THE INTERNATIONAL COUNCIL
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ICCT consulting report:

Methods of converting the type-approval fuel economy and CO_2 emission values of light vehicles: An analysis for New Zealand

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Table of contents

1 Introduction

1.1 Overview

In 2019, the New Zealand Government proposed a Clean Car Discount and a Clean Car Standard, both policies that focus on light-duty vehicle (LDV) type-approval tailpipe CO_2 emissions. These are hereafter referred to collectively as "the LDV low-emission policies."[1] Although the consultation document associated with the proposal indicates that CO_2 emissions will be based on the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), it also indicates that the New European Driving Cycle (NEDC) is to be used to establish the targets, fees, and rebates.

All of New Zealand's LDVs are imports. New vehicles mainly come from Japan, Thailand, and Europe, and the vast majority of used vehicles come from Japan. To implement the LDV low-emission policies, every newly registered LDV must have a CO_2 emission value equivalent to that which would have been measured over the WLTP. Thus, for vehicles not reporting WLTP CO_2, methods are required to convert the reported values to WLTP CO_2 equivalents.

In order to enable the New Zealand Government to decide on a formal protocol for normalizing CO_2 emissions—and, if necessary, fuel efficiency—across test cycles, this work involves a series of analyses to develop methods and algorithms that New Zealand can adopt to determine compliance with the LDV low-emission policies on a WLTP CO_2 equivalent basis. Such methods and algorithms are expected to be reasonably robust and fair for all light vehicle segments; relatively easy to understand and use; the best fit for New Zealand's situation; and capable of covering all light vehicles newly registered or re-registered in New Zealand. This report:

- Documents the key differences between different type-approval procedures and their relative importance in estimating vehicle fuel consumption (Section 2)
- Comprehensively reviews and summarizes the technical literature dealing with test cycle conversion methods and techniques (Section 3)
- Reviews the current New Zealand LDV market for a comprehensive understanding of country of origin and type-approval procedures associated with all newly registered or used imported vehicles (Section 4)
- Determines an appropriate test cycle—WLTP, with or without extra-high-speed phase—that New Zealand can use to determine policy compliance and investigates the necessity of using a standardized fuel when developing test cycle conversion methods (Section 5)

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[1] New Zealand Ministry of Transport, "Moving the Light Vehicle Fleet to Low-Emissions: Discussion Paper on a Clean Car Standard and Clean Car Discount," 2019. Available at https://www.transport.govt.nz/assets/Import/Uploads/Our-Work/Documents/11de862c28/LEV-consultation-document-final.pdf

- Develops a suitable CO_2 emissions conversion method based on available data and tests the proposed approach for a range of top-selling vehicles in New Zealand (Section 6)

1.2 Scope

This analysis focuses on LDVs, including light passenger vehicles (LPVs) and light commercial vehicles (LCVs). By New Zealand's definition, LDVs are cars, sport utility vehicles (SUVs), utes (utility vehicles), vans, and light trucks of 3.5 tonnes gross vehicle mass or less. These vehicles are the target of the LDV low-emission policies, and therefore the targets of the conversion factor analyses documented in this report.

The majority of LDV certifications being processed in New Zealand are based on tests conducted in countries that rely on one of six test procedures. Each test procedure defines driving cycles and testing conditions that a vehicle must follow and this analysis covers all six driving cycles:

- the 3-phase (Class 3) WLTP (3P-WLTP) currently used for certification in Japan
- the 4-phase (Class 3) WLTP (4P-WLTP) currently used for certification in the European Union and countries following EU regulations
- the New European Driving Cycle (NEDC) used for certification in the European Union and countries following EU regulations prior to transitioning to the 4P-WLTP
- the JC08 test cycle used for certification in Japan prior to transitioning to the 3P-WLTP
- the 10-15 Mode test cycle used for certification in Japan prior to the adoption of the JC08 test cycle
- the CAFE test cycle used for certification in the United States and countries that follow U.S. regulations

As described in detail in Section 5.1, this report recommends that the 3P-WLTP serve as the basis for standardization in New Zealand and suggests algorithms to convert data from other cycles to the 3P-WLTP.

This analysis assumes that New Zealand will use CO_2 emissions values to determine compliance with relevant policies. As stated in the proposed LDV low-emission policies, the preferred measure for vehicle fuel efficiency is grams of CO_2 per kilometer of travel (gCO_2/km). This measure ensures all fuel types—for example petrol, diesel, biofuels, electricity, and hydrogen—are treated in an equitable manner. It also focuses directly on the overarching goal of the vehicle fuel efficiency standard, which is to reduce CO_2 emissions. Therefore, the conversion algorithms presented in this report are based on CO_2 emissions in gCO_2/km. In some cases, underlying analysis data expressed in terms of fuel consumption (FC) or fuel economy (FE) are converted to equivalent CO_2 emissions during the algorithm development process. This is explained in detail.

1.3 Methodology and uncertainties

1.3.1 Overview of methodology and data sources

Datasets with results for a large number of vehicles tested over multiple driving cycles are rare. It is uncommon to test the same vehicle over multiple cycles and this is for several reasons. For one, it is expensive to conduct vehicle certification tests. Manufacturers have no incentive to bear the cost of unnecessary testing and regulatory agencies typically have limited funding. Even when manufacturers sell a particular vehicle model across jurisdictions with different testing regimes, modifications are usually made to tailor vehicle characteristics to best suit the demands of each jurisdiction such that test results are not directly comparable. These modifications can range from the recalibration of internal power train controls to external design changes, but the net result is the same—vehicles that bear common nameplates but different characteristics. Thus, great care must be taken to ensure that data assembled from different jurisdictions are actually comparable.

With the exception of the WLTP, most of the testing regimes of interest here were developed before the movement toward automotive globalization. Each regime was developed more or less independently to reflect local market characteristics and fulfill local regulatory requirements. There was little incentive to coordinate demands across jurisdictions since each generally served a captive market. This has certainly changed over the last decade or so, and although there is movement to globalize testing regimes accordingly, independent testing regimes and market characteristics persist to this day.

As a result, most comparative datasets are derived from vehicle simulation modeling studies. Simulation modeling essentially involves running a “vehicle,” as defined by a specified set of design and operating parameters, through one or more specified driving cycles to predict emissions and fuel consumption performance. Simulation modeling studies calculate such data for multiple vehicles and/or multiple driving cycles. As such, the data are comparable, but are limited by the precision of both the underlying model and the underlying vehicle design and performance specifications. It is also not clear that such models capture the variability in vehicle setup and differences in vehicle preconditioning and test protocols, other than the driving cycle definition itself, that are allowed across the different test procedures. This is not meant to impugn the validity of such modeling, as simulation modeling is universally and widely used by both vehicle manufacturers for internal purposes and by regulatory agencies to develop, calibrate, and monitor vehicle performance. Nevertheless, developing a detailed set of vehicle design and operating parameters to serve as model inputs is both time consuming and complex, so simulation modeling studies are also generally limited in scope (number of vehicles modeled, range of parameters investigated, etc.).[2] Most studies that are available for external analysis focus on “most popular” vehicle designs to rightly capture

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[2] It is well worth automotive manufacturers’ time to develop design and operating parameters for their own vehicles to aid in internal development, but these data are confidential and never released.

"average" responses, but this approach can artificially limit the range of variability that might be expected for an entire market.

This analysis relies on real-world test data to the maximum extent possible. This includes data for 4P-WLTP to 3P-WLTP conversions, JC08 to 3P-WLTP conversions, and 10-15 Mode to 3P-WLTP conversions because comparative data is available. NEDC to 3P-WLTP conversions and CAFE to 3P-WLTP conversions are based on a hybrid approach that uses both simulation modeling and laboratory test data. With the exception of the precise translation of 4P-WLTP to 3P-WLTP data when phase-specific data are available, all utilized datasets are processed to derive average relations for equivalent WLTP data converted from other test cycles. Given existing data, this is the best possible approach to developing standardized, defensible conversion algorithms. Section 3 reviews the available datasets and methodologies. Section 6 specifies the dataset and methodology adopted by this analysis to generate each set of conversion factors.

1.3.2 Imprecision of conversion factors

Adopting conversion factors to convert vehicle type-approval CO_2 emissions/fuel consumption values from one test cycle to another is necessarily imprecise. An emission or fuel consumption test procedure consists of a precisely defined driving cycle and an accompanying set of requirements defining how a vehicle must be tested over that cycle. The driving cycle specifies the speed, generally on a second-by-second basis, at which a vehicle must be operated over a defined test period. For example, Figure 1 shows the speed-time trace for the vehicle Class 3 version of the WLTP. The trace looks, and is, quite precise. However, the vehicles subjected to the test cycle are not constrained in their design, and this results in differential energy consumption influences, even in an idealized case where fuel (input) energy is converted to energy at the wheels (tractive energy) with 100% efficiency, i.e., when input energy equals tractive energy.[3]

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[3] A 100% efficient or idealized vehicle can be viewed as a given mass of any given shape that rolls on four frictionlessly attached wheels. The energy required to "push" such a mass through a specified driving cycle is the tractive energy of the cycle *for that given mass/shape/wheel design* and would also equal the input energy if that energy was convertible to motion at 100% efficiency.

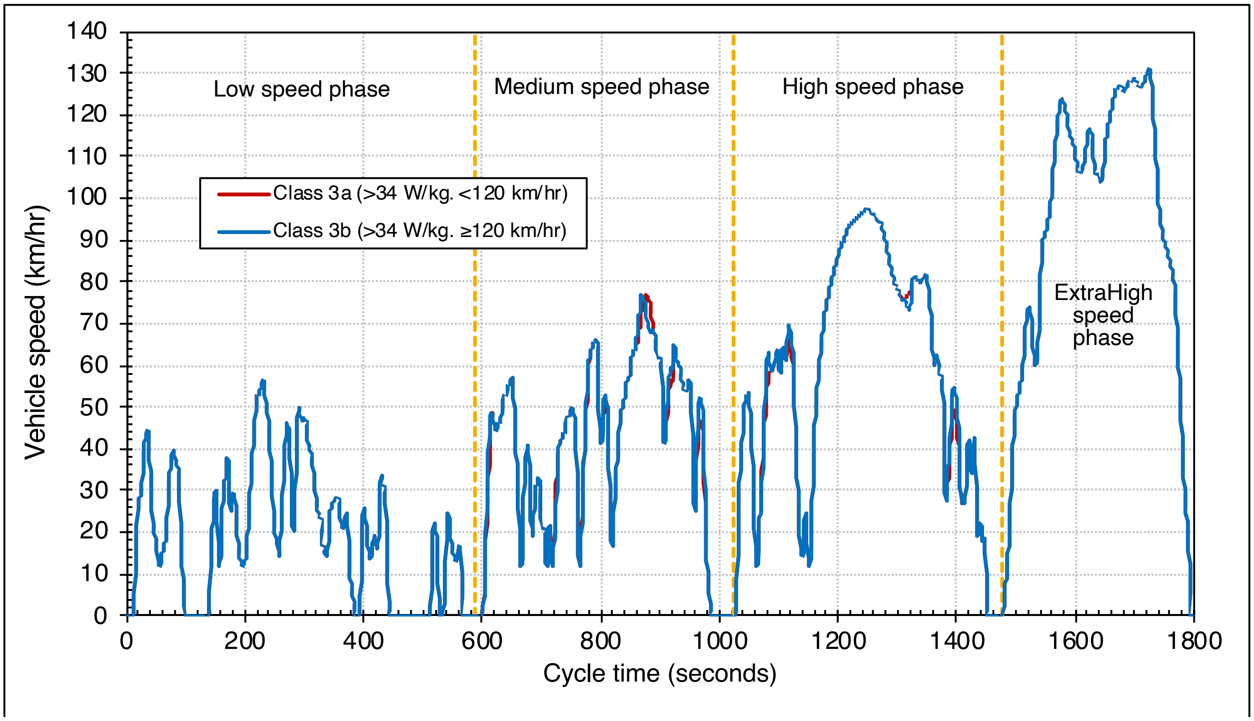

Figure 1. Speed time trace for the WLTP driving cycle

As it executes a driving cycle, even an idealized vehicle is subjected to three forces: tire rolling resistance, aerodynamic drag, and the force required to induce vehicle motion and change speed as dictated by the cycle.[4] For any vehicle, these forces are a function of not only the characteristics of the driving cycle, but also the rolling resistance and rotational inertia of its tires, the vehicle drag coefficient and frontal dimensions, and the vehicle mass. The energy required to propel the vehicle through the driving cycle is equal to the integral of the instantaneous forces over the distance over which they apply. Because distance is the product of velocity and time, required input energy in the case of the idealized vehicle is equal to the integral of the instantaneous product of force and velocity and the time over which that product applies.[5] Thus, the energy required to execute the driving cycle is a function not only of the driving cycle itself, but of the design characteristics of the vehicle being tested. The driving cycle alone is not sufficient to determine input energy requirements, even for a vehicle that converts fuel energy to motive energy with 100% efficiency.

Further complications arise because the significance of the various vehicle design characteristics changes depending on the design of the driving cycle. Aerodynamic drag forces, for example, are less important relative to other energy influences during low speed driving but become quite significant at highway speeds. Thus, the relationship

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[4] Non-idealized vehicles encounter additional forces due to the friction and rotational inertia of the driveline. Additionally, although the test vehicle is stationary during testing, forces equal to those that would be induced on the vehicle if it were actually following the driving cycle in motion are simulated by forces placed on the dynamometer rolls that the vehicle's wheels are engaging.

[5] Energy = $\int_0^x (\text{Force})\,\delta x = \int_0^{vt} (\text{Force} \times \text{Velocity})\,\delta t$ (where x = distance, v = velocity, and t = time).

between the vehicle characteristics affecting energy requirements varies both throughout a given driving cycle and also across two comparative cycles. Two vehicles executing the same cycle can be subject to substantially different energy demands, and the relationships of these vehicles across two differing cycles can be similarly different. Thus, there is no precise relation that applies to all vehicles between energy consumption measurements over differing driving cycles, even if those vehicles convert and deliver fuel energy with 100% efficiency.

Layer on top of this imprecision in cycle energy demand and the differential characteristics of fuel energy conversion efficiency and driveline energy transmission efficiency for non-idealized, i.e., real-world vehicles—all of which also vary from vehicle to vehicle—and it is easy to understand how a precise relation between test results for different cycles that holds for all vehicles is an unapproachable ideal.[6] Any cycle conversion algorithm will be necessarily imprecise. It is simply not possible to impose precise order on a system that has inherently variable energy demands. That said, it is possible to derive general relations, although the variability or error of these relations for any given vehicle can be unavoidably significant. The general relations will hold "on average" as they reflect the average relation of the universe of possible relations, but they will be imprecise for all but an "average" vehicle.

2 Overview of test procedures

2.1 Test procedure comparison

2.1.1 Comparison of parameters of different driving cycles

This section summarizes speed-time traces and descriptive statistics for each of the six test cycles. Two clarifying issues are discussed first, and then we present a detailed comparison of the evaluated test procedures.

CAFE test "cycle"

The CAFE test "cycle" actually relies on two independent test cycles, a CAFE City cycle and a CAFE Highway cycle. Tests over these cycles are conducted independently and weighted together—55% City and 45% Highway—to derive a composite CAFE certification metric. The standardization work reported in this analysis uses the composite CAFE certification metric as the independent parameter subject to standardization. The underlying City and Highway cycle metrics are not used explicitly but are depicted in all charts and tables that present driving cycle characteristics since there is no independent CAFE test "cycle."

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[6] This can be especially true as recent technologies such as hybridization and stop-start systems can further differentiate energy management strategies relative to "conventional" internal combustion engine vehicles. As a result, test cycle speed profiles, which affect the amount of regeneration energy captured by hybrids, and idle time fractions for stop-start may alter the consistency of cross-cycle relations for specific technology subsets.

Class-specific WLTP cycles

The WLTP establishes distinct requirements, including the applicability of different driving cycles, for Class 1, 2, 3a, and 3b vehicles; this is detailed in Table 1. Class 1 vehicles are defined as those with a power-to-weight ratio of 22 W/kg or less. Class 2 vehicles have a power-to-weight ratio of more than 22 W/kg, but not more than 34 W/kg. Class 3a and 3b vehicles have a power-to-weight ratio of more than 34 W/kg. Class 3a vehicles have a rated top speed of less than 120 km/hr, whereas Class 3b vehicles have a rated top speed of at least 120 km/hr.

Table 1. The vehicle classifications of the test cycles in WLTP 2014 technical regulation

Class	Power/unladen weight ratio[a]	Max speed	WLTP[b]
Class 1	≤ 22 W/kg		Low$_1$ + Medium$_1$ + Low$_1$
Class 2	> 22 but ≤ 34 W/kg		Low$_2$ + Medium$_2$ + High$_2$ + Extra-high$_2$
Class 3a	> 34 W/kg	< 120 km/h	Low$_3$ + Medium$_{3\text{-}1}$ + High$_{3\text{-}1}$ + Extra-high$_3$
Class 3b		≥ 120 km/h	Low$_3$ + Medium$_{3\text{-}2}$ + High$_{3\text{-}2}$ + Extra-high$_3$

[a] In the WLTP 2019 technical regulation, the categorization is based on power/mass in running order minus 75kg

[b] For full comparison of the low, medium, high, and extra-high-test cycles for different vehicle classes, see Appendix A.

