if work is done at a constant rate of 1 kilowatt (kW) for one hour. Electric car battery capacity is measured in kWh.
LCV	**Light commercial vehicles** including vans, utes and very light trucks less than 4000kg GVM
LPV	**Light passenger vehicles** including passenger cars and SUV's
NEDC	**New European Driving Cycle** is the current test cycle for type approval of light duty vehicle emissions
PHEV	A **plug-in hybrid electric vehicle** is a type of vehicle that has a battery pack that can be charged up by plugging into a regular electricity supply. In this report PHEV includes vehicles that are configured like a regular hybrid, as well as vehicles that use an electric motor for propulsion but also have an internal combustion engine on board to provide power for

	a generator. These are sometimes called range extended electric vehicles (REEV)
REEV	A **range extended electric vehicle** is a vehicle as vehicles that use an electric motor for propulsion but also have an internal combustion engine on board to provide power for a generator, which maintains a minimum charge level on the battery. REEVs can be plugged in and charged up. REEVs do not use the petrol/diesel engine to directly power the wheels. In this report REEVs are included in the PHEVs category.
SUV	Sports utility vehicle
WLTP	**World Harmonised Light Vehicles Test Procedure** is a new type-approval test procedure for light duty vehicles which is expected to be adopted in Europe and Japan.

Summary

This report provides projections of real world fuel and energy consumption for the Ministry of Transport (**MoT**) Vehicle Fleet Emissions Model. These real world factors are intended to represent the average fuel consumption per 100km of new vehicles sold in a given year. These factors represent average fuel consumption of vehicles operating in the real world under all different driving conditions across all different vehicles within the classification.

Real world fuel consumption factors for diesel and petrol ICE (internal combustion engine) vehicles in New Zealand have been estimated by MoT using fuel consumption and travel data from a large data set of fuel card transactions[1].

We have compared New Zealand's real world and type approval fuel consumption trends with international trends. This comparison found that average fuel consumption for new light duty vehicles in New Zealand is higher compared with Europe and Japan, however trends are similar.

To ensure that real world fuel consumption factors are conservative and relevant to New Zealand, we have calculated all fuel consumption figures for other vehicle types and for all projection years relative to MoT real world factors for New Zealand.

The MoT real world factors underpin the analysis in this report. **We recommend that the MoT analysis of real world fuel consumption is regularly updated and that the analysis is extended to include privately owned vehicles if possible.**

We have developed real world fuel and energy consumption projection factors for New Zealand based on the results of an international literature review. We estimate that real world fuel consumption from petrol and diesel light duty vehicles is likely to reduce by approximately 18% and 15% respectively between 2016 and 2030. For heavy duty vehicles we estimate that real world diesel consumption is likely to reduce by approximately 5% for small trucks and 13% for large trucks between 2016 and 2030. These projected improvements in fuel and energy consumption are:

- technically feasible
- cost effective
- reasonably conservative

However these projections go well beyond current regulatory timeframes so they are inherently uncertain. **We recommend that the projections are regularly reviewed and updated.**

[1] Fuel use factors for this project were provided by Ministry of Transport, including factors for light duty vehicles (Wang et al., 2015) and unpublished factors for heavy duty vehicles.

1 Introduction

1.1 Objectives and scope

The Ministry of Transport (**MoT**) is redeveloping the Vehicle Fleet Emissions Model (**VFEM**) to include many more potential fuel and vehicle combinations. This model is used by MoT to predict New Zealand's energy use out to 2040. The current energy use factors in the VFEM are doing a reasonable job of predicting energy use for the period 2001- 2014.

MoT has commissioned a literature review (as opposed to any real world testing) on the likely efficiency gains that might be expected in vehicles manufactured in each of the years 2016 to 2040, for the following energy types:

1. Conventional petrol
2. Conventional diesel
3. Hybrid petrol
4. Hybrid diesel
5. LPG/CNG
6. Plug-in hybrid - Petrol
7. Plug-in hybrid - Diesel
8. Battery electric

These fuels can apply to the following vehicle types:

- Light passenger (cars and SUVS) split into five bands based on engine size (cc) (<1350, 1350-1599, 1600-1999, 2000-2999, ≥3000)
- Light commercial (vans and utes) split into five bands based on engine size (cc) (<1350, 1350-1599, 1600-1999, 2000-2999, ≥3000)
- Motorcycles/mopeds in split into two engine size (cc) bands (<60, ≥60)
- Trucks split into nine bands based on gross vehicle mass (kg) (<5000, 5000-7499, 7500-9999, 10000-11999, 12000-14999, 15000-19999, 20000-24999, 25000-29999, ≥30,000)
- Buses split into three bands based on gross vehicle mass (kg) (3501-7000, 7001-12000, ≥12001)

This project has produced average energy use factors from 2014 to 2040, for the energy and vehicle combinations that are included in international projections. Some energy and vehicle combinations are not included in international projections because they are not considered cost effective or technically feasible (for example **petrol** trucks and buses).

1.2 Methodology

The project comprised three parts:

1. Benchmarking and international literature review
2. Analysis
3. Reporting

This report briefly describes key assumptions and data sources. The uncertainty in projections is also discussed.

In addition to this report there is an excel spreadsheet which includes all raw data, detailed assumptions, and calculations.

1.3 Report layout

This report is structured as follows:

- **Section 2** of summarises the results of our benchmarking and international literature review on real world fuel consumption.
- **Section 3** briefly describes key the methodology including assumptions and data sources.
- **Section 4** summarises the results of our analysis.
- **Section 5** provides key conclusions.

2 Benchmarking and literature review

This chapter comprises two main parts:

- Benchmarking of fuel consumption and trends to determine whether international real world fuel consumption factors and projections can be applied directly to New Zealand.
- Literature review to identify international real world fuel consumption projections and to understand the uncertainty associated with these.

2.1 Benchmarking

Fuel economy trends: type approval values

New Zealand does not have fuel economy standards for vehicles entering the fleet and does not have any domestic vehicle manufacturers. This means that the fuel economy of vehicles entering the fleet depends on international requirements and trends.

New vehicle fuel efficiency standards and targets, as shown in Figure 1, have required significant improvements in fuel efficiency and reduction in carbon dioxide (**CO_2**) emissions from the light duty vehicle fleet globally. The trends shown in Figure 1 are based on the values that vehicles are type approved to when manufactured.

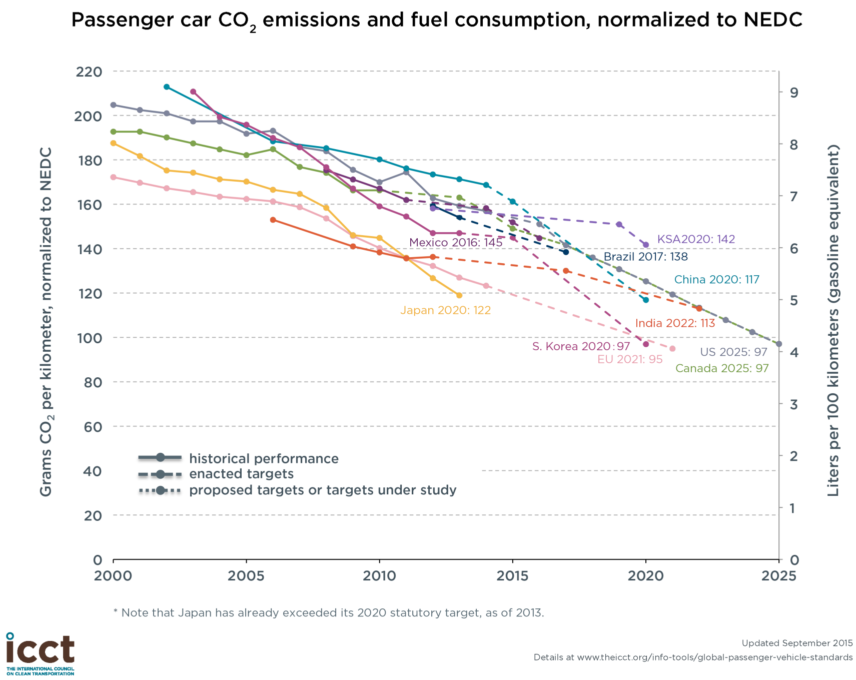

Figure 1: International CO_2 emission standards and targets [Source: ICCT, 2015b]

The majority of vehicles being imported into New Zealand are built to European (new vehicles) or Japanese (used vehicles) standards. Figure 2, shows the trends in type approval emissions from new vehicles entering the New Zealand fleet. This shows that new vehicles entering the New Zealand fleet have higher CO_2 emissions (and fuel consumption) on average compared with European and Japanese vehicles. However, the overall trend in emissions is similar.