Source: United Nations Addendum 15: Global technical regulation No. 15 Worldwide harmonized Light vehicles Test Procedure. Established in the Global Registry on 12 March 2014. Retrieved from https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29r-1998agr-rules/ECE-TRANS-180a15e.pdf

Among the countries that are currently adopting WLTP, only a very small number of vehicles are certified outside of Class 3. In Japan, all LPVs except one model sold in 2015 fall under Class 3.[7] For the European Union, 99.9% of LPVs and 98.5% of LCVs sold from 2005 to 2018 fall under Class 3.[8] For New Zealand, registration data show that 99.9% of new LDVs sold from 2015 to 2019 belong to Class 3.[9] There is insufficient information about imported used vehicles to analyze vehicle categorization, but 97% of used LDVs are imported from Japan and the European Union (this is described in detail in Section 4.2). Therefore, no conversion methodologies were developed for Class 1 or Class 2 vehicles.

Further, the driving cycle for Class 1 vehicles includes only low- and medium-speed phases. By definition, these vehicles are not capable of executing the Class 3 driving cycle, so it would be difficult and highly misleading to try to develop a 3P-WLTP

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[7] Ministry of Land Infrastructure Transport and Tourism of Japan. “Summary of the joint meeting on introducing international standards in passenger car fuel efficiency testing,” (2016), https://www.mlit.go.jp/common/001124598.pdf

[8] Based on EU data purchased by ICCT. The data include the power to curb weight ratio for 95% of 2005–2018 EU PV registrations and 77% of LCV registrations.

[9] Based on New Zealand data provided by MOT. Due to invalid or null values for curb weight and power of some models, this ratio reflects 99.3% of the new LDVs sold from 2015 to 2019.

equivalent certification value. If encountered during standards implementation, Class 1 WLTP certification values should be used directly and without change. Although the Class 2 driving cycle, like that of Class 3 vehicles, includes four phases, Class 2 vehicles are also, by definition, not capable of executing the Class 3 driving cycle and therefore are not candidates for developing a 3P-WLTP equivalent certification value. If encountered, Class 2 WLTP certification values should also be used directly and without change.

Class 3a and 3b vehicles are subject to very similar four-phase driving cycles. Figure 1 above depicts both cycles, and the only differences are modestly less aggressive accelerations in the medium- and high-speed phases of the cycle. In conducting the analyses summarized in this report, 84 road load combinations with different mixes of rolling resistance, aerodynamic drag, and vehicle mass were simulated over the Class 3a and 3b cycles, and in all cases the tractive energy requirements of the two cycles were within 1%–2%.[10] Because the two cycles are very similar and few vehicles are expected to be certified with rated speeds below 120 km/hr, the Class 3b cycle forms the basis for both the 4P-WLTP and 3P-WLTP statistics reported herein. However, it is expected that all developed Class 3b statistics can be applied to Class 3a data with little or no added error. In other words, the relationship between Class 3b 3P-WLTP and 4P-WLTP data is expected to be consistent with that same relationship for Class 3a vehicles, even though the latter are not treated explicitly.

Table 2 compares various parameters of the six evaluated test cycles. The CAFE test cycle is a combination of the EPA Federal Test Procedure (FTP75) and the Highway Fuel Economy Test (HWFET) driving cycle. Speed-time traces and descriptive statistics for each of these cycles are included in Appendix A of this report.

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[10] Tractive energy is the energy that a vehicle would need to execute the driving cycle. It is equal to the input energy if fuel energy could be converted to “energy at the wheels” with 100% efficiency. To undertake this evaluation, the analysis relies on proprietary software developed by Meszler Engineering Services (MES). Tractive energy calculations are physics-based calculations that use force equations to quantify the energy required to induce motion for a given driving cycle and set of opposing forces. ICCT has previously subjected the MES software to confirmatory testing against the tractive energy requirements predicted by independent researchers such as Ricardo, Inc., and estimates have agreed to within 0–3% without either researcher having perfect knowledge of the other’s vehicle configuration assumptions.

Table 2. Descriptive parameters of the driving cycles

	Units	FTP75 weighted	HWFET	CAFE	NEDC	10-15 Mode	JC08	WLTC 3-phase[a]	WLTC 4-phase[a]
Start condition		43% cold/ 57% hot	hot		cold	hot	25% cold/ 75% hot	cold	cold
Duration	s	1369	765		1180	660	1204	1477	1800
Distance	km	11.99	16.51		11.03	4.16	8.17	15.01 (14.94)	23.27 (23.19)
Mean velocity	km/h	31.5	77.7	43.0	33.6	22.7	24.4	36.6 (36.4)	46.5 (46.4)
Max. velocity	km/h	91.2	96.4		120.0	70	81.6	97.4	131.3
Stop phases		18	2		14	8	12	8	9
Durations									
Stop	s	241	4		280	206	346	220	226
Constant driving	s	109	126		475	142	21	59 (60)	66 (67)
Acceleration	s	544	338		247	166	432	625 (642)	789 (806)
Deceleration	s	475	297		178	146	405	573 (555)	719 (701)
Shares									
Stop		17.6%	0.5%	13.3%	23.7%	31.2%	28.7%	14.9%	12.6%
Constant driving		8.0%	16.5%	10.1%	40.3%	21.5%	1.7%	4.0% (4.1%)	3.7%
Acceleration		39.7%	44.2%	40.8%	20.9%	25.2%	35.9%	42.3% (43.5%)	43.8% (44.8%)
Deceleration		34.7%	38.8%	5.7%	15.1%	22.1%	33.6%	38.8% (37.6%)	39.9% (38.9%)
Max. acceleration	m/s^2	1.48	1.43		1.04	0.81	1.69	1.67	1.67
Min. deceleration	m/s^2	-1.48	-1.48		-1.39	-0.83	-1.19	-1.50	-1.50
Mean positive 'vel*acc' (acceleration phases)	m^2/s^3	3.86	3.45		4.97	4.14	3.34	4.07 (3.78)	4.54 (4.29)
Mean positive 'vel*acc' (whole cycle)	m^2/s^3	1.53	1.52		1.04	1.04	1.20	1.72 (1.64)	1.99 (1.92)
Max. positive 'vel*acc'	m^2/s^3	19.19	15.17		9.22	10.50	11.60	17.37 (12.70)	21.01

[a] The Class 3 WLTP cycle is separated into two segments, one applicable to Class 3b vehicles with a rated speed of at least 120 km/hr and one to other Class 3 vehicles, Class 3a vehicles. When a single value is listed for the WLTP cycle, it applies equally to both segments. When two values are listed, the top value applies to the "at least 120 km/hr" Class 3b segment and the bottom value applies to the "less than 120 km/hr" Class 3a segment.

2.1.2 Comparison of parameters of different test procedures

In addition to the differences in test cycle speed and time profiles, there are significant differences in test procedures that can affect relations across test cycles. Such differences include road load determination, test temperatures, definition of vehicle mass, battery charge status, preconditioning cycle, and other factors. A number of studies have found that the difference in vehicle mass and test temperature can influence vehicle fuel economy as much as velocity and road grade.[11] Table 3 compares key test procedure parameters of the two test cycles that constitute the CAFE test cycle, NEDC, 10-15 Mode, JC08, and WLTP; the parameters are the same for 3P-WLTP and 4P-WLTP. The effects of test procedure differences are inherently reflected in the data used to support the development of cross-cycle conversion algorithms, and are, therefore, not explicitly isolated.

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[11] Peter Mock et al., *The WLTP: How a new test procedure for cars will affect fuel consumption values in the EU*, (ICCT: Washington, D.C., 2014), https://theicct.org/sites/default/files/publications/ICCT_WLTP_EffectEU_20141029_0.pdf; Gao, J. et al., "Fuel consumption and exhaust emissions of diesel vehicles in worldwide harmonized light vehicles test cycles and their sensitivities to eco-driving factors," *Energy Conversion and Management* 196 (2019), 605–613.

Table 3. Comparison of test procedure parameters that could affect CO_2 emissions

	FTP75 weighted	HWFET	NEDC	10-15 Mode	JC08	WLTP
Gear shift strategy for manuals	Vehicle specific	Vehicle specific	Fixed gear positions	Fixed gear positions	Fixed gear positions	Vehicle specific gear positions
Road load determination						
Tire size/type	Vehicle specific	Vehicle specific	Worst tire			Vehicle specific
Tire tread depth	>50% usable tread	>50% usable tread	>3,000km or 50%–90%			80%–100%
Tire pressure	Manufacturer recommended specification	Manufacturer recommended specification	Not defined	< 150% of listed specification	< 150% of listed specification	Not defined
Aerodynamics	Representative of production	Representative of production	worst			Vehicle specific, use of movable parts
Warm-up	30 min. at 50 mph	30 min. at 50 mph	Not defined	15 min. at 60km/h	15 min. at 60km/h	>20 min. at 118 km/h
Test temperatures						
Soak area	20°C–30°C	20°C–30°C	20°C–30°C	20°C–30°C	20°C–30°C	14°C/23°C
Test cell	20°C–30°C	20°C–30°C	20°C–30°C	20°C–30°C	20°C–30°C	14°C/23°C
Vehicle masses						
Test mass	Tare + 136kg[a]	Tare + 136kg[a]	Tare + 100kg	Tare + 110kg	Tare + 110kg	Tare + 100kg + extras +payload
Inertia	Discrete classes	Discrete classes	Discrete classes	Discrete classes	Discrete classes	Vehicle specific
Rotating masses	Simulation of total inertia	Simulation of total inertia	Simulation of total inertia	1.8%	+1.8%	+1.5% for 1-axle dyno
Other						
Vehicle running in	< 10,000 miles Adjustment if > 6,200 miles	< 10,000 miles Adjustment if > 6,200 miles	> 3,000km			3,000km–15,000km
Pre-conditioning cycle	1x UDDS	FTP or highway	Diesel: 3x EUDC Petrol: 1x UDC, 2x EUDC	15 mode	JC08	WLTC
Battery state of charge	No charging before test	No charging before test	Not defined	Not defined	Test within 4 hours after complete charging	No charging before test
Four wheel drive	1-axle dyno allowed; EPA may confirm using 2-axle dyno	1-axle dyno allowed; EPA may confirm using 2-axle dyno	1-axle dyno			2-axle dyno only

[a] Test mass in the United States includes options that are installed on at least 33% of the vehicles within each model.

2.2 Reference fuels

The differences in reference fuel used by different countries in type-approval testing can influence test results because the carbon content, energy density, and octane characteristics can differ. Table 4 compares the reference fuel specifications adopted by the United States for CAFE testing, China for NEDC testing, the European Union for NEDC and WLTP testing, and Japan for 10-15 Mode and JC08 testing. Note that even countries that adopt the same test procedure can require differing fuels; reference fuel requirements are rarely the same for all parameters. For example, the reference fuel requirements under the NEDC procedure are different in China and the European Union.

Moreover, fuel properties will vary across different batches of test fuel, even for test fuels that comply with the same reference fuel requirement under the same test procedure. The impact of specific test fuel properties on the conversion algorithms is further analysed in Section 5.2.

Table 4. Comparison of reference fuels used in testing in different countries

	CAFE (U.S.[a])	NEDC[b] (EU)	NEDC (China)	10-15 Mode (Japan)	JC08 (Japan)	WLTP (EU)
Petrol						
Research octane number (RON)	97	95	92–94/95–98	90–92 (regular) 99–101 (premium)	90–92 (regular) 99–101 (premium)	95–98
Distillation (°C)						
10% evaporated	49–57	[c]	50–65	45–55	45–55	[d]
50% evaporated	93–110	[c]	90–105	90–100	90–100	[d]
90% evaporated	149–163	[c]	150–165	140–170	140–170	[d]
Final boiling point	213	190–210	190–200	215	215	170–195
Hydrocarbon composition (vol %)						
Olefins	10% max	3%–13%	10%–15%	15%–25%	15%–25%	6%–13%
Aromatics	35% max	29%–35%	27%–32%/ 30%–35%	20%–45%	20%–45%	25%–32%
Saturates	remainder	report				report
Benzene		1% or less	0.8%	1% or less	1% or less	1% or less
Lead (mg/liter)	13	5	5	Not detected	Not detected	5
Total sulfur (ppm)	10–80	10	10	10 or less	10 or less	10
Vapor pressure (kPa)	55.2–63.4	56–60	56–60	56–60	56–60	56–60
Ethanol		4.7–5.3		Not detected	Not detected	9–10
Diesel (without biodiesel)						
Cetane number	40–50	52–54				52–56
Cetane index	40–50		52–54	53–57	53–57	46 min
Distillation range (°C)						
Initial boiling point	171–204					
10% evaporated	204–238					
50% evaporated	243–282	245	245–300	255–295	255–295	245

90% evaporated	293–332	345–350 (at 95% point)	325–350 (at 95% point)	300–345	300–345	345–360 (at 95% point)
Final boiling point	321–366	370		370 or less	370 or less	370
Total sulfur (ppm)	7–15	10	10	10	10	10
Hydrocarbon composition (%)	27% aromatics, min		4% PAH	25% or less aromatics	25% or less aromatics	
Flashpoint (°C)	54.4 min	55 min	55 min	58 min	58 min	55 min
Viscosity (mm^2/s)	2.0–3.2	2.3–3.3	2–7.5	3.0–4.5	3.0–4.5	2.3–3.3

[a] The United States is in the process of changing test fuels to a standard E10 91 RON fuel, but will provide test procedures adjustments to maintain fuel economy and CO_2 equivalent to the fuel listed in the chart.
[b] Requirement for E5 fuel. There is a separate requirement for E10 fuel, as with the requirement for E10 fuel under EU WLTP.
[c] EU NEDC requires 24%–44% evaporated at 70°C, 48%–60% evaporated at 100°C, 82%–90% evaporated at 150°C.
[d] EU WLTP requires 34%–46% evaporated at 70°C, 54%–62% evaporated at 100°C, 86%–94% evaporated at 150°C.

3 Technical literature review of test cycle conversion methods

This section presents a review of the latest research and databases that have been or can be used for generating test cycle conversion algorithms. Although all methods and data sources were considered and compared for this analysis, only some were ultimately selected for detailed analysis. The rationale for selection is specified in Section 6, where the detailed conversion algorithms for each pair of test cycles are presented.

3.1 2004 Pew study

The earliest rigorous study that investigated the relationship between various test cycles dates from 2004 and was prepared for the Pew Center on Global Climate Change (hereafter, “the Pew study”).[12]

The Pew study was conducted to compare fuel economy and emission standards in various global markets. As part of this work, Pew researchers developed a methodology to equilibrate standards based on different test cycles and procedures. The methodology included the use of a quasi-simulation model called the Modal Energy and Emissions Model (MEEM). Although the researchers developed fixed ratios to convert from one testing regime to another, the study report includes the MEEM-based fuel consumption estimates for several test cycles, including the 10-15 Mode cycle, the NEDC, and the U.S. CAFE cycles. The Pew study included modeling results for six petrol and five diesel vehicles. Modeling for both fuels includes vehicles ranging from small cars to pickup trucks and SUVs. Although this study is now outdated, it contains data for test cycles such as the 10-15 Mode cycle adopted by Japan and the U.S. CAFE City cycle adopted by South Korea that are not typically included in more current research.

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[12] Feng An and Amanda Sauer, “Comparison of Passenger Vehicle Fuel Economy and GHG Emission Standards Around the World;” December 2004. Available at https://www.c2es.org/document/comparison-of-passenger-vehicle-fuel-economy-and-ghg-emission-standards-around-the-world/

Table 5 and Table 6 summarize the modeling results for selected representative petrol and diesel vehicle models and detail the ratios used to convert fuel efficiency values from test cycle to test cycle.

Table 5. MEEM simulation results for petrol vehicle fuel efficiency (mpg) under selected test cycles

Test cycles	Average speed (mph)	**Small car** 2004 Ford Focus ZTS	**Large car** 2003 Toyota Camry SE V6	**Minivan** 2003 Dodge Grand Caravan ES FWD	**SUV** 2003 Ford Explorer XLT 4wd	**Pickup** 2004 Chevrolet Silverado 1500 LS Rwd SB	**Crossover** 2003 Saturn Vue AWD
Japan 10-15	14.8	22.5	20.1	16.9	13.9	12.8	18.7
FTP75	19.5	26.8	22.1	20.2	16.9	15.4	22.0
NEDC	20.9	27	24.7	21.1	17.6	15.8	22.8
CAFE	32.4	30.9	26.6	24.1	20.2	18.2	25.7
HWFET	48.2	38.1	35.8	31.6	26.5	23.4	32.1
Ratios	Average ratio						
CAFE/NEDC	1.13	1.14	1.08	1.14	1.15	1.15	1.13
CAFE/Japan[a]	1.35	1.37	1.32	1.43	1.46	1.43	1.37
CAFE/ FTP75	1.18	1.15	1.21	1.20	1.19	1.18	1.16
NEDC/Japan	1.23	1.20	1.23	1.25	1.27	1.24	1.22

[a] Considering that most Japanese models are car models, the authors chose to use an average ratio of 1.35.

Table 6. MEEM simulation results for hypothetical diesel models fuel efficiency (mpg) under selected test cycles

Test cycles	**Average speed (mph)**	**Small car** 2L VW TDI	**Large car** 2.7L VW TDI	**Minivan** 3.1L VW TDI	**SUV** 3.8L VW TDI	**Pickup** 3.7L VW TDI
Japan 10-15	14.8	33.3	30.3	26.2	23.6	24.2
FTP75	19.5	37.8	33.9	28.8	25.6	26.2
NEDC	20.9	38.5	35.0	29.4	26.4	26.2
CAFE	32.4	43.6	39.5	32.7	28.7	29.4
HWFET	48.2	53.7	49.3	39.2	33.7	34.5
Ratios	Average ratio					
CAFE/NEDC	1.12	1.13	1.13	1.12	1.09	1.12
CAFE/Japan[a]	1.31	1.31	1.30	1.25	1.22	1.21
CAFE/FTP75	1.14	1.15	1.16	1.14	1.12	1.12
NEDC/Japan	1.13	1.16	1.16	1.12	1.12	1.08

[a] Considering that most Japanese models are car models, the authors chose to use an average ratio of 1.31.

3.2 2014 ICCT study on key test cycle conversion factors

A 2014 simulation-based comparative study performed by the ICCT (hereafter, "the 2014 ICCT study") is the latest comprehensive effort that investigates the relationships among several key test cycles.[13] This study updated a similar ICCT study from 2007.[14] In the 2014 ICCT study, CO_2 and efficiency estimates were derived for a series of test cycles, including the U.S. CAFE, NEDC, 4P-WLTP, and JC08 cycles, and for a range of vehicle design and technology characteristics using a vehicle simulation modeling tool developed by Ricardo, Inc. called the Data Visualization Tool (DVT). The tool is based on MSC.Easy5, a comprehensive simulation model also developed by Ricardo.[15] The DVT allows a user to select from a set of predefined technologies and driving cycles and vary vehicle design characteristics over specified ranges to derive CO_2 and fuel consumption estimates. The ICCT exercised the DVT over the breadth of allowable inputs to derive comparative CO_2 and fuel consumption estimates for the driving cycles of interest.

The 2014 ICCT study simulated a large number of current and advanced petrol, hybrid, and diesel vehicles with automatic and manual transmissions with both a 2008 baseline and with technologies projected for 2020 and beyond. Different types of regression analyses were developed and evaluated using the modeled CO_2 emission data in order to describe the dependencies for each pair of driving cycles. The different regressions can be used based on the availability of information related to vehicle architecture, aerodynamic drag, and engine technology. Developed conversion algorithms evaluate petrol and diesel data separately.

The equation below and Table 7 show the results of single regression with calculated intercept. This is a so-called "universal approach" that adopts a linear weighting of two independent petrol and diesel regressions for each pair of driving cycles. Among other approaches evaluated in the study, this approach has lower accuracy but higher usability because it requires little technical knowledge of the vehicle subject to cycle conversion.

$$\text{Universal approach: } C2 = ((a1 * DS + a2) * C1) + (d1 * DS + d2),$$

where C1 and C2 are the CO_2 emission values for the test cycles being converted from and to, respectively; DS is the diesel sales share; and a1, a2, d1, and d2 are coefficients as specified in Table 7.

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[13] Kühlwein, J., German, J., and Bandivadekar, A. "Development of Test Cycle Conversion Factors Among Worldwide Light-Duty Vehicle CO_2 Emission Standards;" ICCT White Paper, September 2014. Available at https://theicct.org/publications/development-test-cycle-conversion-factors-among-worldwide-light-duty-vehicle-co2

[14] An, F., Gordon, D., He, H., Kodjak, D. & Rutherford, D. (July 2007). *Passenger vehicle greenhouse gas and fuel economy standards: A global update*. Washington DC: The International Council on Clean Transportation. Available at https://theicct.org/sites/default/files/publications/PV_standards_2007.pdf

[15] Ricardo, Inc. and MSC.Software Corporation, MSC.EASY5 Powertrain Library V4.1. For more, see Kasab, J. & Subbarao, V. "User guide for Data Visualization Tool," May 9, 2012. Available at https://theicct.org/sites/default/files/Ricardo_Data_Visualization_Tool_UserGuide_v09-May-2012.pdf

Table 7. Parameters of universal approach

C2 (gCO_2/km)	C1 (gCO_2/km)	a1	a2	d1 (gCO_2/km)	d2 (gCO_2/km)	StdErr(C2) (gCO_2/km)
CAFE	NEDC	-0.0975	0.8658	9.852	14.076	4.40
NEDC	CAFE	0.0884	1.1325	-7.480	-13.739	5.10
CAFE	JC08	-0.1162	0.7212	7.602	36.736	8.35
JC08	CAFE	0.0941	1.2749	0.030	-38.423	11.30
CAFE	WLTC	-0.0348	0.9318	11.826	-8.827	4.20
WLTC	CAFE	0.0587	1.0454	-14.600	12.590	4.47
NEDC	JC08	-0.0227	0.8457	-2.891	24.840	5.76
JC08	NEDC	0.0290	1.1430	3.786	-24.907	6.73
NEDC	WLTC	0.0486	1.0475	5.037	-22.727	7.73
WLTC	NEDC	-0.0494	0.8984	-3.752	28.059	7.11
JC08	WLTC	0.0722	1.1532	11.230	-45.172	14.67
WLTC	JC08	-0.0653	0.7319	-6.170	53.293	11.56

There are a number of other regression results in the 2014 ICCT study that either show lower conversion accuracy or require more information on installed vehicle technology or road load characteristics. This review presents only the so-called universal approach that reflects a tradeoff between accuracy and usability.

3.3 EU studies on NEDC and 4P-WLTP conversion

The Joint Research Center (JRC) of the European Commission has conducted several studies over the last few years that quantified relationships between NEDC and 4P-WLTP data.[16] The relative frequency of such work is a direct result of the European Union's recent transition from an NEDC-based to a WLTP-based compliance regime. These studies generally relied on simulation modeling using CO_2MPAS or similar models and laboratory testing.

A particularly detailed study conducted in the Netherlands estimated the relationship between NEDC and 4P-WLTP data for 151,993 petrol and 20,817 diesel vehicles registered from 2018 to 2019.[17] It provides aggregate regression statistics for both petrol and diesel vehicles. Table 8 summarizes the key resulting conversion factors in these studies.

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[16] Tsiakmakis, S., Fontaras, G., Ciuffo, B., and Samaras, Z., "A simulation-based methodology for quantifying European passenger car fleet CO_2 emissions," *Applied Energy* 199 (2017): 447–465; Tsiakmakis, S., Fontaras, G., Anagnostopoulos, K., Ciuffo, B., Pavlovic, J., and Marotta A., "A simulation-based approach for quantifying CO_2 emissions of light duty vehicle fleets. A case study on WLTP introduction," Transportation Research Procedia 25 (2017): 3898–3908; Tsokolis, D., Tsiakmakis, S., Dimaratos, A., Fontaras, G., Pistikopoulos, P., Ciuffo, B., and Samaras Z., "Fuel consumption and CO_2 emissions of passenger cars over the New Worldwide Harmonized Test Protocol," *Applied Energy* 179 (2016): 1152–1165; Pavlovic, J., Marotta, A., and Ciuffo, B., "CO_2 emissions and energy demands of vehicles tested under the NEDC and the new WLTP type approval test procedures," *Applied Energy* 177 (2016): 661–670.

[17] Ligterink, N., Cuelenaere, R., and Stelwagen, U., "Aspects of the transition from NEDC to WLTP for CO2 values of passenger cars - Phase 3: After the transition;" TNO 2019 R10952; July 2, 2019.

Table 8. Summary of regression results of EU studies

Method	Samples	Regression results (y– CO_2g/km under WLTP (H/L[a]); x–CO_2g/km under NEDC)	Source
Simulation + test	12 petrol and 14 diesel	y = 0.808x + 48.275 (R sq = 0.89)	(Tsiakmakis, Fontaras, Cluffo, & Samaras, 2017) in Footnote 16
Simulation	2014 fleet of 4500 models	y (H) = 0.8018x + 41.477 (R sq = 0.9072)	(Tsiakmakis, et al., 2017) in Footnote 16
Test	12 petrol and 8 diesel	y (H) = 1.1x + 2.6 (R sq = 0.94) ($100 < x < 180$) y (H) = 0.47x + 113.7 (R sq = 0.81) ($160 < x < 220$)	(Tsokolis et al., 2016) in Footnote 16
Test	20 petrol and 11 diesel	y (H) = 1.11x ± 0.06 y (L) = 1.01x ± 0.05	(Pavlovic, Marotta, & Cluffo, 2016) in Footnote 16
Type-approval data	151,993 petrol and 20,817 diesel	y = 1.08x + 14.5 (petrol) y = 1.12x + 15.6 (diesel)	(Ligterink, Cuelenaere, & Stelwagen, 2019) in Footnote 17

[a] H/L indicates worst (WLTP-H) and best (WLTP-L) cases of WLTP procedure, which are usually impacted by the test mass and road load to be used for the simulation.

3.4 Other studies

There are a number of other studies that provide information about the relationships among different test cycles, but they are not appropriate as support for detailed analysis of the type dealt with herein. For example, in the technical document that supports the regulatory document of the China 2025 fuel consumption standards, a figure with about 120 sample vehicles is included to compare WLTP and NEDC CO_2 emission values.[18] The regression results show that CO_2 emission levels (g/km) under WLTP are, on average, 10.57% higher than CO_2 emission levels under NEDC and the gap is higher for heavier vehicles. In addition, a table compares the 2020 fuel consumption targets (l/100km) for each weight class under NEDC and 4P-WLTP; there are 16 pairs of data values, one pair for each weight class. Nonetheless, the sources of the original data are unclear, as is the composition of the sample fleet. More importantly, the relationships presented in the document contradict the findings of most other studies where the sources of data and methodologies are more clearly defined and defensible.[19] The ICCT has questioned the validity of the NEDC to WLTP conversion method in its public

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[18] Ministry of Industry, Information, and Technology (MIIT). 2019. The policy-making explanation of GB27999–Fuel consumption evaluation methods and targets for passenger cars.

[19] In the China document, the adjustment between NEDC and WLTP gets larger for heavier vehicles, whereas the EU studies and ICCT studies show the opposite.

comment on the regulatory documents, and more details are in the comment document.[20]

4 Assessment of New Zealand 2019 import fleet

An assessment of New Zealand's 2019 LDV import fleet is conducted to (a) help determine the test cycle that New Zealand could use for compliance with policies that aim to lower the average emission value of these imported vehicles; and (b) evaluate if there is any special vehicle type or segment of LDVs sold in New Zealand that are not commonly included in existing studies and need to be separately considered for conversion factor generation.

The data used for fleet analysis came from two sources. One was directly provided by the New Zealand Ministry of Transport, and the other is Motor Vehicle Register data published by the New Zealand Transport Agency.[21] The fleet analysis is primarily based on the first data source and supported by the second. The New Zealand Ministry of Transport has pointed out issues related to data quality, so the information summarized in this section should not be seen as a precise fleet evaluation but rather a general trend review sufficient to assess the two previously stated goals.

4.1 Market share of new and used imported LPV and LCV

Based on registration information for the 2019 LDV fleet, 82.5% of the LDVs sold in New Zealand are LPVs and 17.5% are LCVs (see Figure 2, left). Half the fleet registered in 2019 consisted of new vehicles and the other half were used vehicles. For LPVs, 43% of the vehicles were new vehicles, whereas 83% of the LCVs were new vehicles (see Figure 2, right).

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[20] ICCT. (2019). Comments on China's proposed 2021-2025 fuel consumption limits, evaluation methods, and targets for passenger cars. Available at https://theicct.org/news/comments-chinas-proposed-2021-2025-fuel-consumption-limits-evaluation-methods-and-targets on April 10, 2020.

[21] New Zealand Transport Agency. 2019. Motor Vehicle Register. Available at https://opendata-nzta.opendata.arcgis.com/search?q=motor%20vehicle%20register.

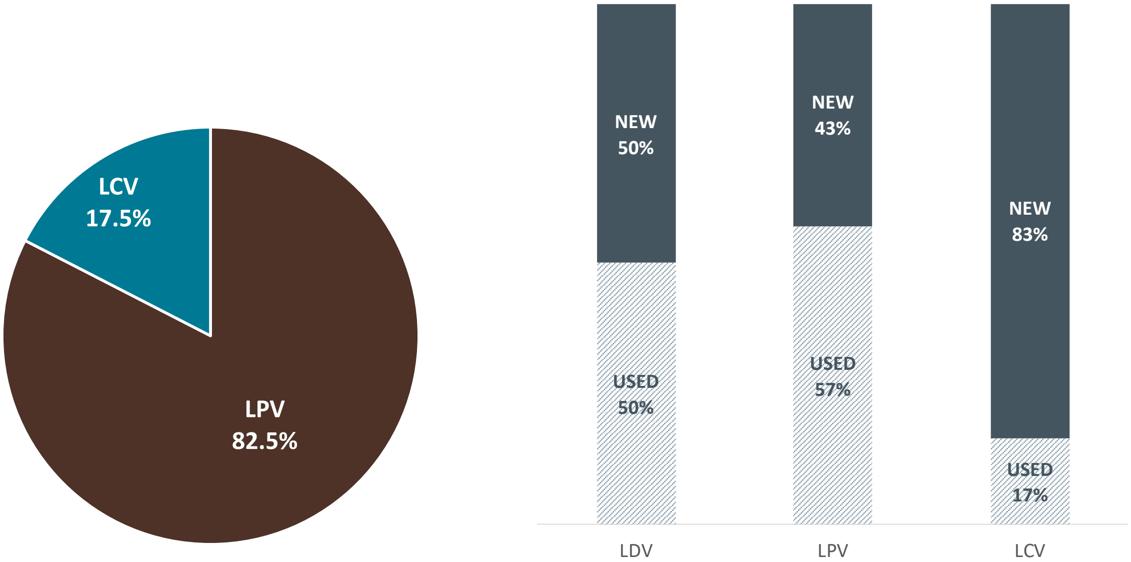
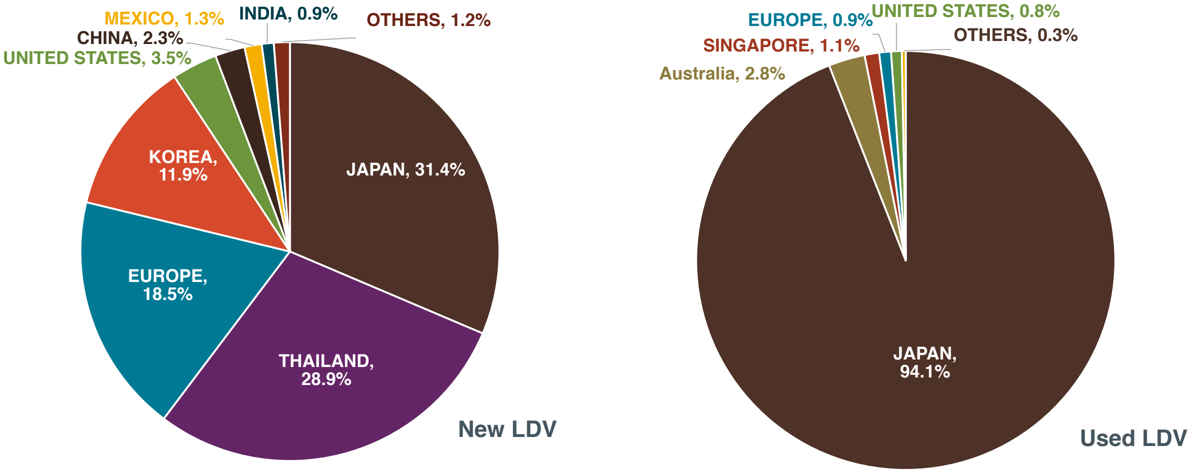


Figure 2. Market share by vehicle type (left) and by new or used vehicles (right)

4.2 Import fleet by country of origin

The vast majority of new LDVs imported into New Zealand come from eight countries or regions: Japan, Thailand, Europe, South Korea, the United States, China, Mexico, and India. LDVs imported from these countries accounted for 99% of the newly registered fleet in 2019. Other origin countries include Australia, Canada, Malaysia, South Africa, Indonesia, Mexico, Argentina, Singapore, and the Philippines, but the number of LDVs imported from these countries is minimal.

While new vehicles are primarily imported from Japan, Thailand, Europe, and South Korea, almost all used vehicles can be traced to Japan and Australia, and of these, the large majority are from Japan. Figure 3 shows the split of origin countries of new and used LDVs, LPVs, and LCVs imported into New Zealand in 2019.