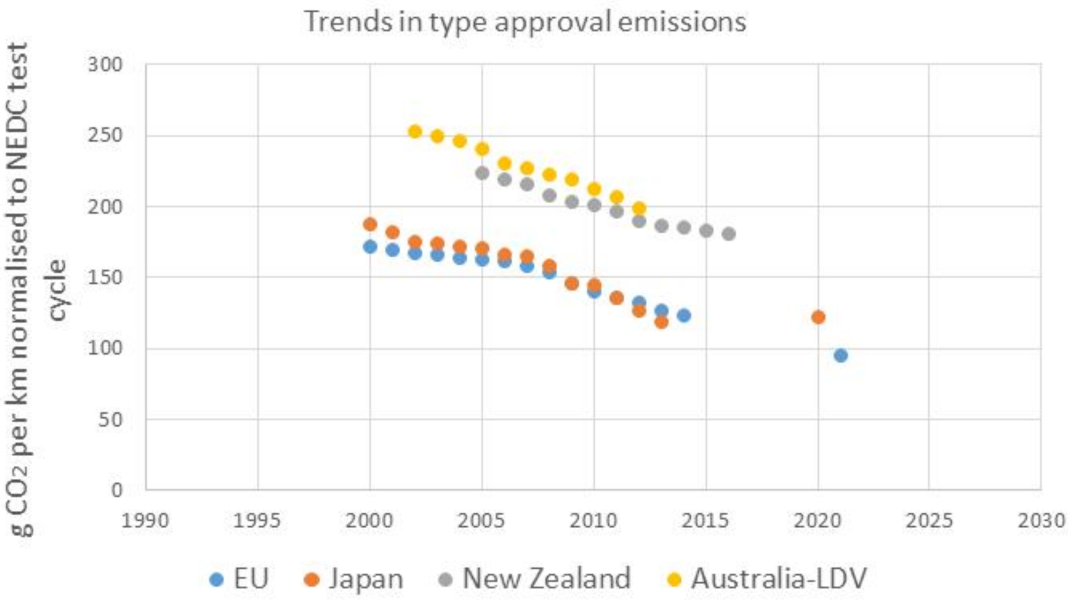

Figure 2: Trends in average type approval CO_2 emissions from new vehicles in New Zealand compared with Europe, Japan and Australia [Source: ICCT, 2015b and MoT, 2016. See accompanying spreadsheet for details]

MoT research has identified a relationship between engine size (or engine displacement measured in cubic centimetres or cc) and fuel efficiency for New Zealand vehicles (Wang *et al*., 2015). To better understand the difference between average New Zealand CO_2 emissions compared with Europe and Japan, we have investigated the effect of engine displacement on average CO_2 emissions internationally. As shown in Figure 3, the average engine size of new vehicles in New Zealand is higher than in Japan and European countries. Figure 3 also shows that countries with larger average engine size tend to have higher average CO_2 emissions. We have concluded that the difference in engine size accounts for at least some of the difference between average (type approved) fuel efficiency of new vehicles in New Zealand compared with Japan and Europe.

Fuel economy trends: real world values

Studies carried out overseas and in New Zealand (Wang *et al*., 2015) have found that vehicles on the road generally consume more fuel than the fuel efficiency values that they are type approved to when manufactured. Research has also shown that this gap between real world and type approved fuel consumption is growing, as illustrated in Figure 4.

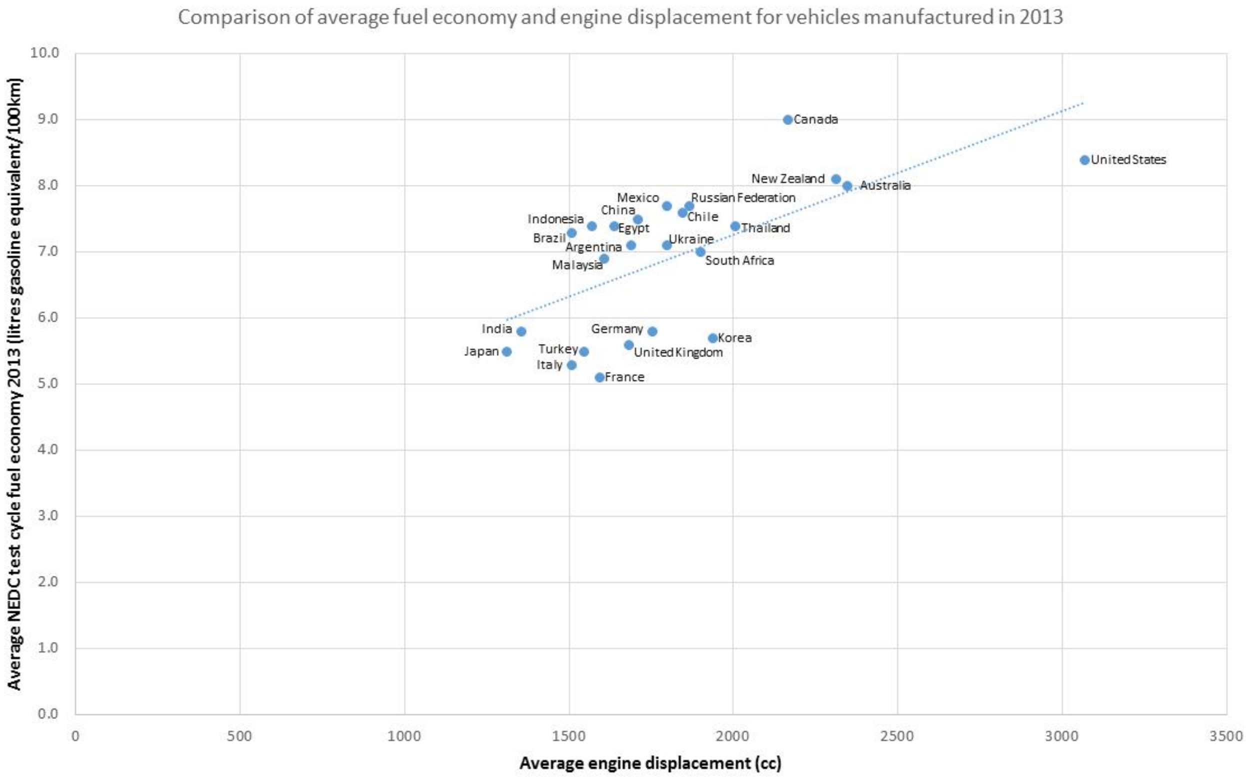

Figure 3: Comparison of average fuel economy (l/100km) and engine displacement (cc) for light duty vehicles internationally [Source: OECD/IEA 2016 and MoT. See accompanying spreadsheet for details]