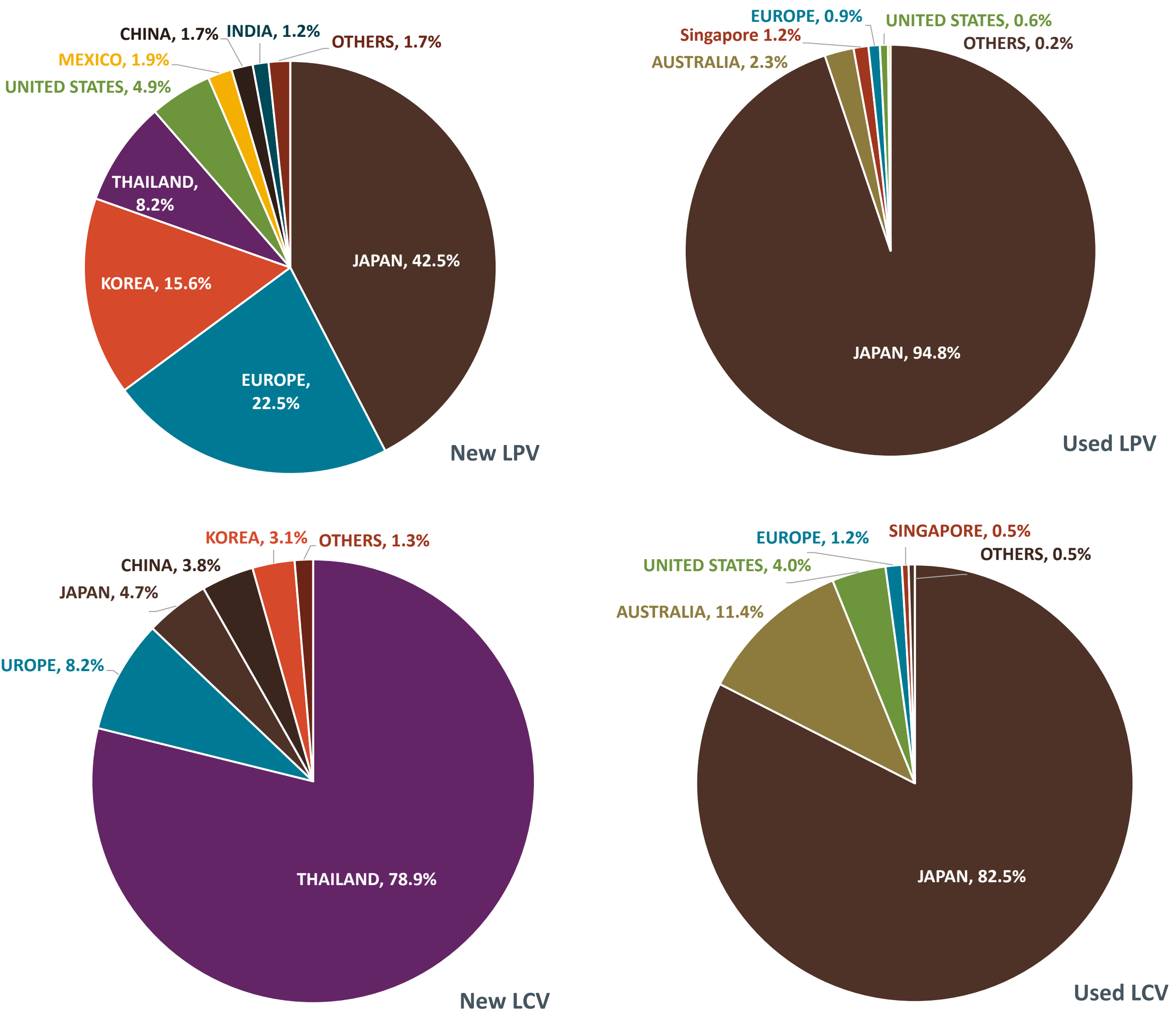


Figure 3. Market share of 2019 LDV, LPV, and LCV registrations by origin country

4.3 Estimation of certified test cycle from 2021

Concerning the previous countries of imported used LDVs, the test cycles of reported vehicle CO_2 emission values include the NEDC, U.S. CAFE (2-cycle), JC08, 10-15 Mode, 3P-WLTP, and 4P-WLTP (see Table 9). It is expected that used vehicles imported to New Zealand will continue being reported under these test cycles for a long time because there is currently no age limitation for importing used LDVs in New Zealand.[22] Over time, used vehicles imported from Japan will be dominated by 3P-WLTP and used vehicles imported from Europe and other countries will be increasingly certified under 4P-WLTP.

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[22] As of March 1, 2020, all used light-duty vehicles coming into New Zealand are required to have electronic stability control. The rule prevents, to some extent, some very old used vehicles from entering New Zealand. The rule is available at https://www.transport.govt.nz/land/electronic-stability-control/

Table 9. Previous countries of imported used LDVs and corresponding test cycles

Export country	2019 used LDV market share	Test cycle used to first certify the vehicles
Japan	94.1%	10-15 Mode JC08 3P-WLTP
United States	0.8%	U.S. CAFE
Europe and others	5.1%	NEDC 4P-WLTP

For imported new vehicles, the test cycles used to certify vehicles are usually determined by the destination market. Because most new vehicles sold to New Zealand are also sold to Australia, which is a much bigger market than New Zealand, the certified test cycle will likely follow the test cycle requirements of Australia. According to 2019 registration data, 97.8% of the new LDVs imported to New Zealand are certified under the NEDC, 2% are certified under WLTP, and 0.2% are certified under JC08.[23] Because Australia has not determined if or when to introduce the WLTP, it is estimated that the vast majority of new vehicles imported to New Zealand will continue being certified under the NEDC with a small percentage of new LDVs being certified under the 4P-WLTP and 3P-WLTP cycles.

4.4 Fleet characteristics of imported LPVs and LCVs in New Zealand

Figure 4 shows the market share trend of imported LDVs by fuel type. The imported LDVs in New Zealand consist mostly of petrol and diesel vehicles, although there is an increasing penetration of hybrid petrol vehicles, battery electric vehicles (BEVs), and a small share of plug-in hybrid petrol vehicles (PHEVs-petrol).

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[23] The 2% includes 0.8% that are marked as certified under NEDC/WLTP. Additionally, 31.4% of new LDVs were imported from Japan in 2019, but only a very small portion are certified under JC08.

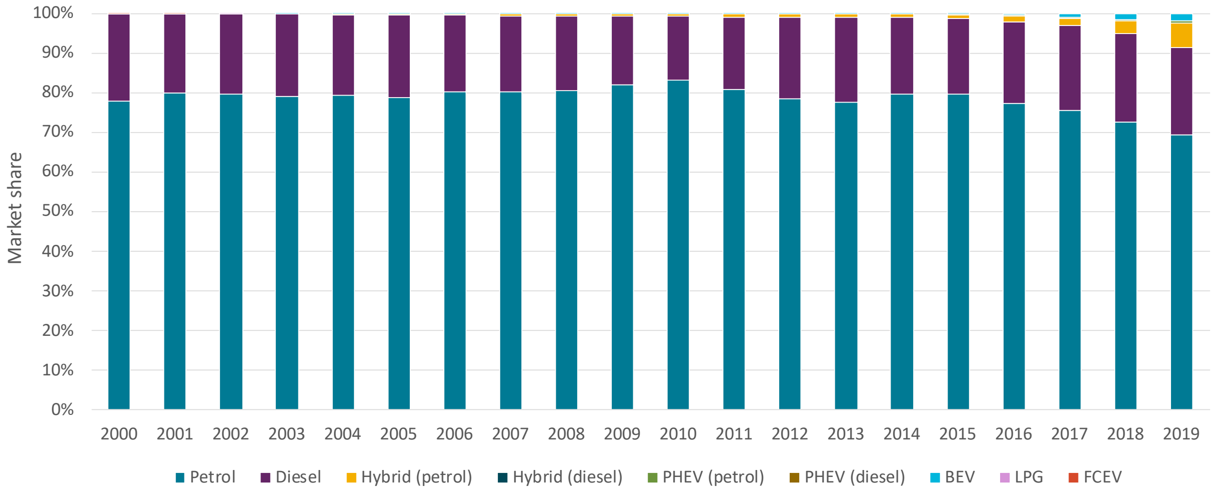

Figure 4. Market share from 2000 to 2019 of new and used LDV registrations by fuel type

Figure 5 breaks down the 2019 registration distribution by LPV and LCV. The LPV segment is dominated by petrol vehicles but also includes a mix of diesel, hybrid, BEVs, and PHEVs. The LCV segment is dominated by diesel vehicles with only a small penetration of petrol vehicles. The types of fuel used by LDVs in New Zealand are the mainstream fuels used by LDVs in other key vehicle markets. There is no alternative fuel that needs to be specially considered for the analyses documented in this report.

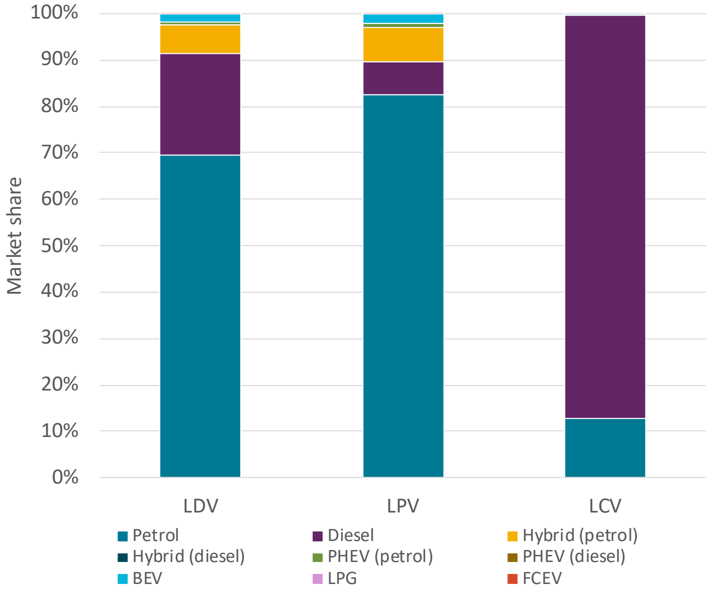

Figure 5. Market share by fuel type of 2019 imported new and used LDVs, LPVs, and LCVs

Figure 6 and Figure 7 summarize the market share of imported new and used LDVs by body type for LPV and LCV. The body types are taken directly from the registration data provided by the New Zealand Ministry of Transport. For LPVs, body types include station wagon, hatchback, saloon (known in other markets as a sedan), sports car, and convertible; station wagon, hatchback, and saloon dominate the market. Note that most models categorized under station wagon are SUVs, not station wagons by general definition. For LCVs, body types include utility, light van, heavy van, cab and chassis, caravan, minibus, flat-deck truck, and other truck; utility and light vans dominate the market.

The significant market share of LCV utility vehicles, commonly called "utes" in New Zealand and Australia, is noteworthy because this type of vehicle is not commonly seen in other key vehicle markets. Utes are halfway between sedan/SUVs and pickup trucks and can be driven with a regular driver's license. Therefore, a more detailed analysis was conducted to determine whether utility vehicles would require special attention to ensure the applicability of developed conversion algorithms.

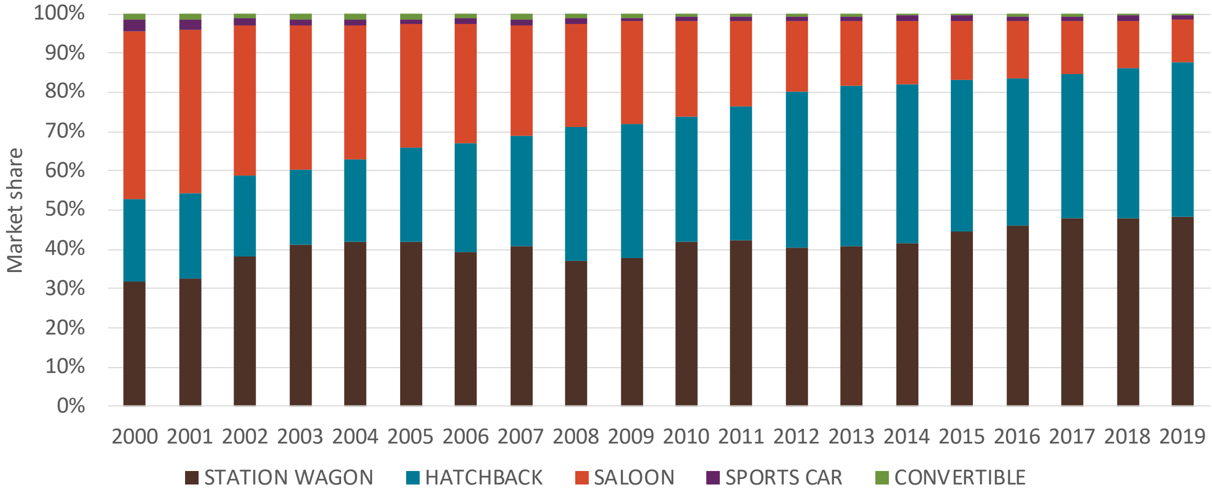

Figure 6. Market share of 2000 to 2019 new and used LPV registrations by body type

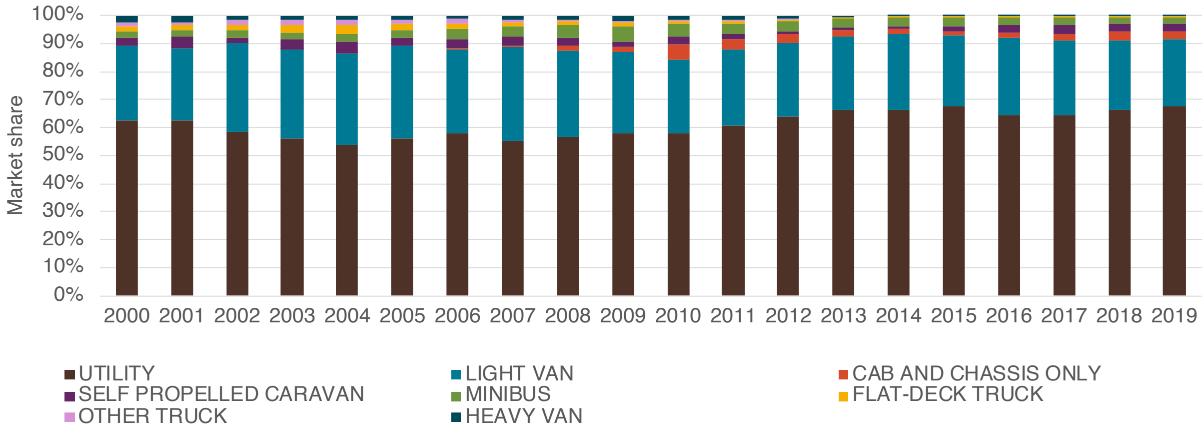

Figure 7. Market share of 2000 to 2019 new and used LCV registrations by body type

Due to dataset limitations, information on rated power and curb weight is only available for new imported vehicles. Fortunately, most utes are new rather than used vehicles. According to the database, all utes are categorized as NA class vehicles, equivalent to the N1 European classification.[24] Other vehicle classes are MA, MB, MC, MD1, and MD2, which are equivalent to European class A, B, C, D, and E vehicles.[25] Figure 8, Figure 9, and Figure 10 illustrate the distributions of rated power, curb weight, and power-to-weight ratio for utes as compared to other vehicle segments. The boxplots present the distribution of each parameter for each segment. The vertical lines reflect the range of the parameter and the two connected boxes in the middle reflect the mean and the adjoining quartiles, representing 50% of vehicles in each vehicle class.

New utes are roughly similar in mass to NA, MB, and MC class vehicles, and similar in rated power to NA and MC class vehicles. In terms of power-to-weight ratio, which to some extent reflects vehicle performance, utes are consistent with NA, MA, MB, and MC class vehicles. Although the characteristic analysis of utes is limited by the availability of information in the database, the comparisons show that key characteristics of utes are generally consistent with the characteristics of other LDV classes. Therefore, no special consideration is expected to be required to characterize the CO_2 emission performance of utes with regard to test cycle conversion algorithm generation.

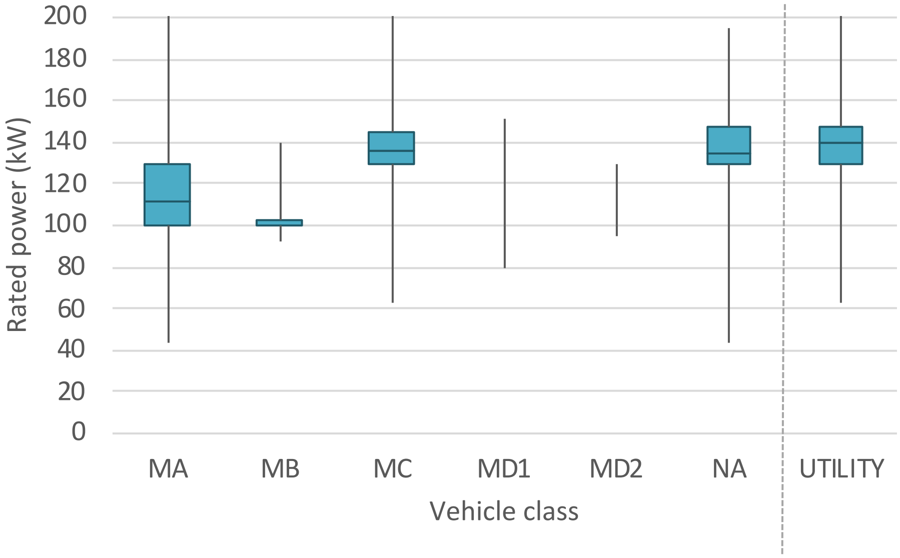

Figure 8. Comparison of power distribution of utility vehicles with other vehicle segments

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[24] N1 vehicles are vehicles for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes.

[25] A class refers to mini cars; B class refers to small cars; C class refers to medium cars; D class refers to large cars; E class refers to executive cars.