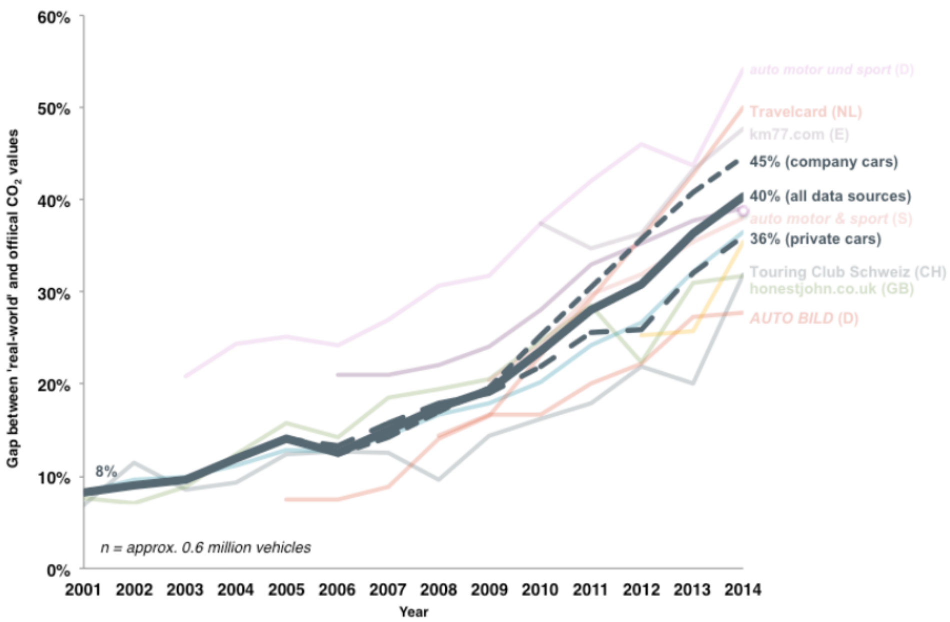

Figure 4: Gap between real-world and official CO_2 emission values for various real-world data sources, including average estimates for private cars, company cars, and all data sources.
[Source: ICCT, 2015b]

Figure 5 compares the trend in type approval and real world CO_2 emissions in New Zealand and Europe. This shows that average type approval and real world CO_2 emissions (and fuel consumption) from new vehicles entering the New Zealand fleet are higher compared with European vehicles, however the overall trend is similar.

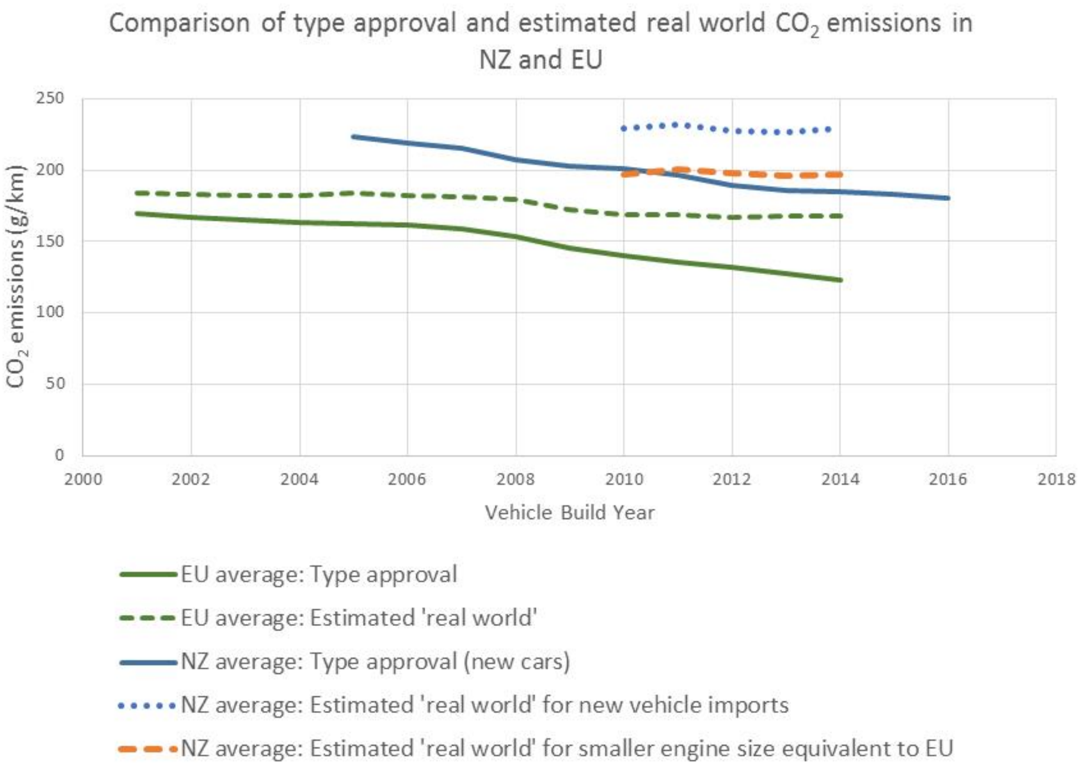

Figure 5: Comparison of type approval and estimated real world CO_2 emissions in New Zealand and Europe [Source: ICCT, 2015b and MoT, 2016. See accompanying spreadsheet for details]

Figure 5 also shows estimated real world fuel consumption for new vehicles entering the New Zealand fleet with engine size equivalent to new European vehicles, and with the proportion of diesel vehicles equivalent to Europe[2]. This shows that, even for vehicles with equivalent engine size, the estimated real world CO_2 emissions and fuel consumption for average new vehicles in New Zealand is approximately 18% higher, compared with average new vehicles in Europe. This difference may be due to New Zealand having heavier vehicles, and a higher proportion of SUVs on average compared with Europe. However, further investigation would be required to confirm this.

Our overall conclusions from the benchmarking analysis are:

- Average fuel consumption of new light duty vehicles in New Zealand is higher compared with Europe and Japan.
- To ensure that fuel consumption estimates are conservative and relevant to New Zealand we have calculated all fuel consumption figures relative to real world factors from New Zealand.
- Trends in fuel consumption are similar in New Zealand compared with Europe and Japan. We have therefore concluded that it is reasonable to apply international projected rates of fuel efficiency improvement directly to New Zealand.

[2] The method to estimate real world emissions for smaller engines is described in Appendix 1.

2.2 Literature review: fuel efficiency projections

International fuel efficiency standards and targets (as shown in Figure 1) require improvement of fuel efficiency over time. These provide some information about the general direction of fuel efficiency in future. However, this project requires:

- Real world fuel consumption. As discussed in Section 2.1, there is an increasing discrepancy between regulated fuel efficiency and real world results.
- Projections of fuel consumption to 2040. This is well beyond the currently regulated timeframe.
- Data for specific fuel and vehicle types including light duty and heavy duty vehicles.

To identify projections for this project we have reviewed a range of international projections and publications including:

- Committee on Climate Change, 2015. *Sectoral scenarios for the Fifth Carbon Budget, Technical Report*.
- EA Energy Analyses, 2016. *Green Roadmap 2030: Scenarios and tools for a conversion of Danish transport's energy consumption*.
- GFEI, 2016. *Fuel Economy State of the World 2016: Time for global action*
- ICCT, 2015c. *Advanced tractor trailer efficiency technology potential in the 2020 to 2030 timeframe*. White paper prepared by Delago, J. & Lutsey, N.
- Miller, 2016. *Reducing CO_2 emissions from road transport in the European Union: An evaluation of policy options*.
- MIT, 2015. *On the Road Towards 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions*, Prepared by Sloan Automotive Laboratory, Massachusetts Institute of Technology
- Sims, R *et al.*, 2014. Transport in: *Climate Change 2014: Mitigation of climate change. Contribution of working group III to the fifth assessment report of the Intergovernmental Panel on Climate Change*.

From this review we have identified two key studies that provide **real world** fuel consumption projections relevant for this project. These include a detailed study that has been undertaken for policy development in the European market (Hill *et al.*, 2012) and the MIT, 2015 report.

Hill *et al.*, 2012

Detailed studies that have been undertaken for policy development in Europe (Hill *et al.*, 2012) and in the US market (EPA/NHTSA, 2012). These detailed studies provide robust estimates of the effectiveness of a wide range of technologies.

The results of the European and US studies are broadly comparable. However, for this project, the European study is most relevant because:

- A significant proportion of New Zealand vehicles are built to European standards

- The European report (Hill *et al.*, 2012) provides projections to **2050** whereas the US study extends to 2025
- The Hill *et al.*, 2012 report provides estimated **real world** fuel consumption

The Hill *et al.*, 2012 analysis has recently been reviewed and updated on behalf of the European Commission, but detailed results have not yet been published (GFEI, 2016). The UK Committee on Climate Change has incorporated the updated analysis in their 2015 scenario assessment (Committee on Climate Change, 2015). According to the Committee on Climate change (2015) report:

- Conventional car efficiency could feasibly improve by around 37% on a real world basis between 2010 and 2030. This is similar to the Hill *et al.*, 2012 estimate.
- The average abatement costs of conventional vehicle efficiency improvement is higher than previous estimates, mainly reflecting the increased gap between real-world and test-cycle emissions and lower projected fuel prices.
- The estimated conventional vehicle efficiency improvements in 2030 are cost-effective relative to the average carbon value projected over the lifetime of a new vehicle in 2030. Improving the efficiency of conventional vehicles is a low-regrets measure and is included in all of the Committee on Climate Change projections.
- Updated projections for PHEV and BEVs suggest that there are more opportunities to improve real world efficiency compared with previous estimates. Updated projections for improvement of the energy efficiency of PHEVs and BEVs are slightly more optimistic compared to the Hill *et al.*, 2012 study.
- There is little new evidence on efficiency of heavy goods vehicles. Climate Change Committee 2015 projections for heavy goods vehicles are based on the Hill *et al.*, 2012 study.

We conclude that the Hill *et al.,* 2012 study provides a robust assessment of the potential reduction in real world fuel consumption for a wide range of technologies. The projected reductions are considered cost effective. However, the projections go well beyond regulated requirements so there is considerable uncertainty about the extent that these reductions will actually be achieved.

MIT, 2015

The MIT, 2015 report provides a "realistic but aggressive" scenario for improvement of light duty vehicle fuel efficiency. The authors confirm that it is appropriate to apply the projections globally stating that:

> *the relative values and how they change, are closely comparable for different sizes and types of vehicles in the various major world regions, with similar assumptions about the technologies involved and how they combine and progress. This "self-similar" characteristic is not exact, but, given the uncertainties involved, it is usually an appropriate assumption.*

The "realistic but aggressive" factors are described as neither overly optimistic or pessimistic. The factors are:

- intended to represent the average new vehicle sold in any given year (not the best)
- based on engineering analysis as well as judgements

- generated expecting that policies and regulations will push the development of fuel economy but not including demand specific policies
- based on the assumption that petroleum prices will continue to rise gradually, but will not become really high over the next few decades

Some key assumptions include:

- vehicle size is held constant across different propulsion technologies and over time
- vehicle weight is reduced by 15% by 2030, and an additional 15% by 2050
- 10% improvement in acceleration time to 2030, tapering off to no further improvement by 2050
- vehicle content (features) and auxiliary loads will increase over time following recent history

Overall the factors result in an improvement of around 1.5% to 2% compounded which is roughly 30% to 50% better than the historical record.

We conclude that the MIT 2015 study provides an assessment of potential reduction in real world fuel consumption from **light duty vehicles** that incorporates realistic assumptions and is internationally applicable.

Comparison of projections: light duty vehicles

To assess the conservatism of projections we have compared the results for light duty vehicles from three projections as follows:

1. The European study (Hill *et al.*, 2012), which provides projections of technically feasible and cost effective improvements in energy consumption to **2050**
2. A “realistic but aggressive” scenario from MIT, 2015 which projects energy consumption to **2050**
3. A 2010 projection from the Ministry of Environment of Japan which is published in the MIT, 2015 report. The MIT, 2015 report judges the Japanese projection as “conservative”. This Japanese projection goes to **2030 and has been extrapolated by MIT to provide a conservative projection to 2050.**

For petrol and diesel ICEs the comparison is shown in Figures 6 and 7.

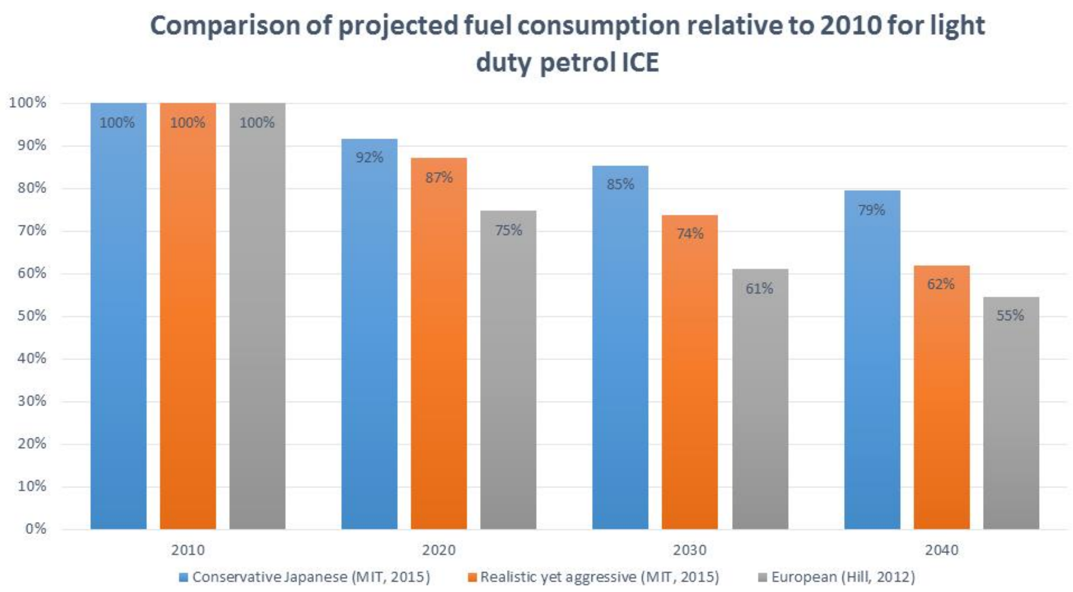

Figure 6: Comparison of projected fuel consumption relative to 2010 for light duty petrol ICE

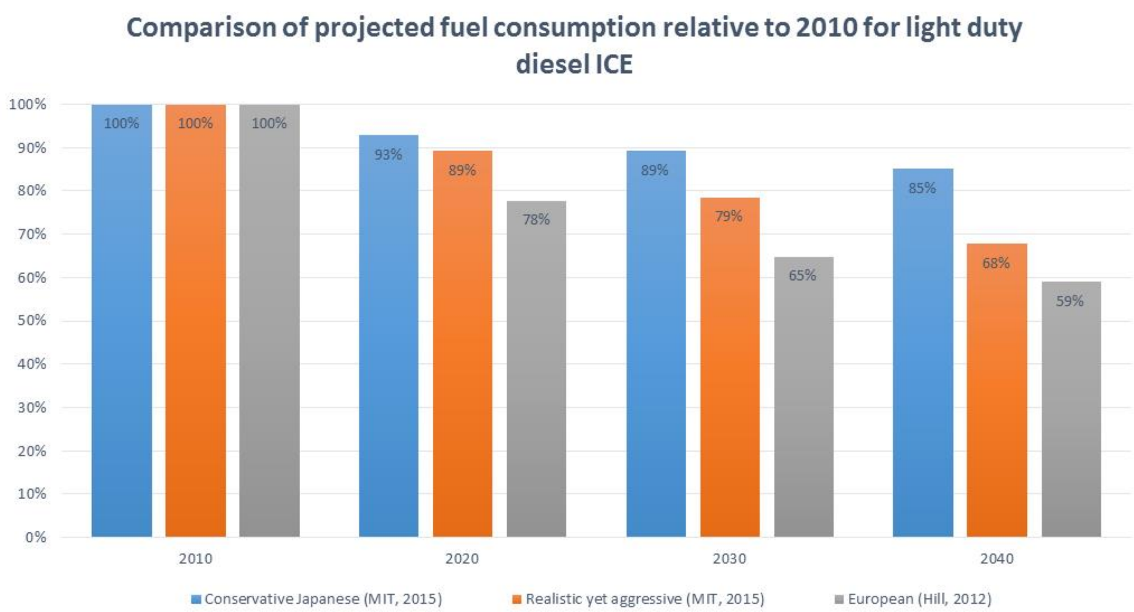

Figure 7: Comparison of projected fuel consumption relative to 2010 for light duty diesel ICE