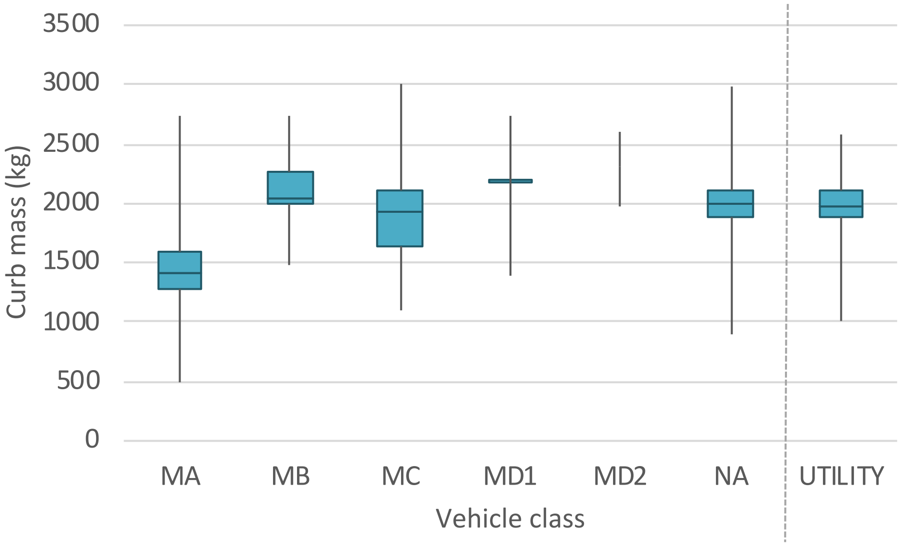

Figure 9. Comparison of curb mass distribution of utility vehicles with other vehicle segments

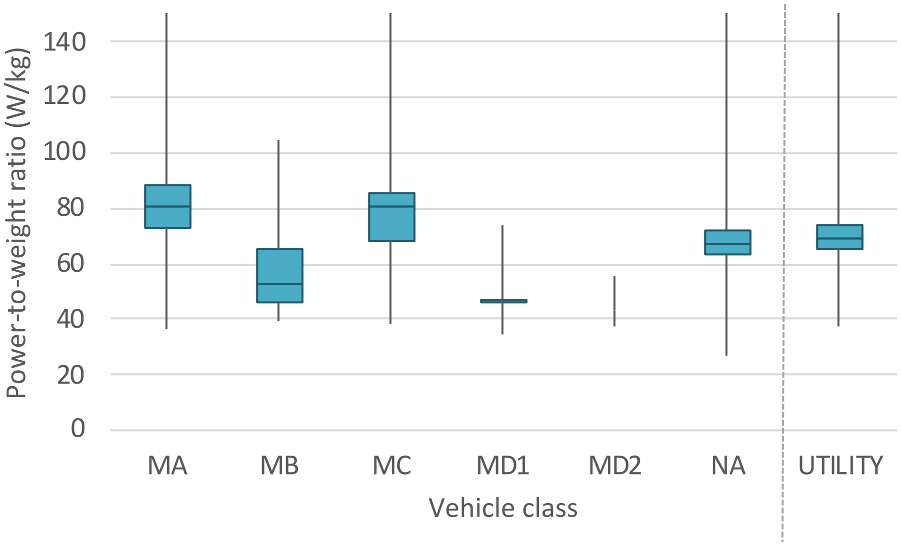

Figure 10. Comparison of power-to-weight distribution of utility vehicles with other vehicle segments

5 Assumptions for standardizing CO_2 emission data

Before developing test cycle conversion algorithms, two things must be established. The first is a determination as to an appropriate test cycle that New Zealand can use to determine regulation compliance. The second is a determination as to the necessity of using a standardized fuel during the performance of test cycle conversions. Based on information presented in Sections 2 through 4, this section addresses these two issues and specifies the assumptions used for the conversion algorithm generation presented in Section 6.

5.1 Choice of test cycle for compliance with vehicle CO_2 emission policies

According to the New Zealand Ministry of Transport's public consultation document on policies that aim to lower the average emission value of imported vehicles, imported new vehicles will be required to have CO_2 emission values determined by the WLTP.[26] The undetermined issue is whether to adopt the 3P-WLTP or the 4P-WLTP as the compliance test cycle. This report suggests adopting the 3P-WLTP as the compliance test procedure for two reasons: [27]

a. More of the vehicles imported to New Zealand from 2021 onward will be certified under the 3P-WLTP than any other cycle

As discussed in Section 4.3, it is estimated that the majority of used LDVs are imported from Japan and will be increasingly certified under the 3P-WLTP over time. The vast majority of new imported LDVs will be certified under the NEDC cycle and will have to be converted to equivalent WLTP values regardless of whether New Zealand chooses to adopt the 3P-WLTP or 4P-WLTP. In addition, and as detailed in section b, below, it is more practical to ask that vehicles certified under the 4P-WLTP be reported in equivalent 3P-WLTP values than vice versa. Therefore, adopting the 3P-WLTP will enable New Zealand to receive fuel efficiency or CO_2 values from importers in the same or similar form as the original type-approval values for an increasing number of used imported vehicles.

b. CO_2 emissions certified under the 4P-WLTP can be precisely converted to 3P-WLTP equivalents

All certification data based on the 4P-WLTP is precisely convertible. WLTP certification requires the collection and reporting of both phase-specific and composite cycle test data, and this facilitates the precise calculation of 3P-WLTP data. The specific calculation methodology is:

$$\text{3P-WLTP} = 0.20614(P1) + 0.31680(P2) + 0.47706(P3)$$

where P1, P2, and P3 are the respective reported test results for phases 1 (low speed), 2 (medium speed), and 3 (high speed) of the WLTP cycle.

For quality control purposes, the reported composite 4P-WLTP value can be replicated to within several decimal places using the following four-phase weighting:

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[26] New Zealand Ministry of Transport, "Moving the Light Vehicle Fleet to Low-Emissions: Discussion Paper on a Clean Car Standard and Clean Car Discount," 2019. Available at https://www.transport.govt.nz/assets/Import/Uploads/Our-Work/Documents/11de862c28/LEV-consultation-document-final.pdf

[27] The recommendation is for class 3 vehicles, and 99.9% of new light-duty vehicles sold in New Zealand from 2015 to 2019 belong to Class 3. See details in Appendix B.

$$4P\text{-}WLTP = 0.13300(P1) + 0.20441(P2) + 0.30782(P3) + 0.35477(P4)$$

These calculations are not based on inferred relationships. Instead, they simply apply the appropriate weighting factors to each phase of the WLTP. Results are precise to within several decimal places.[28]

Current reliance on the 4P-WLTP in both the European Union and countries relying on EU certification requirements means that calculating precise 3P-WLTP values will be possible for a significant portion of the New Zealand new vehicle fleet that is not directly certified on the 3P-WLTP. If the 4P-WLTP data available to New Zealand does not include phase-specific data, that data should be requested from manufacturers. It is collected as an integral component of the 4P-WLTP certification process and, therefore, would not require any additional testing to produce.

Together these two cases should allow precise 3P-WLTP data to be applied to the large majority of the New Zealand new vehicle fleet and an ever increasing portion of the used vehicle fleet.

5.2 Choice of emission factors for FE/FC to CO_2 emission conversion

This report assumes that the New Zealand Ministry of Transport can set emission factors (kg CO_2/L) when converting CO_2 emissions from FE and FC values for both new and used imported vehicles. The impact of emission factors will be minimal and will be independent of the conversion accuracy presented in this report for three reasons:

a. Emission factors are only needed if CO_2 emission values are not available.

For laboratory testing of vehicle FE or FC, the carbon in the exhaust is measured to calculate the amount of fuel burned during the test. This is because carbon emissions are a chemical measure of the mass of consumed fuel. For countries that regulate FE or FC, the tests usually collect tailpipe emissions of CO_2, carbon monoxide (CO), and hydrocarbons (HC), then use mass balance calculations to derive the FE or FC.

In cases where New Zealand uses CO_2 values to determine compliance with standards, if a vehicle was originally type approved in CO_2 g/km, the values can be directly used to determine compliance with standards. If the vehicle reports type-approval information as FE or FC, New Zealand should first investigate if the CO_2 g/km values are also available from the type-approval testing. If the CO_2 g/km values are not available, New Zealand needs to convert the value into CO_2 g/km using domestically defined emission factors (see Figure 11).

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[28] Note that equivalent 4P-WLTP values cannot be similarly calculated from 3P-WLTP measurements due to the missing phase 4 results. Thus, using the 3P-WLTP as the basis for establishing standardized fuel consumption or CO_2 emissions estimates results in a substantially greater ability to use precise calculations in lieu of average relations.

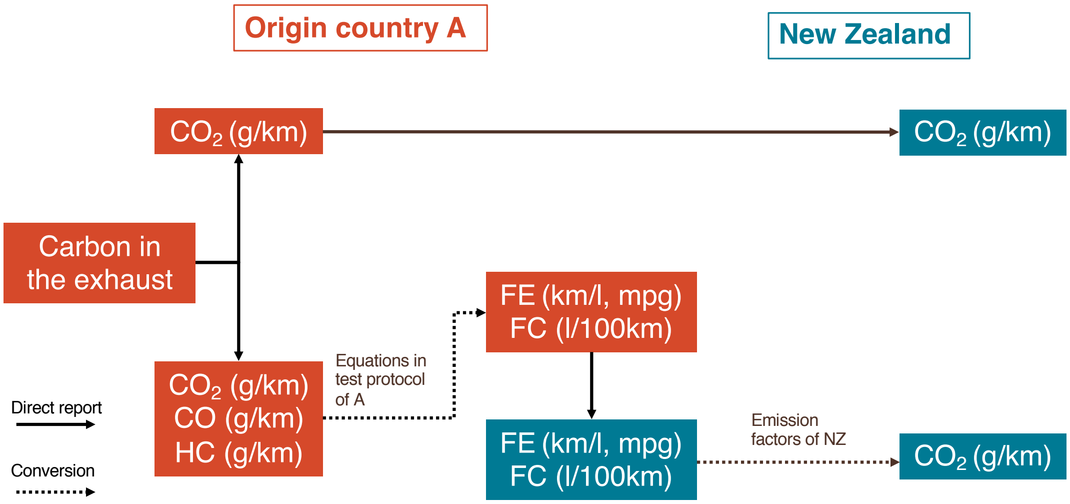

Figure 11. Illustration of the vehicle fuel efficiency or CO_2 emission type-approval information received by New Zealand

b. It is impractical to use the emission factors of standard fuels used in type-approval procedures in origin countries.

Table 4 in Section 2.2 illustrated how reference fuel requirements are different from test procedure to test procedure, and that even for countries that adopt the same test procedure, the reference fuel requirement can be different. Another important reality is that fuel properties will vary across different batches of test fuel, even if all the batches comply with the reference fuel requirement in a given country. Indeed, in the U.S. CAFE type-approval test procedure, the FE in miles per gallon (mpg) for petrol vehicles is converted from emissions data using the following equation:

$$\text{FE in mpg} = \frac{5174 \times 104 \times \mathrm{CWF} \times \mathrm{SG}}{[(\mathrm{CWF} \times \mathrm{HC}) + (0.429 \times \mathrm{CO}) + (0.273 \times \mathrm{CO2})\,] \times [(0.6 \times \mathrm{SG} \times \mathrm{NHV}) + 5471)]}$$

Where:
HC = grams/mile HC
CO = grams/mile CO
CO2 = grams/mile CO_2
CWF = carbon weight fraction of test fuel
NHV = net heating value by mass of test fuel
SG = specific gravity of test fuel

The CWF, NHV, and SG values in the equation are all determined by analysis of a fuel sample taken from the fuel supply. According to U.S. Environmental Protection Agency (EPA) regulations, a sample shall be taken after each addition of fresh fuel into the fuel supply. Moreover, the fuel shall be resampled once a month to account for any fuel property changes during storage. That means the fuel specification, including carbon intensity, will vary according to the source of the testing fuel. Therefore, it is impractical for New Zealand to identify the specifications of each batch of test fuel to convert FE or FC values back to CO_2 emission values.

c. The emission factors chosen will have minimal impact on conversion accuracy.

The conversion from reported FE or FC values to CO_2 emissions using preset conversion factors will introduce a small discrepancy in methodology compared with the vehicles where the value is directly reported in CO_2 g/km. However, the impact of CO and HC will be minor, especially for vehicles that will meet Euro 5 and Euro 6 emission standards.

The differences in reference fuel used by different countries in type-approval testing will influence the test results, because the carbon intensity, energy density, and octane number will differ. Due the different requirements for reference fuel, it is clear that the impact of reference fuel on CO_2, FE, and FC values happened before the values were reported to New Zealand, and thus will not be affected by the emission factors defined by New Zealand.

In general, the impact of test fuel on carbon to FE or FC conversion is already reflected in the type-approval FE or FC and CO_2 emission values that New Zealand will receive from origin countries. The fuel carbon intensity defined by New Zealand to convert reported FE or FC values to CO_2 emissions will not change those elements during testing. It will also have minimal impact on conversion accuracy across different test cycles.

6 Conversion factors (method and results)

6.1 4P-WLTP to 3P-WLTP relations

A conversion from 4P-WLTP to 3P-WLTP is required for two distinct purposes. The primary purpose is for application to vehicles tested on a cycle other than the WLTP. With the possible exception of those developed in Japan, the datasets used to develop conversions from a non-WLTP cycle to the WLTP cycle always reflect the 4P-WLTP, so moving from the non-WLTP cycle to the 3P-WLTP is a two-step process.[29] The second purpose is for application to vehicles tested over the 4P-WLTP for which phase-specific test results that would allow for the precise conversion to 3P-WLTP results are not available.

To develop a generalized conversion from the 4P-WLTP to the 3P-WLTP, this analysis uses an EU certification database for 2019 vehicles obtained from the Vehicle

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[29] Although two steps are required for these conversions, this analysis mathematically combines the steps so that the two conversions involve only a single set of conversion parameters and thus appear identical to a single step conversion. Doing this creates no loss in precision.

Certification Agency of the United Kingdom Department for Transport.[30] This database (hereafter, “the EU database”) contains actual WLTP test results for 5,492 EU vehicle configurations available from 36 different vehicle manufacturers for purchase in the UK in 2019. Results are available for both the composite WLTP and its four component phases. Thus, comparable and precise 3P-WLTP and 4P-WLTP results can be derived for a wide range of vehicles.

The EU database was first subjected to a series of quality control checks. Fifty-four records were excluded because they applied to electric vehicles and had no corresponding WLTP data. One record for a petrol hybrid vehicle was excluded due to missing WLTP data. Forty-one records (two petrol, 39 diesel) were excluded because the reported composite WLTP value was greater than the value for any of the four component WLTP phases; that is not possible. One additional petrol record was excluded because the reported FE in mpg and FC in l/100km data were numerically identical, likely the result of a transcription error.

For the remaining 5,395 records, the reported composite 4P-WLTP fuel consumption rate was compared to the 4P-WLTP fuel consumption rate calculated by weighting reported results for each of the four component phases. All but 48 of the records agreed to within a difference of ±0.1 l/100km, the level of precision associated with the reported data. Those 48 records (38 petrol, 9 diesel, and 1 diesel hybrid electric vehicle or “HEV”) were excluded, and that yielded a usable dataset of 5,347 test records.

To the extent that the dataset includes manufacturers that produce a large number of variants of a specific vehicle model, this can introduce a bias and therefore the dataset was collapsed at two levels: the manufacturer-engine displacement-fuel level and the manufacturer-engine displacement-engine power-fuel level.[31] The dual stratification criteria are primarily to allow for a gauge of analytical sensitivity, answering the question of whether the two stratification criteria yield substantially different results. Collapsed fuel consumption and emissions data are calculated as the average of all component records, and stratification yields a compacted database that contains a single distinct record for each combination of the stratification criteria. The manufacturer-displacement-fuel stratification yields a collapsed dataset of 178 records, and the manufacturer-displacement-power-fuel stratification yields a collapsed dataset of 355 records.

Figure 12 and Figure 13 depict basic distributional data for the WLTP data in the EU database. Both figures depict data from the more resolved manufacturer-displacement-power-fuel stratification, but the data from the manufacturer-displacement-fuel stratification is visually indistinguishable from that depicted in the figures. As indicated, 3P-WLTP data are quite similar to 4P-WLTP data.

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[30] United Kingdom Department for Transport, Vehicle Certification Agency; “New Car Fuel Consumption & Emission Figures;” December 2019. Booklet and data available at: https://carfueldata.vehicle-certification-agency.gov.uk/downloads/download.aspx?rg=2019

[31] Fuel, in the context used here, means stratification by diesel, diesel hybrid, petrol, petrol hybrid, and electricity.

As can be seen in Figure 12, this is because phase 4 results are only slightly higher than those of phases 2 and 3, which account for just less than 80% of 3P-WLTP weighting. Phase 1 results, with a 3P-WLTP weight that is 50% higher than its 4P-WLTP weight, pulls the composite results nearly in line with 4P-WLTP results.

Table *10* provides regression statistics for the two dataset stratifications. All regressions are of the form 3P-WLTP = *a*(4P-WLTP) + *b*, where *a* represents the rate of change (slope) of the relation and *b* represents a constant offset (intercept), and applicable units are gCO_2/km.[32] Separate relations are presented for petrol and diesel vehicles as fueling type is easily distinguishable.[33] Figure 14 provides a graphical depiction of the relations.

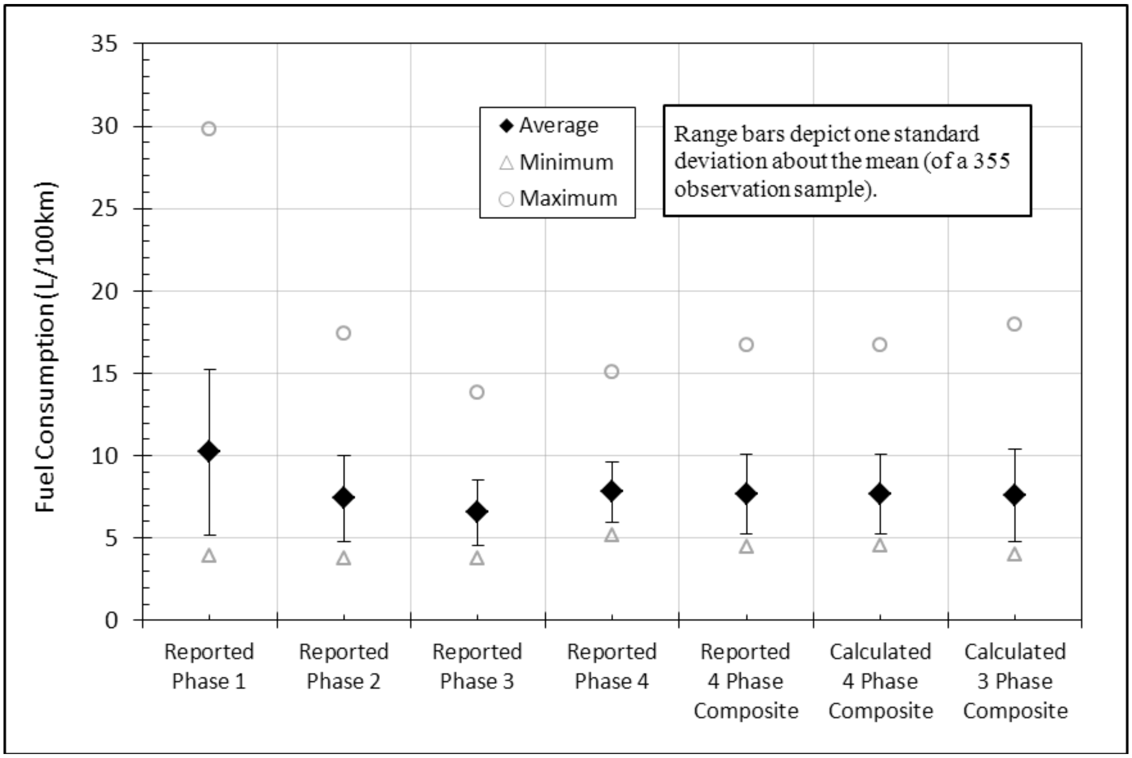

Figure 12. Distribution statistics for WLTP data in the EU database

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[32] Appendix C provides an overview of the rationale for specifying a linear formulation, including a discussion of why alternative formulations are not recommended.

[33] In the context of the relations presented, diesel includes diesel hybrids and petrol includes petrol hybrids.

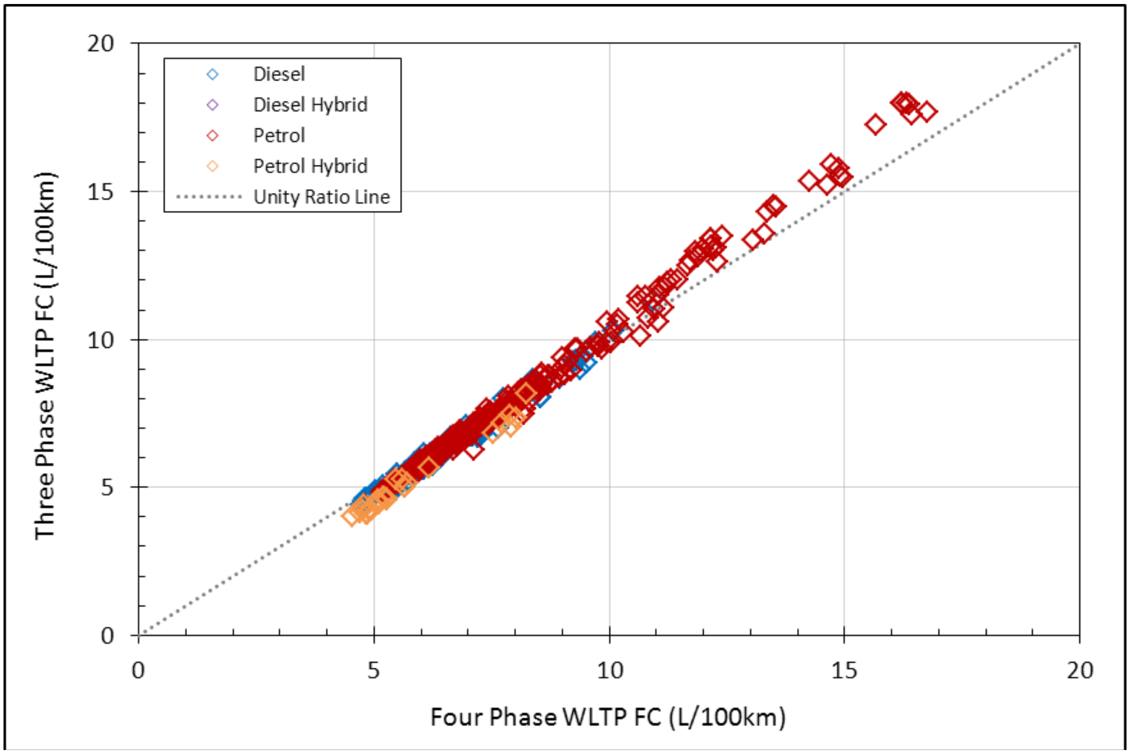

Figure 13. Relationship between 4P-WLTP and 3P-WLTP data in the EU database

Table 10. Parameters for converting 4P-WLTP data to 3P-WLTP equivalents

Data Description	Data Points	*a*	*b* (gCO$_2$/km)	r^2	Standard Error of Prediction (gCO$_2$/km)	Unity Relation Crossover (gCO$_2$/km)
EU Database, Petrol, Stratification A	125	1.1597	-32.2882	0.993	6.44	202.2
EU Database, Diesel, Stratification A	53	1.0665	-16.9849	0.988	4.13	255.5
EU Database, Petrol, Stratification B	235	1.1569	-31.0519	0.993	6.35	197.9
EU Database, Diesel, Stratification B	120	1.0497	-14.4674	0.984	4.49	291.2

Relations are of the form: 3P-WLTP = *a*(4P-WLTP) + *b*, where both 3P-WLTP and 4P-WLTP are in units of gCO$_2$/km.
Stratification A is manufacturer-engine displacement-fuel.
Stratification B is manufacturer-engine displacement-engine power-fuel.

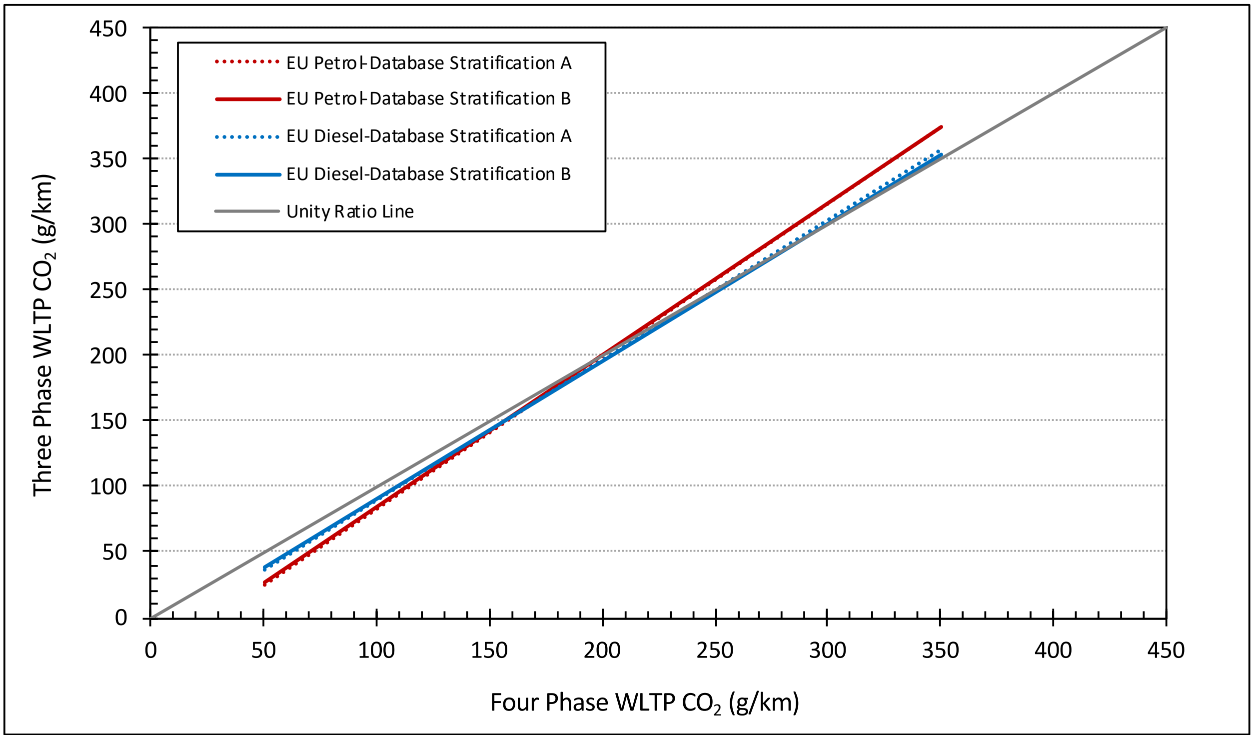

Figure 14. Graphical depiction of 4P-WLTP to 3P-WLTP conversion relations

For consistency, all regression statistics in this report are reported in CO_2 space. Raw data in fuel consumption space were converted to CO_2 equivalent data using fuel carbon contents of 2400.5 g/petrol liter and 2667.3 g/diesel liter. The carbon content values are those assumed by Ricardo, Inc. in developing the aforementioned modeling tool used by the ICCT for a 2014 cross-cycle study. The study and tool are further discussed in the sections that follow and form the basis of the presented CAFE driving cycle relations.

Note also that separate relations are provided for petrol and diesel vehicles. A combined relationship independent of fuel could also be developed, but this is not recommended. A combined relation requires specifically weighting the separate petrol and diesel relations in accordance with a given metric, such as the ratio of petrol to diesel vehicles in New Zealand, or a 50/50 split, or the ratio of such data in the analysis dataset, etc. None of these or any other approaches would improve on the accuracy of the relations when applied to a specific vehicle, and because fuel type is an easily identifiable parameter, it makes little sense to trade accuracy for little to no improvement in ease of application.

Similarly, separate relations can be generated for non-hybrid and hybrid vehicles, or hybrids and various subsets of non-hybrid vehicles, but such relations are not provided here for several reasons. First, the data available to develop relations is limited and it is easy to spread data too finely without proper constraint. For example, only three diesel hybrid data points are available in the EU database. Petrol hybrid data includes 26 data points and, while still limited, is a candidate for separate consideration. A separate relation is not provided for hybrids for several reasons. As mentioned, the number of data points is still limited. Additionally, petrol hybrid data is available only over a relatively narrow range of data, from about 4.5 to 8 l/100km, as compared to the larger EU dataset. Thus, the relation would have to be extrapolated, potentially for both higher and lower fuel consumption vehicles. While this is not different than the case for non-hybrids for low fuel consumption vehicles, the net effect of recommending two independent extrapolations would be problematic. Independent regressions for petrol hybrids and non-hybrids would result in a crossover of the derived relations at about 4.2 l/100km (approximately 100 gCO_2/km), such that non-hybrid 3P-WLTP estimates for 4P-WLTP estimates below the crossover point would be lower than those of hybrids. Because there is no technical rationale for such behavior, this crossover is assumed to be an artifact of the relative sparseness of the hybrid data. Finally, the differential between estimates based on a combined relation and separate hybrid and non-hybrid relations are modest when compared with standard error estimates. Detailed residual distributions presented in Appendix F show that the general performance of hybrid and non-hybrid emission conversions based on a single "all vehicle" relation are not substantially different across any of the evaluated cycles. Given these considerations, it is expected that the hybrid data are generally consistent with the low fuel consumption non-hybrid data; as that is indeed depicted in Figure 13, a combined relation is appropriate. It may, however, be worthwhile to revisit this situation as more hybrid data become available.

Finally, stratification of relations by technology requires not only identification of the technology in the underlying dataset, but identification of that same technology in practice; the latter is needed for identification of the appropriate relation to apply. Technologies such as the type of hybrid system employed, the presence of a stop-start system, etc., can be difficult to determine both for available analysis data and, if available for analysis, for users, and this results in highly specified relations. Users of such relations will need to have access to sufficiently detailed information about the vehicle subject to conversion before a specific conversion relation can be applied. Given the quantity and general consistency of data available to develop relations, it does not appear appropriate to impose requirements beyond the presented fuel type distinction.

6.2 NEDC to 3P-WLTP relations

This analysis relies on the EU database to develop a relation between NEDC and 3P-WLTP test results.[34] The EU database includes composite CO_2 emission rate data

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[34] Section 3.3 describes several references that quantify relationships between NEDC and 4P-WLTP data. Although the data utilized in those references are generally more limited, they are, nevertheless, also generally consistent with those used for this analysis. The one exception to the more limited nature of the data is a detailed study conducted in the Netherlands that estimates the relationship between NEDC and 4P-WLTP data for 151,993 petrol and 20,817 diesel vehicles registered during the 2018-2019 time period. They are generally consistent with those developed in this analysis. The major difference is that the statistics developed for this analysis have somewhat reduced slopes and higher intercepts than those of the Netherlands study, so that 4P-WLTP estimates are lower in the upper end of the CO_2 range. For example, at 50 gCO_2/km NEDC, this analysis estimates 4P-WLTP emissions at 77 g/km for diesel and 74 g/km for petrol, as compared to 72 ($\Delta = -5$) and 69 ($\Delta = -5$) g/km respectively for the Netherlands relations;

for both the NEDC and the composite 4P-WLTP; phase-specific NEDC data are not available. The NEDC data are believed to primarily be simulation data derived from the 4P-WLTP test data using the EU Joint Research Centre's CO_2MPAS model.[35,36,37] It is possible that some of the database records are based on actual NEDC testing, but it is not possible to determine source information from the included data. This dataset serves as the primary source of WLTP and NEDC data for this analysis. The CO_2MPAS model is a simulation model designed to alleviate the requirement for EU vehicle manufacturers to test vehicles over both the WLTP and NEDC procedures. Following completion of required WLTP testing, manufacturers are allowed to use the CO_2MPAS model to estimate an equivalent NEDC test result, which can then be used to demonstrate compliance with EU fleet average CO_2 standards that were adopted under a previously applicable NEDC testing regime. Although these NEDC data are likely simulation-based, they represent officially authorized NEDC performance for EU compliance purposes. This analysis is by design generalizing the relationship between CO_2MPAS simulations and measured 4P-WLTP data for the vehicles included in the EU database. The CO_2MPAS model is vehicle model specific and thus cannot produce a generalized relation even though such relations surely underlie CO_2MPAS algorithms. This analysis is, in effect, producing a generalized relation from data associated with thousands of executions of the CO_2MPAS model.

In addition to the records excluded for quality control purposes, as previously described when detailing 4P-WLTP to 3P-WLTP conversion, this analysis excludes an additional three petrol records for which the fuel carbon content implied by the reported 4P-WLTP fuel consumption and CO_2 emissions data was not reasonable. The resulting 5,344 record database was subjected to the same stratification procedures previously described for the 4P-WLTP to 3P-WLTP conversion.

Figure 15 shows the distribution of 4P-WLTP versus NEDC data in the EU database. Although the figure depicts data from the more resolved manufacturer-displacement-power-fuel stratification, the data from the manufacturer-displacement-fuel stratification are visually indistinguishable from those depicted in Figure 15. As the figure shows, there is a strong correlation between the

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but at 350 g/km NEDC, the estimates are 388 g/km for diesel and 364 g/km for petrol in this analysis as compared to 408 (Δ = +20) and 392 (Δ = +28) g/km respectively for the Netherlands relations. This analysis relies on the cited EU database for three primary reasons. First, the raw data are available, allowing for detailed, quality assured analysis and appropriate data stratification, whereas the available Netherlands report provides only aggregate relation statistics. Second, as the Netherlands data are registration based, they reflect a de facto sales weighting that cannot be evaluated with regard to applicability in New Zealand (or elsewhere). Finally, the EU database is the source of the 4P-WLTP to 3P-WLTP relations for this analysis and thus serves as an internally consistent source for NEDC data.

[35] https://pypi.org/project/co2mpas/

[36] Commission Implementing Regulation (EU) 2017/1153 of 2 June 2017 setting out a methodology for determining the correlation parameters necessary for reflecting the change in the regulatory test procedure and amending Regulation (EU) No 1014/2010 (https://eur-lex.europa.eu/eli/reg_impl/2017/1153/2017-07-28)

[37] Generally, the use of the CO_2MPAS is mandatory, so it is expected that most of the NEDC results are based on CO_2MPAS model predictions. There are, however, allowances for actual testing to be used in place of CO_2MPAS. The certification database reports, but does not provide, a means to identify the source of the NEDC data.

NEDC and 4P-WLTP data, and that was expected, but there is also considerable variability—on the order of 50 gCO_2/km—over a wide range of NEDC values.

Given the virtual equivalency of the data for the manufacturer-displacement-fuel and the more resolved manufacturer-displacement-power-fuel stratifications, only statistics for the latter are presented. Once developed, regression statistics were algebraically combined with the 4P-WLTP to 3P-WLTP regression statistics with no loss in precision to derive an aggregate NEDC to 3P-WLTP relation. Table 11 presents the resulting regression statistics. The regression is of the form 3P-WLTP = *a*(NEDC) + *b*, where *a* represents the rate of change (slope) of the relation and *b* represents a constant offset (intercept). Applicable units are gCO_2/km. Separate relations are presented for petrol and diesel vehicles as fuel type is easily distinguishable.[38] Figure 16 provides a graphical depiction of the relations.