European regulations require a reduction in average CO_2 emissions from passenger cars of around 30% between 2010 and 2020 on a type approval basis[3]. This is expected to translate to a real world reduction of approximately 15% to 20% depending on the test cycle and the effectiveness of the test relative to real world emissions[4] (Miller, 2016). As shown in Figures 6 and 7, the projected reduction in fuel consumption from light duty ICE vehicles

[3] On a type approval basis average CO_2 emissions for passenger cars in Europe are required to reduce from 140g CO_2/km in 2010 to 95 g CO_2/km in 2021 according to the NEDC test cycle.

[4] Miller, 2016 estimates that real world CO_2 emissions will reduce from 171gCO_2/km in 2010 to 142gCO_2/km in 2021 under the NEDC test cycle assuming a target of 95gCO_2/km and a real world gap of 49% in 2021. The report also estimates that real world emissions will fall to134gCO_2/km under the WLTP test assuming a target of 109gCO_2/km and a real world gap of 23% in 2021.

between 2010 and 2020 ranges from 25% according to Hill *et al.,* to 13% according to MIT 2015, and 8% according to the Japanese government 2010 projection.

Relative to the currently expected reduction in average real world CO_2 emissions from passenger cars of 15% to 20% between 2010 and 2020, the Hill *et al.*, 2012 projections appear optimistic and the Japanese projection appears pessimistic, at least for European vehicles.

Approximately half of vehicles imported to New Zealand are built to Japanese standards so it is important to consider whether projections are realistic for Japanese vehicles. It is possible that fuel efficiency from Japanese vehicles could lag behind international trends, but this seems unlikely based on historic trends. As shown in Figure 1, Japanese fuel efficiency standards have improved at a similar rate to European standards over the past 15 years. Fuel efficiency requirements are regularly reviewed and updated under the Japanese Top Runner programme. Japan also has tax incentives in place to encourage consumers to purchase fuel efficient vehicles (Government of Japan, 2015).

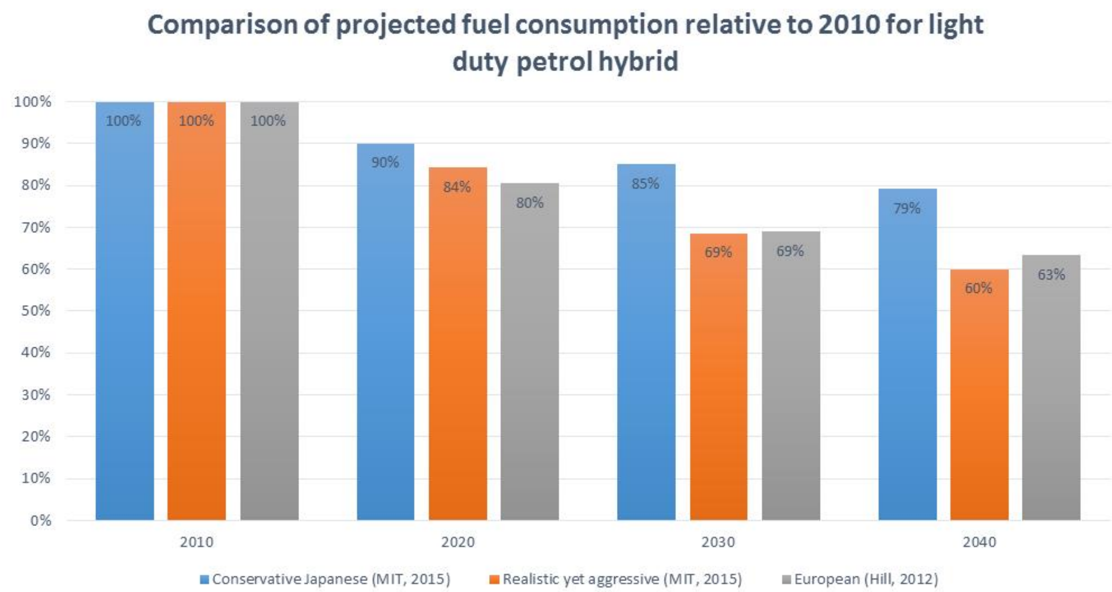

Figure 8: Comparison of projected fuel consumption relative to 2010 for light duty petrol hybrid

For hybrid vehicles the MIT, 2015 projection and the Hill *et al.*, 2012 projection are similar as shown in Figure 8. Projections for hybrid, plug in hybrid and battery electric vehicles are more uncertain than ICE projections because these are relatively new technologies and are evolving quickly. Based on our recent review of electric vehicle trends (Metcalfe et al., 2015) we are aware that projections and expectations about battery weight, efficiency and cost have improved considerably since 2012. On this basis, we consider that the Hill *et al.,* 2012 projections for hybrid, plug in hybrid and electric vehicles are likely to be conservative.

Overall, based on our literature review and the comparison of projections we conclude that improvements in fuel economy are uncertain and could realistically be anywhere between the Japanese 2010 and Hill *et al.,* 2012 projections shown in Figure 6 to 8. However, based on current trends and expectations we consider that the MIT, 2015 projection appears to be reasonably conservative and realistic for new ICE vehicles. For hybrid, plug in hybrid and electric vehicles we consider that the Hill *et al.,* 2012 projections are conservative and represent the best available information.

Comparison of projections: heavy duty vehicles

There is limited information about heavy duty vehicle fuel efficiency and projections. In the European Union there has been no historical requirement to measure fuel efficiency and CO_2 emissions from heavy duty vehicles. According to data from industry in Europe, new HCV fuel consumption and CO_2 emissions performance improved steadily until the mid-1990s, then stabilised and did not materially improve further in the last decade (European Commission, 2014). This is consistent findings in New Zealand where the fuel efficiency of new HDV's has not changed significantly over the past decade[5].

Heavy duty vehicle efficiency is only regulated in four markets (Canada, China, Japan and US). As shown in Figure 9, the Japanese regulations are expected to reduce average fuel consumption from heavy duty vehicles by 12% in 2015 compared to 2006 (approximately 1.3% per annum).

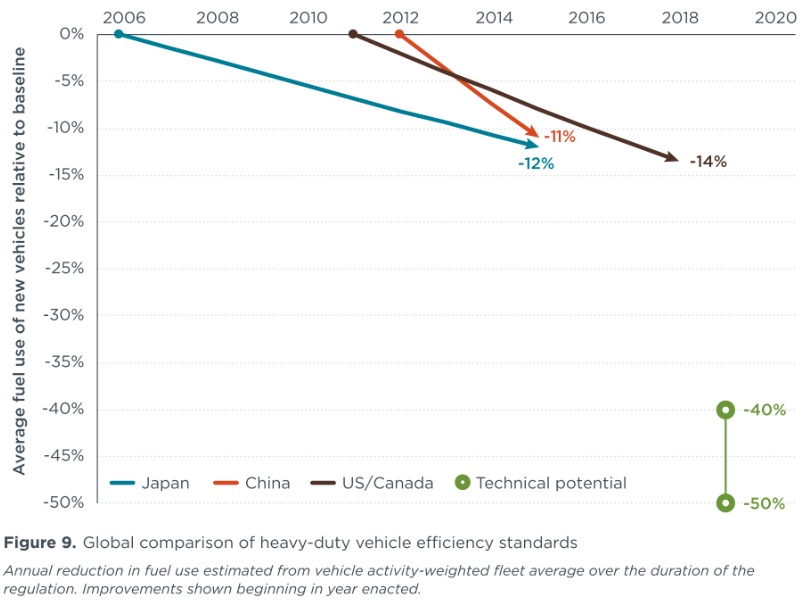

Figure 9: Global comparison of heavy-duty vehicle efficiency standards [Source: Miller, 2014]

The European Commission is currently developing policy to regulate heavy duty vehicle fuel efficiency. The European Commission has developed scenarios for evaluation of policy options including a baseline "no policy change" scenario. Under this scenario HDV fuel efficiency is assumed to improve by close to 1% annually over the period 2015-2030. The Commission staff working document explains:

> *...this is a reversal versus latest fuel efficiency trends that have been influenced by the regulatory introduction of several generations of new 'Euro' exhaust gas pollutant standards, leading to some fuel efficiency losses and an overall standstill of HDV fuel consumption performance in the recent years. In the assumed absence of new and more stringent exhaust gas pollutant standards (the baseline scenario is prepared on a no-policy change basis) a resumption of regular vehicle fuel efficiency improvements appears realistic, even without policy actions to curb fuel consumption and CO_2 emissions.*

The Hill *et al.,* 2012 projections show that there is technical and cost effective potential to reduce fuel consumption between 2010 and 2030 by around 30% for articulated trucks. This

[5] Data provided by MoT

is consistent with an ICCT assessment (ICCT, 2015c) which concludes that there are several available technology packages that could reduce fuel consumption of articulated trucks by 30% to 40% compared with 2010 levels.

The Hill *et al.,* 2012 report includes projections for a range of heavy duty vehicles and buses. The report notes that a range of projections are required because the results for heavy duty vehicles cannot necessarily be scaled according to size. Heavy duty vehicles are diverse in their relative sizes, technical specifications and usage patterns. So for example, in smaller trucks that are typically used in urban areas hybrid powertrains will have a greater impact due to significant stop start activity and speed fluctuations, compared to heavier trucks used for long haul operations. Conversely, the application of aerodynamic improvements has most benefit for large vehicles that are travelling at high speeds for a significant proportion of their activity.

The Hill *et al*., projections show that there is technical and cost effective potential to reduce fuel consumption between 2010 and 2030 by around 13% for small rigid trucks, 25% for large rigid trucks and 30% for articulated trucks.

Overall, we conclude that there is considerable uncertainty in future projections of heavy duty vehicle fuel efficiency. We consider that the rate of improvement could realistically be anywhere between no improvement (0% per annum in keeping with recent trends) and the projections from Hill *et al., 2012*.

For this project we recommend 50% of the Hill *et al.*, projected rates of improvement as a reasonably conservative middle ground.

Under this 50% of the Hill *et al.,* 2012 scenario, the maximum annual rate improvement is 1% per annum for articulated trucks. This is reasonable compared with the rate of improvement required to date in regulated markets (including Japan at approximately 1.3% per annum) as well as the baseline “no policy change” scenario considered by the European Commission, which assumed annual average improvement of close to 1% annually.

3 Methodology: real world energy consumption projections

The projections in this report are intended to represent real world fuel consumption. These real world factors are the average fuel consumption per 100km of new vehicles sold in a given year. They are based on fuel consumption of vehicles operating in the real world under all different driving conditions. These factors represent an average across all different vehicles within the classification.

For this project we assumed that the data provided by MoT is representative of real world fuel consumption of vehicles manufactured in 2012. Fuel consumption factors for other vehicle types, and for all projection years are calculated relative to these real world factors.

This section of the report briefly summarises the key assumptions. Detailed assumptions and calculations are provided in the accompanying spreadsheet.

3.1 Light duty vehicles: base year

Real world fuel consumption factors for light duty diesel and petrol ICE (internal combustion engine) vehicles in New Zealand have been estimated by MoT using fuel consumption and travel data from fuel card transactions (Wang *et al.*, 2015).

To estimate fuel consumption for hybrid vehicles, plug in hybrids and electric vehicles we used factors from a recently published ICCT working paper on costs and carbon emissions from electric vehicles (Wolfram and Lutsey, 2016). This paper provides updated energy and fuel consumption levels for 2010 power trains as shown in Table 1. These factors incorporate real world adjustments for 2010 vehicles based on a comprehensive review of recent literature.

Table 1: Updated electric energy and fuel consumption levels of 2010 power trains [Source: Wolfram and Lutsey, 2016]

Fuel	2010 Power Train	2010 real world adjustment factor	Adjusted Fuel Consumption kWh/100km	Adjusted Electricity Consumption kWh/100km	Relative to Equivalent ICE	Relative to Petrol ICE
Petrol	ICE	1.24	70.3		100%	
Diesel	ICE	1.24	56.0		100%	
Petrol	HEV	1.41	55.5		79%	
Diesel	HEV	1.41	50.2		90%	
Petrol	PHEV (operating on fuel)	1.41	55.5		79%	
Diesel	PHEV (operating on fuel)	1.41	50.2		90%	
BEV	BEV and PHEV operating on electric	1.41		20.4		29%

Based on factors shown in Table 1, fuel consumption for all vehicles was calculated relative to the MoT real world fuel consumption factor for the equivalent internal combustion engine. For example:

> *1600–1999cc petrol HEV fuel consumption = 1600-1999cc petrol ICE MoT real world fuel consumption x* ***79%***

To estimate fuel consumption for PHEVs (plug in hybrid electric vehicles) we need to estimate the proportion of time that the vehicle operates on electricity. We assume **48%** of driving in electric mode based on the results of a recent review (Plötz *et al.*, 2015). This report estimates an average of 48% for large vehicles, typical of the currently available PHEVs in New Zealand (Mitsubishi Outlander, Toyota Prius and Volvo V60).

Fuel consumption of PHEV's was calculated relative to the equivalent MoT fuel consumption. For example:

> *1600–1999cc petrol PHEV petrol consumption = 1600-1999cc petrol ICE MoT real world fuel consumption x* ***79%*** *x (100% -* ***48%****)*

Electricity consumption is calculated on the same basis, for example:

> *1600–1999cc petrol PHEV electricity consumption = equivalent energy consumption of 1600-1999cc petrol ICE MoT real world fuel consumption x* ***29%*** *x (****48%****)*

Battery electric vehicles are calculated on the same basis i.e. ***29%*** of the equivalent energy consumption of a petrol ICE.

3.2 Light duty vehicles: projections

All projected energy consumption factors are calculated relative to the base year factors using the reduction rates shown in Table 2 as follows.