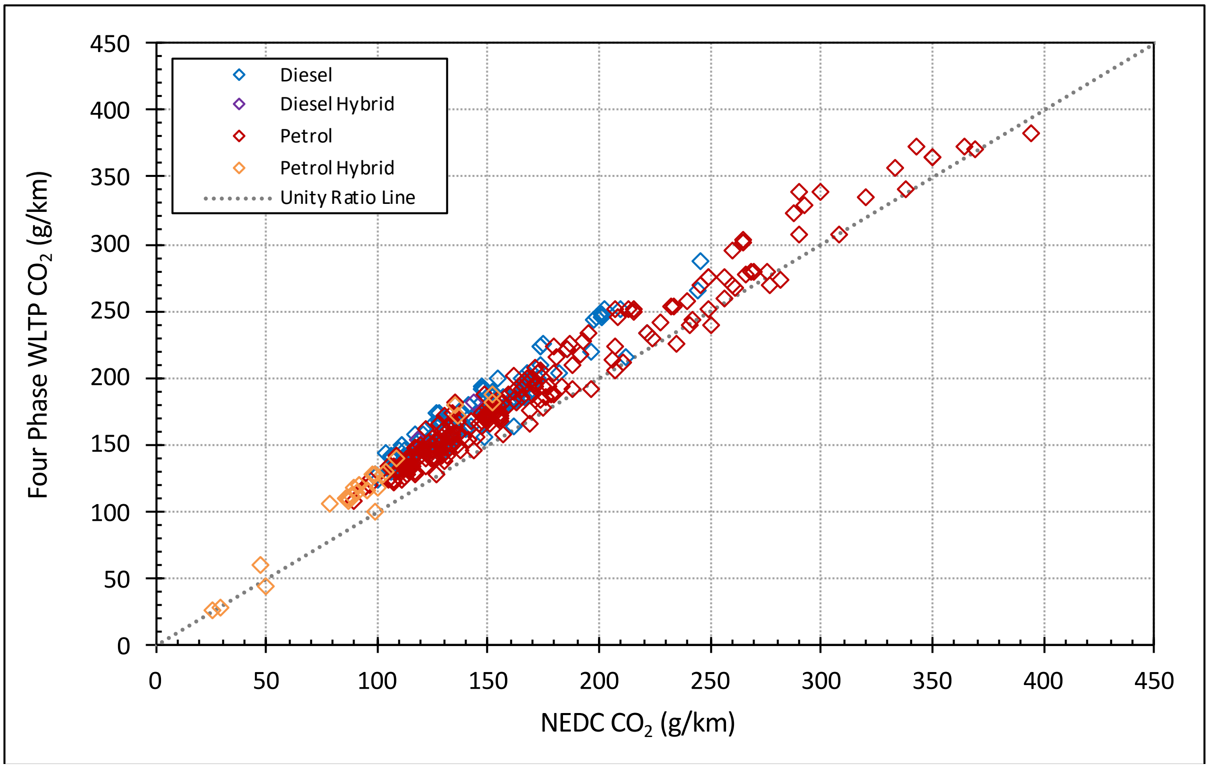

Figure 15. Relationship between NEDC and 4P-WLTP data in the EU database

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[38] As was the case with the 4P-WLTP to 3P-WLTP conversion, it is possible to generate a separate relation for hybrid and non-hybrid petrol vehicles. However, relations are not presented herein for the same reasons described in the 4P-WLTP to 3P-WLTP conversion discussion. The only difference for the NEDC to 4P-WLTP conversion would be that the hybrid and non-hybrid relations would cross in such a way as to make converted hybrid emissions higher than converted non-hybrid emissions for NEDC emissions greater than about 100 gCO_2/km. In the absence of a theoretical rationale for such a crossover, the differential between the hybrid and non-hybrid relations is likely an artifact of a small hybrid sample. As shown by the residual statistics presented in Appendix D, both hybrid and non-hybrid vehicles are served well by a combined relation.

Table 11. Parameters for converting NEDC data to 3P-WLTP equivalents

Data Description	Data Points	*a*	*b* (gCO_2/km)	r^2	Standard Error of Prediction (gCO_2/km)	Unity Relation Crossover (gCO_2/km)
EU Database, Petrol, Stratification B	235	1.1194	-1.1618	0.968	13.12	9.7
EU Database, Diesel, Stratification B	120	1.0871	12.7300	0.914	10.68	-146.2

Relations are of the form: 3P-WLTP = *a*(NEDC) + *b*, where both 3P-WLTP and NEDC are in units of gCO_2/km.
Stratification A is manufacturer-engine displacement-fuel (data not shown).
Stratification B is manufacturer-engine displacement-engine power-fuel.

The data point and r^2 parameters indicate statistics for the underlying 4P-WLTP = a_1(NEDC) + b_1 analysis, prior to algebraic aggregation with a separate 3P-WLTP = a_2(4P-WLTP) + b_2 analysis (the statistics for which are reported in Table 1). The aggregated statistics are developed as follows: $a = (a_1)(a_2)$, $b = (a_2)(b_1) + b_2$, and standard error = $[(\text{standard error}_1)^2 + (\text{standard error}_2)^2]^{0.5}$.

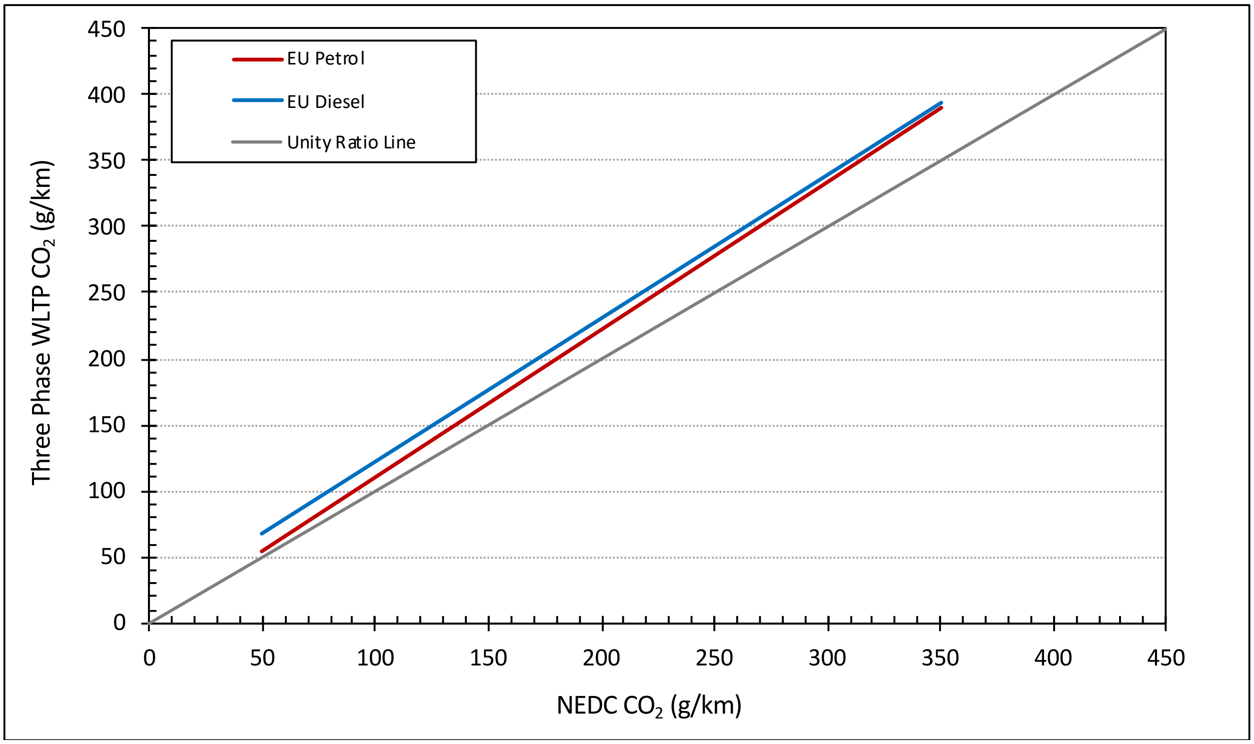

Figure 16. NEDC to 3P-WLTP conversion relations

6.3 JC08 to 3P-WLTP relations

Two sources of comparative test data, both provided by the New Zealand Ministry of Transport and both traceable to the Japan Ministry of Land, Infrastructure, Transport and Tourism (MLIT), were used to develop the relationship between measurements taken on the JC08 and 3P-WLTP test cycles. One dataset contains data for vehicle certifications from 2015 through 2018 (hereafter, “the MLIT 2015–2018 dataset”) and one contains data for certifications of indeterminate timing (hereafter, “the MLIT supplemental JC08 dataset”).[39] The MLIT 2015–2018 dataset includes 11,601 records,

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[39] Data transmitted from the New Zealand Ministry of Transport in two files. File “MLIT (Japan) new registration 2015-2018.xlsx” contains the MLIT 2015-2018 data. File “Japanese with Multiple Regimes_20200316.xlsx” contains the MLIT supplemental data.

only 99 of which report both JC08 and 3P-WLTP data. The MLIT supplemental JC08 dataset includes 405 records, all of which report both JC08 and 3P-WLTP data.

The combined 504-record JC08 and 3P-WLTP dataset contains a substantial number of records that are for the same vehicle across multiple certification years and for multiple variants of a vehicle with identical or very similar emissions data. To avoid biasing the analysis toward vehicles with multiple reported records, the dataset was stratified by vehicle make and model code. This resulted in a collapsed dataset of 49 unique (comparative) records, as depicted in Figure 17.

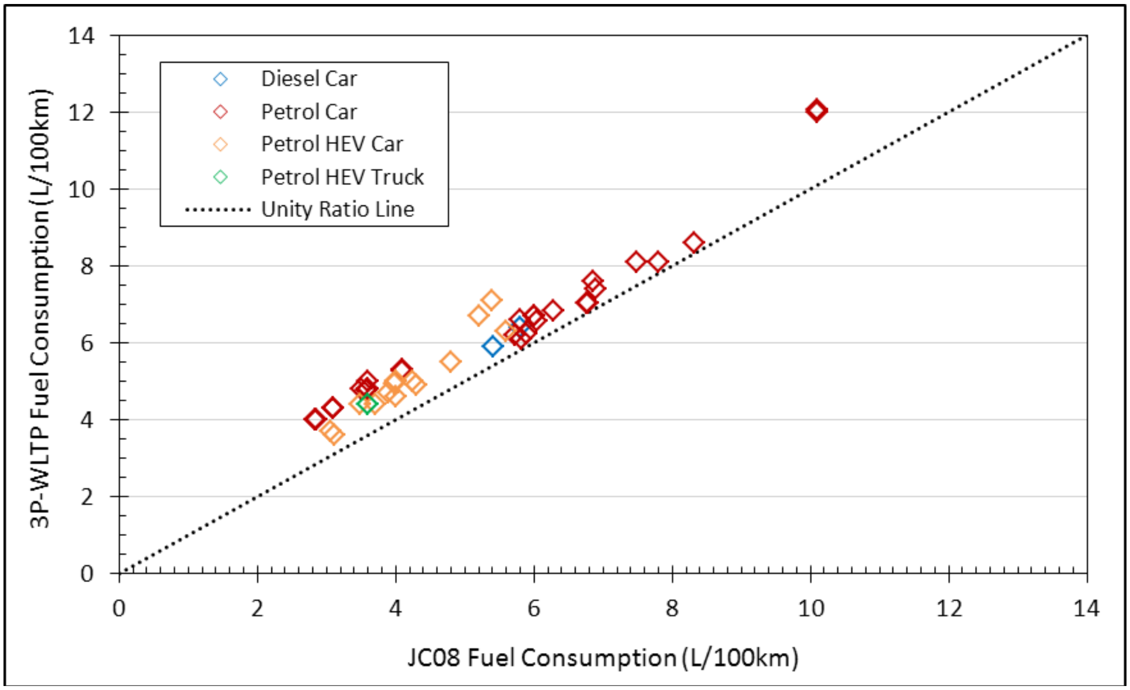

Figure 17. Relationship between JC08 and 3P-WLTP data in the MLIT 2015–2018 and supplemental JC08 datasets

As indicated in Figure 17, the MLIT data are in fuel consumption space. Of the 504 unstratified dataset records, all contain comparative fuel consumption data, but only 405 contain explicit CO_2 data. Thus, all analysis is performed in fuel consumption space and converted to CO_2-equivalents using fuel carbon contents of 2,400.5 g/petrol liter and 2,667.3 g/diesel liter. Recall that these carbon contents are those assumed by Ricardo, Inc. in developing a modeling tool used in the 2014 ICCT study. These values are used throughout the analyses and documented herein for consistency.[40] This report presents

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[40] The records for which comparative fuel consumption and comparative CO_2 data are available in the Japan datasets (including data for 801 10-15 Mode cycle records, as discussed in detail in the 10-15 Mode section of this report) indicate fuel carbon contents ranging from 2,576 to 2,603 g/L for diesel and 2,294 to 2,380 g/L for petrol. These vary from the standardized values used to develop the statistics in this report by 2.4%–3.4% for diesel and 0.8%–4.4% for petrol. Care should be exercised with regard to the diesel estimates as there are only 12 records with comparative diesel fuel consumption and CO_2 data. The petrol estimates are based on data from more than 1000 records and are, therefore, more robust.

all results in CO_2 space, but corresponding relationship parameters in fuel consumption space can be calculated precisely from the provided statistics.

As presented in Figure 17, it is difficult to identify trends across vehicle and technology types due to the relative sparsity and general consistency of the data. This is consistent with similar observations for other cycles. Moreover, given the paucity of diesel data—two records—this analysis relies on a single JC08 to 3P-WLTP fuel consumption relation for all vehicles. This single "all vehicle" relation is converted to separate CO_2 relations for diesel and petrol vehicles, with the difference between the two reflecting only the differential fuel carbon contents of the fuels.

Table 12 presents the derived relationship statistics. All regressions are of the form 3P-WLTP = *a*(JC08) + *b*, where *a* represents the rate of change (slope) of the relation and *b* represents a constant offset (intercept). Applicable units are gCO_2/km. Separate relations are presented for petrol and diesel vehicles as fueling type is easily distinguishable. Nonetheless, as previously stated, both are based on the same underlying data. Figure 18 provides a graphical depiction of the relations.

Table 12. Parameters for converting JC08 data to 3P-WLTP equivalents

Data description	Data points	*a*	*b* (gCO_2/km)	r^2	Standard error of prediction (gCO_2/km)	Unity relation crossover (gCO_2/km)
MLIT Data, Petrol, All Data Points	49	0.9695	24.6742	0.947	10.08	807.8
MLIT Data, Diesel, All Data Points			27.4167		11.20	897.6

Relations are of the form: 3P-WLTP = *a*(JC08) + *b*, where both 3P-WLTP and JC08 are in units of gCO_2/km.

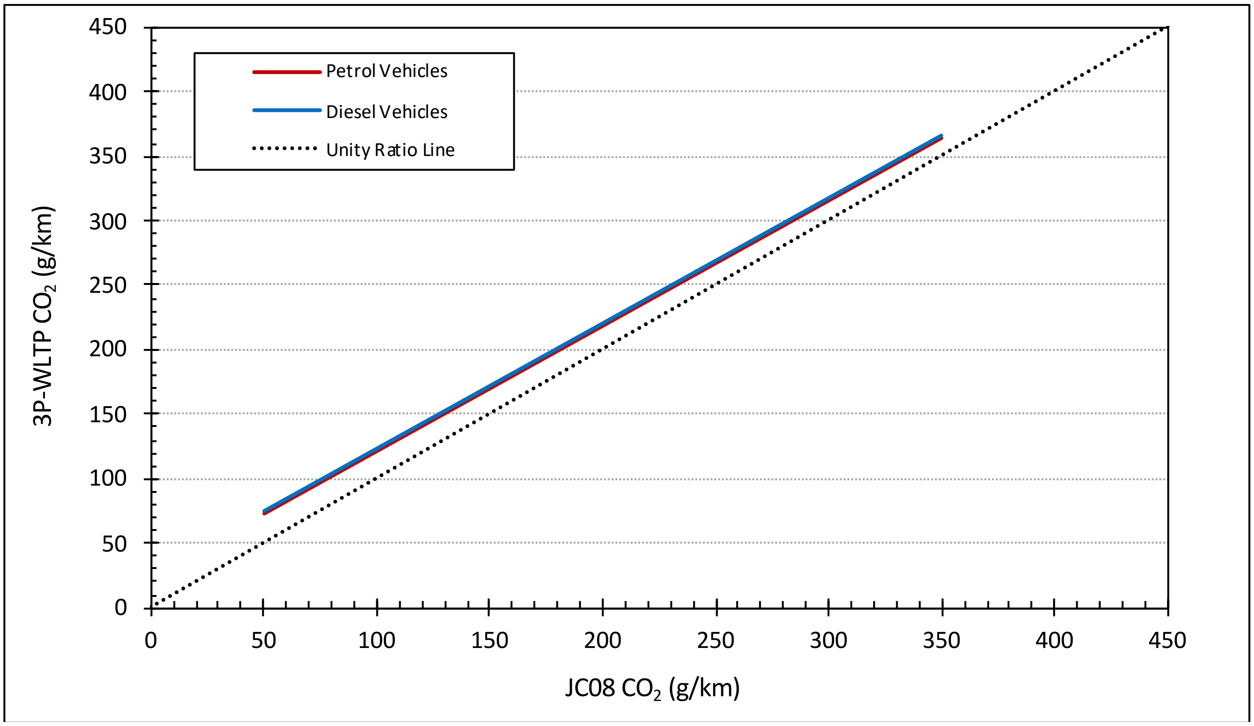

Figure 18. JC08 to 3P-WLTP conversion relations

6.4 CAFE to 3P-WLTP relations

The literature review conducted in support of this work found no current quantitative data related to the relationship between the U.S. CAFE and the WLTP test cycles. This is not unexpected, because the United States has not demonstrated a desire to move toward WLTP adoption. The latest effort to investigate the relation between U.S. CAFE and WLTP data continues to be the 2014 ICCT study described in Section 3.2. The 2014 ICCT study is of direct utility for this work as it includes many of the driving cycles of interest to New Zealand; continues to be timely in that it considers vehicle technology data spanning the 2010 to 2025 timeframe; reflects data developed through rigorous methodologies consistent with industry practice; and uses analytical methods that are reliable and scientifically defensible. In short, it represents the best resource available in the absence of actual data or a similar, more comprehensive simulation modeling study. This analysis supplants the 2014 ICCT study with regard to the NEDC and the JC08, as the cited EU certification data and MLIT test data are more comprehensive and more recent; that is not the case for the CAFE cycle.