Table 2: Improvement in fuel efficiency assumed in projections for light duty vehicles

Category	Fuel	Power-train	Reduction in fuel consumption over 10 year period			Notes
			2010 to 2020	2020 to 2030	2030 to 2040	
LPV	Petrol	ICE	13%	13%	12%	1
		HEV	20%	14%	8%	2
		PHEV	HEV factor for petrol and BEV factor for electricity			
	Natural gas	ICE	petrol ICE factor			
	Diesel	ICE	11%	11%	11%	1
		HEV	15%	13%	8%	2
		PHEV	HEV factor for diesel and BEV factor for electricity			
	Electric	BEV	9%	10%	5%	2
LCV	Petrol	ICE	13%	13%	12%	1
		HEV	14%	9%	9%	2
		PHEV	HEV factor for petrol and BEV factor for electricity			
	Natural gas	ICE	petrol ICE factor			
	Diesel	ICE	11%	11%	11%	1
		HEV	10%	9%	8%	2
		PHEV	HEV factor for diesel and BEV factor for electricity			
	Electric	BEV	7%	6%	6%	2

Notes:
1 Rate of reduction in the MIT, 2015 "realistic but aggressive" projection of real world fuel consumption to 2050
2 Rate of reduction in Hill. et al, 2012 projection of real world fuel consumption to 2050

3.3 Heavy duty vehicles: base year

Real world fuel consumption factors for heavy duty diesel ICE vehicles in New Zealand have been calculated by Mot using a large data set of real world fuel consumption and travel data.

Bus fuel consumption factors were not available so these are based on fuel consumption estimates from Hill *et al*., 2012.

Based on factors shown in Table 3, fuel consumption for all other vehicles was calculated relative to the MoT real world fuel consumption factor for the equivalent internal combustion engine.

3.4 Heavy duty vehicles: projections

New Zealand heavy duty vehicles are classified by weight so we have assumed that:

- small rigid truck projections apply to all trucks less than 15 tonnes GVM

- large rigid truck projections apply to all trucks between 15 tonnes and 25 tonnes GVM
- articulated truck projections apply to all trucks over 25 tonnes GVM

All projected energy consumption factors are calculated relative to the base year factors using the reduction rates shown in Table 4 as follows.

Table 3: Relative fuel consumption factors assumed for base year heavy duty vehicles

Category	Fuel & powertrain	GVM	Relative to equivalent ICE	Notes
HCV	Diesel HEV	<15000kg	81%	ratio reported in Hill *et al.,* 2012 for small rigid truck
		<25000kg	91%	ratio reported in Hill *et al.,* 2012 for large rigid truck
		>25000kg	94%	ratio reported in Hill *et al.,* 2012 for atriculated truck
	Natural gas ICE	<15000kg	115%	ratio reported in Hill *et al.,* 2012 for small rigid truck
		<25000kg	114%	ratio reported in Hill *et al.,* 2012 for large rigid truck
		>25000kg	114%	ratio reported in Hill *et al.,* 2012 for atriculated truck
	BEV	<15000kg	31%	ratio reported in Hill *et al.,* 2012 for small rigid truck
		other weights		not applicable because no factors provided in Hill *et al.,* 2012. Not considered feasible.
Bus	HEV	all weights	71%	ratio reported in Hill *et al.,* 2012 for bus
	BEV	all weights	30%	ratio reported in Hill *et al.,* 2012 for bus

Table 4: Improvement in fuel efficiency assumed in projections for heavy duty vehicles

Category	Fuel	Power-train	Reduction in fuel consumption over 10 year period: 2010 to 2020	2020 to 2030	2030 to 2040	Notes
HCV<15 tonne	Diesel	ICE	3%	4%	3%	1
		HEV	0%	4%	3%	1
	Electric	BEV	4%	6%	5%	2
	Natural gas	ICE	3%	4%	2%	1
HCV rigid >15 tonne	Diesel	ICE	5%	8%	4%	1
		HEV	5%	9%	5%	1
	Natural gas	ICE	5%	8%	3%	1
HCV articulated >25 tonne	Diesel	ICE	8%	10%	5%	1
		HEV	7%	10%	5%	1
	Natural gas	ICE	8%	10%	4%	1
Bus	Diesel	ICE	3%	6%	2%	1
		HEV	1%	5%	2%	1
	Natural gas	ICE	3%	6%	2%	1
	Electric	BEV	1%	5%	5%	2

4 Results

Detailed results of our projections are provided in the accompanying spreadsheet. A selection of key results are illustrated in Figures 10, 11 and 12.

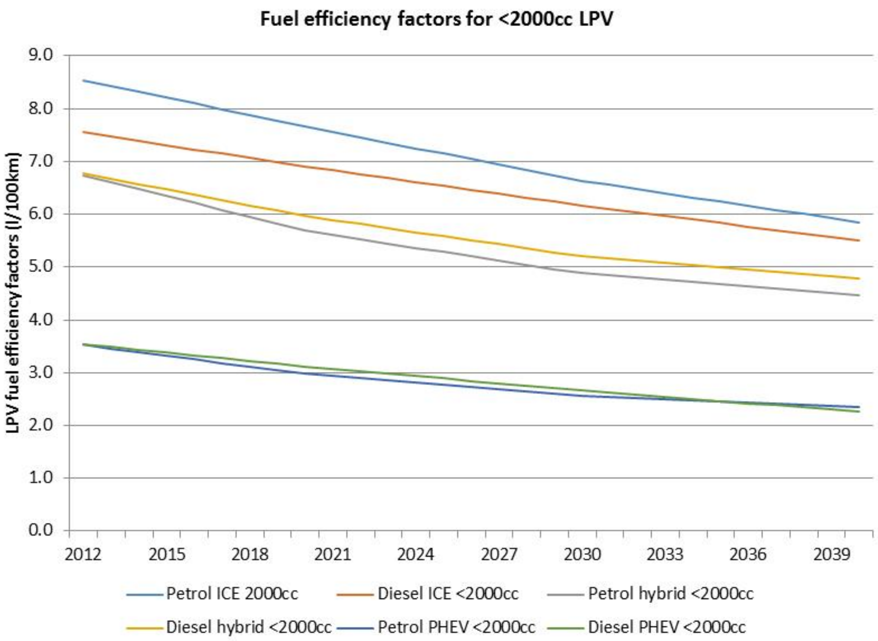

Figure 10: Fuel efficiency factors and projections for LPV <2000cc

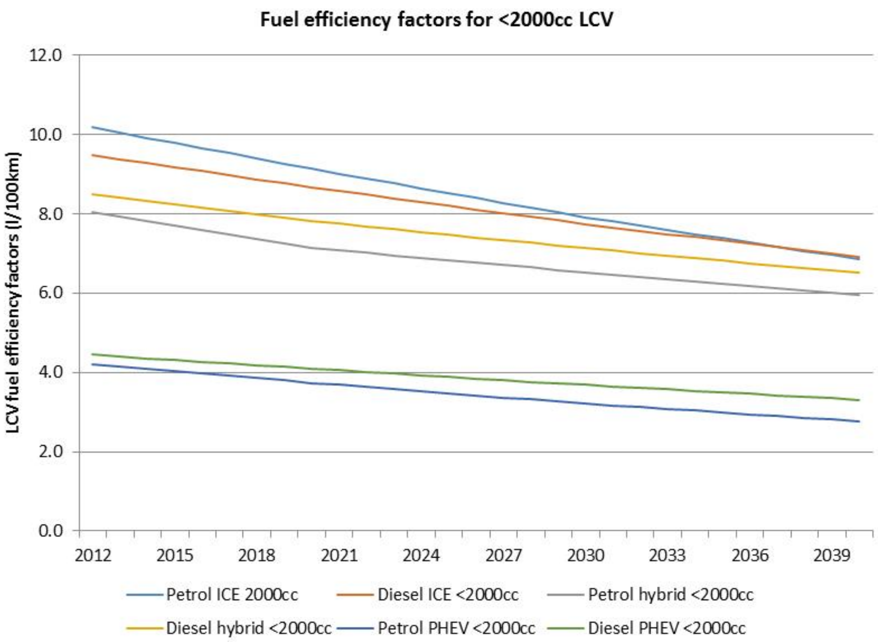

Figure 11: Fuel efficiency factors and projections for LCV <2000cc

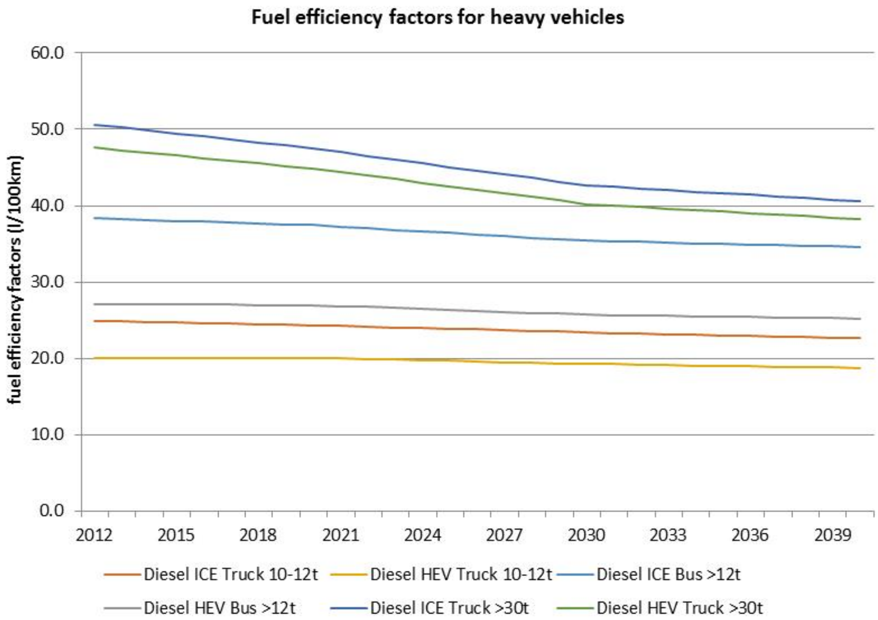

Figure 12: Fuel efficiency factors and projections for heavy vehicles

5 Conclusions and recommendations

Real world fuel consumption factors for diesel and petrol ICE (internal combustion engine) vehicles in New Zealand have been estimated by MoT using fuel consumption and travel data from a large dataset of real world fuel card transactions[6].

This project developed factors for other vehicle types and for future years. To ensure that these factors are conservative and relevant to New Zealand we have calculated all fuel consumption figures relative to MoT real world factors for New Zealand.

The MoT real world factors underpin this analysis. **We recommend that the MoT analysis is regularly updated. It is also important that the analysis is extended to include privately owned vehicles, including older vehicles and vehicles manufactured to Japanese standards** (as recommended by Wang et al., 2015).

We have developed projection factors for New Zealand vehicle fuels and energy consumption based on international projections.

The projected fuel and energy consumption factors are based on improvements that are

- technically feasible
- cost effective
- reasonably conservative

However these projections go well beyond current regulatory timeframes so they are inherently uncertain.

We recommend that the projections are regularly reviewed and updated.

[6] Fuel use factors for this project were provided by Ministry of Transport, including factors for light duty vehicles (Wang et al., 2015) and unpublished factors for heavy duty vehicles.

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Appendix 1

This appendix describes the calculation to estimate NZ average real world CO_2 emissions for smaller engine size equivalent to Europe as shown in Figure 5. The proportion of diesel and petrol vehicles has also been adjusted to be equivalent to the European fleet.

Calculation of real world CO_2 emissions from New Zealand vehicles with European equivalent engine size and proportion of diesel vehicles

1. **Estimate real world CO_2 emissions for new vehicle imports based on NZ average type approval emissions for new vehicle imports and real world uplift factors.** Real world CO_2 is calculated for petrol and diesel separately based on equation 1:

$$RW\ CO_2\ (g/km)_{year,fuel} = type\ approval\ CO_{2_{year,fuel}} \times RW\ uplift\ factor_{year,fuel}$$

Equation 1

where:

- year is the analysis year 2010 to 2014
- fuel is petrol or diesel
- type approval CO_2 = average CO_2 emissions for the analysis year as reported by MoT (quarterly fleet statistics) for **NZ New Petrol** vehicles and **NZ New Diesel** vehicles
- RW uplift factors (real world uplift factors) were estimated from Figures 9 and 10 of Wang et al., 2015 for each analysis year as follows:

Year	Petrol RW uplift factor	Diesel RW uplift factor
2010	14%	13%
2011	18%	18%
2012	20%	18%
2013	22%	21%
2014	24%	21%

2. **Adjust NZ real world CO_2 to estimate CO_2 emissions from NZ vehicles with smaller engine size equivalent to Europe** as follows:

$$RW\ CO_2\ for\ EU\ engine\ size(g/km)_{year,fuel} = RW\ CO_2\ (g/km)_{year,fuel} \times CC\ adjustment_{year,fuel}$$

Equation 2

where:

- CC $adjustment_{year,fuel}$ are shown in Table 5. These factors are calculated for each analysis year and for petrol and diesel as described in steps 4 to 6 following.
- *year* is the analysis year 2010 to 2014
- *fuel* is petrol or diesel

3. **Calculate weighted average** real world CO_2 emissions based on the proportion of diesel and petrol vehicles in the European fleet.

Calculation of CC adjustment

This section describes the calculation of the CC adjustment factor used in Equation 2. The adjustment factor has been estimated for each analysis year to account for any changes in average engine size in Europe and New Zealand.

MoT research has established a relationship between real world fuel consumption and engine size for New Zealand (Wang et al., 2015). We have used this relationship to estimate an adjustment factor as follows.

4. Estimate NZ real world fuel consumption for petrol vehicles with New Zealand average engine size and for petrol vehicles with European engine size according to equation 4:

$$\boldsymbol{NZ\ RW\ petrol\ consumption\quad (l/100km) = 0.0015 \times engine\ size\ (cc) + 5.86}$$

Equation 3

5. Estimate real world fuel consumption for NZ diesel vehicles with New Zealand average engine size and for NZ diesel vehicles with European engine size according to equation 5:

$$\boldsymbol{NZ\ RW\ diesel\ consumption\quad (l/100km) = 0.0021 \times engine\ size\ (cc) + 3.92}$$

Equation 4

6. Calculate CC adjustment factors for petrol and diesel for each analysis year according to equation 6 and 7:

$$\boldsymbol{Petrol\ CC\ adjustment_{year} = \frac{NZ\ RW\ petrol\ consumption\ EU\ engine\ size_{year}}{NZ\ RW\ petrol\ consumption\ NZ\ engine\ size_{year}}}$$

Equation 5

and

$$\boldsymbol{Diesel\ CC\ adjustment_{year} = \frac{NZ\ RW\ diesel\ consumption\ EU\ engine\ size_{year}}{NZ\ RW\ diesel\ consumption\ NZ\ engine\ size_{year}}}$$

Equation 6

Table 5: CC Adjustment factors

Vehicle build year	New Zealand				Europe		Estimated NZ real world fuel efficiency for average EU engine cc		CC Adjustment factor to estimate NZ RW CO_2 for EU engine size	
	Average engine capacity new vehicles		Estimated real world fuel efficiency for average NZ engine cc		Average engine capacity new vehicles [2]					
	Petrol cc	Diesel cc	Petrol* l/100km	Diesel** l/100km	Petrol cc	Diesel cc	Petrol* l/100km	Diesel** l/100km	Petrol	Diesel
2010	2317	2603	9.3	9.4	1450	1800	8.04	7.7	86%	82%
2011	2219	2614	9.2	9.4	1440	1800	8.02	7.7	87%	82%
2012	2152	2602	9.1	9.4	1425	1800	8.00	7.7	88%	82%
2013	2124	2639	9.0	9.5	1400	1800	7.96	7.7	88%	81%
2014	2119	2687	9.0	9.6	1360	1800	7.90	7.7	87%	81%