The one complication with regard to using the 2014 ICCT study is that the WLTP existed, but was not yet adopted, at the time of study performance. The study therefore includes the WLTP driving cycle in the form in which it existed at the time of performance, which was WLTP Class 3 version 5. What was ultimately adopted was version 5.3 for Class 3b vehicles. To ensure that this does not result in bias, a comparative exercise was conducted for this analysis. As shown in Figure 19, the only difference between the WLTP cycle included in the 2014 ICCT study and the Class 3b cycle ultimately adopted is the acceleration profile for a single "hill" in the high-speed phase of the cycle, wherein the 2014 study cycle exhibits a higher instantaneous acceleration of shorter duration, as compared to the lower instantaneous acceleration and longer duration of the adopted cycle. Although both cycles "get to the same place," the 2014 study cycle gets there quicker. To evaluate the significance of this difference, this analysis estimated the tractive energy required to execute the two cycles for 84 vehicle configurations, spanning the range from small car to large light truck.[41] In all cases, the tractive energy requirements of the two cycles varied by no more than about one quarter of one percent (0.14%–0.26%). Given this similarity, this study treats the 2014 ICCT WLTP cycle as equivalent to the adopted 4P-WLTP for Class 3b vehicles.[42]

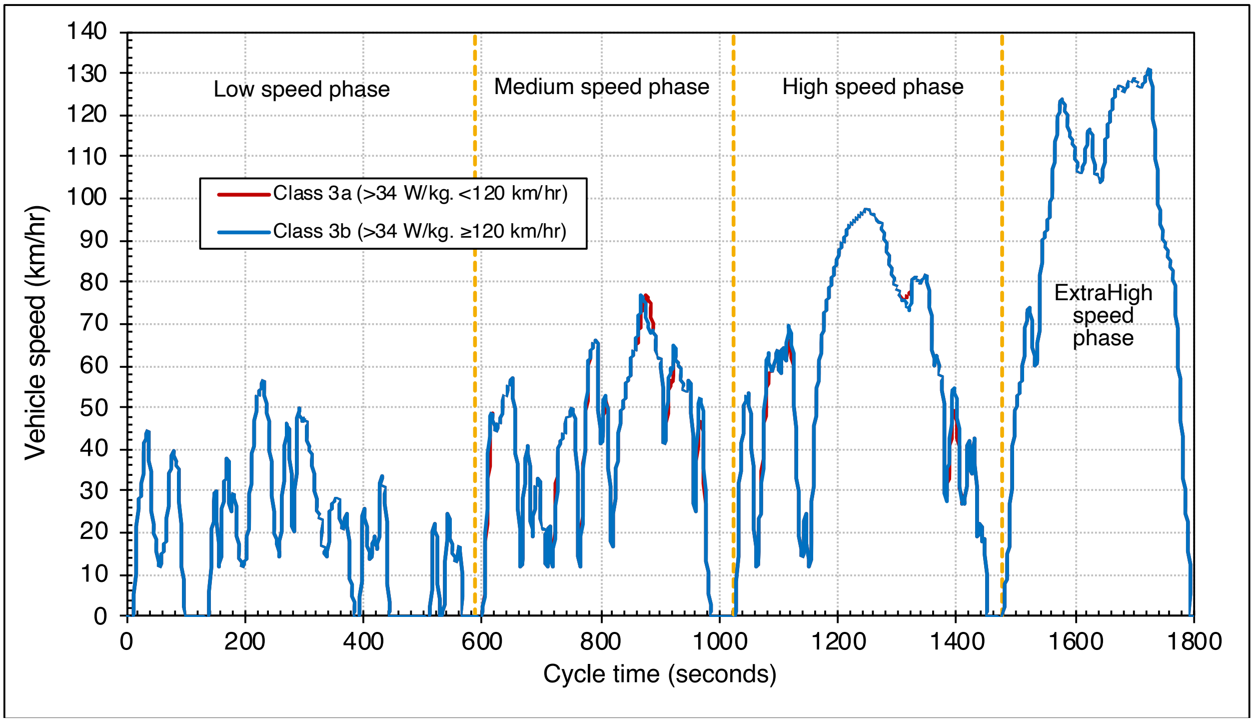

Figure 19. 4P-WLTP versus the version 5 WLTP cycle used in the 2014 ICCT study

Figure 20 shows the distribution of CAFE versus 4P-WLTP data in the 2014 ICCT study. These data are "well behaved" and show definitive trends and constrained deviation from the mean. Nevertheless, it is clear that variability is as high as 50 gCO_2/km for a range of CAFE values. As for the other investigated cycles, relations were developed for

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[41] Tractive energy is the energy that a vehicle would need to execute the driving cycle. It is equal to the input energy if fuel energy could be converted to "energy at the wheels" with 100% efficiency. To undertake this evaluation, the analysis relies on proprietary software developed by Meszler Engineering Services (MES). Tractive energy calculations are physics-based calculations that utilize force equations to quantify the energy required to induce motion (for a given driving cycle and set of opposing forces). ICCT has previously subjected the MES software to confirmatory testing against the tractive energy requirements predicted by independent researchers such as Ricardo, Inc., and estimates have agreed to within 0-3% (without either researcher having perfect knowledge of the other's vehicle configuration assumptions).

[42] It should be noted that emissions of species other than CO_2 (which are not the focus of this analysis) are more sensitive to vehicle load and that the differences between the two versions of the WLTP may not be as insignificant when such species are of interest.

petrol and diesel vehicles separately.[43] Moreover, as with the NEDC relations, the resulting regression statistics for the CAFE to 4P-WLTP cycle were algebraically combined with 4P-WLTP to 3P-WLTP regression statistics with no loss in precision to derive an aggregate CAFE to 3P-WLTP relation. Table 13 presents the resulting statistics. All regressions are of the form 3P-WLTP = *a*(CAFE) + *b*, where *a* represents the rate of change (slope) of the relation and *b* represents a constant offset (intercept). Applicable units are gCO_2/km. Figure 21 provides a graphical depiction of the relations.

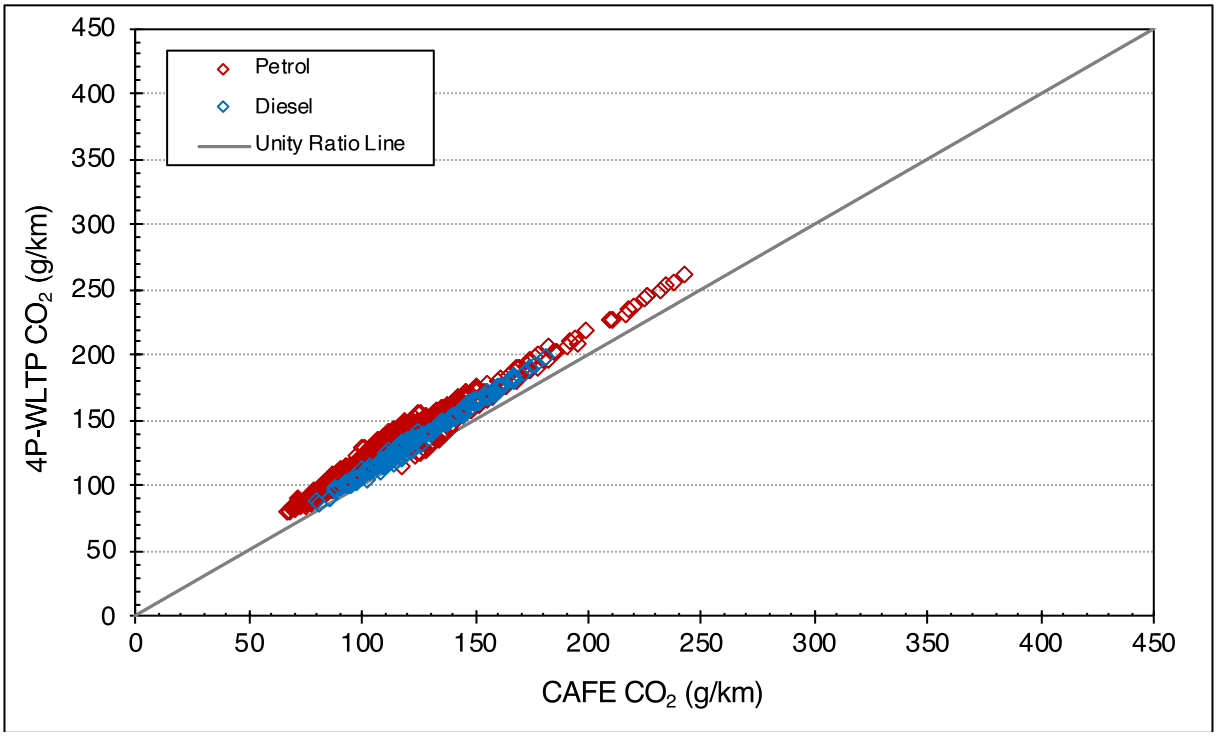

Figure 20. CAFE versus 4P-WLTP data from the 2014 ICCT study

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[43] The 2014 ICCT study does allow for the examination of specific technology subsets. An analysis of petrol hybrid and petrol non-hybrid vehicles indicates that hybrid-specific and non-hybrid advanced ICE technology relations vary by only 2%–3% (2-3 gCO_2) over the range of data available for hybrids (about 80–160 gCO_2/km) – with hybrids predicted to have higher 4P-WLTP/CAFE ratios than non-hybrids. Both relations vary from an all vehicle relation by 2%–6% over the same range. Moreover, extrapolation of the hybrid relation would crossover the all vehicle relation at about 93 gCO_2, so that hybrid 4P-WLTP/CAFE ratios would be higher for CAFE emissions above 93 gCO_2 and lower for emissions below 93 gCO_2. Given the relative consistency of estimates and the lack of a theoretical justification for altered behavior above and below 100 gCO_2, this analysis assumes that hybrid and non-hybrid technology differentials are an artifact of sampling and applies a common relation to both.

Table 13. Parameters for converting CAFE data to 3P-WLTP equivalents

Data description	Data points	*a*	*b* (gCO_2/km)	r^2	Standard error of prediction (gCO_2/km)	Unity relation crossover (gCO_2/km)
2014 ICCT Study, Petrol, All Data Points	763	1.2094	-16.4856	0.974	7.95	78.7
2014 ICCT Study, Diesel, All Data Points	175	1.1589	-16.5771	0.990	5.11	104.3

Relations are of the form: 3P-WLTP = *a*(CAFE) + *b*, where both 3P-WLTP and CAFE are in units of gCO_2/km.

The data point and r^2 parameters indicate statistics for the underlying 4P-WLTP = a_1(CAFE) + b_1 analysis, prior to algebraic aggregation with a separate 3P-WLTP = a_2(4P-WLTP) + b_2 analysis (the statistics for which are reported in Table 1 above). The aggregated statistics are developed as follows: $a = (a_1)(a_2)$, $b = (a_2)(b_1) + b_2$, and standard error = $[(\text{standard error}_1)^2 + (\text{standard error}_2)^2]^{0.5}$.

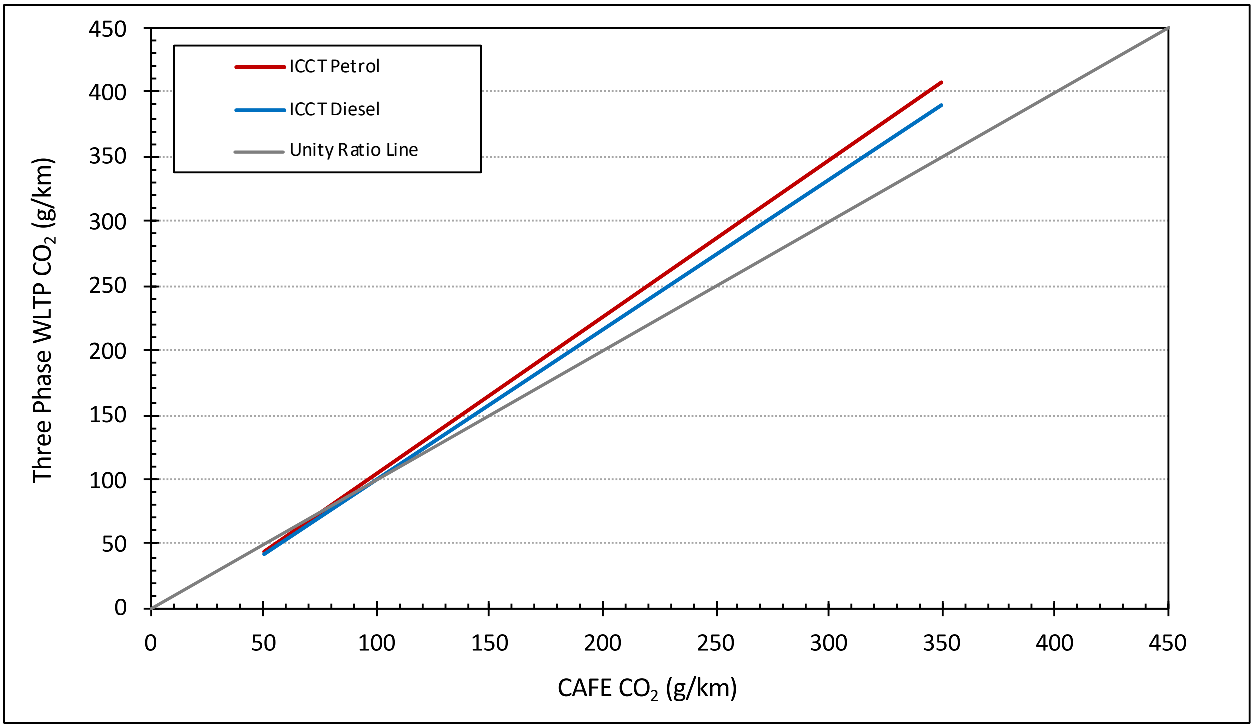

Figure 21. CAFE to 3P-WLTP conversion relations

6.5 10-15 Mode to 3P-WLTP relations

The Japan 10-15 Mode cycle is a relatively old, and inactive, cycle. It has not been used to certify new vehicles for a decade. Transition from the 10-15 Mode cycle to the JC08 began in 2005 and was complete by 2011. As a result, the 10-15 Mode cycle has not been used for research purposes for a long time. As that was also true in 2014, the cycle is not included among those evaluated in the 2014 ICCT study. It is expected that the number of vehicles that were certified on the 10-15 Mode cycle will be small in number and rapidly declining. Nevertheless, comparative test data continues to be reported for Japanese certifications.

Two sources of comparative test data, both provided by the New Zealand Ministry of Transport and both traceable to the Japan MLIT, were used to develop the relationship between measurements taken on the 10-15 Mode and JC08 test cycles. One dataset is the MLIT 2015–2018 dataset that is used for generating JC08 to 3P-WLTP relationship and one contains data for certifications of indeterminate timing (hereafter, “the MLIT supplemental 10-15 Mode dataset”).[44] The New Zealand Ministry of Transport also provided a third dataset assembled by the Society of Automotive Engineers of Japan that contains comparative 10-15 Mode and JC08 test data (hereafter, “the JSAE dataset”). That was combined with the MLIT 2015–2018 and MLIT supplemental 10-15 Mode dataset to create an aggregate analysis dataset.[45]

The MLIT 2015–2018 dataset includes a total of 11,601 records, 744 of which report both 10-15 Mode and JC08 data. The MLIT supplemental 10-15 Mode dataset includes 801 records, all of which report comparative 10-15 Mode and JC08 data. The JSAE dataset includes 4,945 records, all of which report comparative 10-15 Mode and JC08 data. Accordingly, the aggregate analysis dataset contains 6,490 records.

The combined 6,490 record 10-15 Mode and JC08 dataset contains a substantial number of records that are for the same vehicle across multiple certification years and for multiple variants of a vehicle with identical or very similar emissions data. To avoid biasing the analysis toward vehicles with multiple reported records, the dataset was stratified by vehicle make and model code. This resulted in a collapsed dataset of 336 records. Six of these records were excluded from analysis due to reported data that is obviously in error. All are for Mercedes-Benz vehicles and all report 10-15 Mode fuel consumption that is about three times that of reported JC08 fuel consumption; this contrasts with other Mercedes-Benz models that exhibit ratios consistent with those of other manufacturers. Thus, the analysis dataset consists of 330 unique (comparative) records, as depicted in Figure 22.

As indicated in Figure 22, the aggregated dataset is processed in fuel consumption space. Of the 6,490 unstratified records, all contain comparative fuel consumption data, but only 801 contain explicit CO_2 data. Thus, all analysis is performed in fuel consumption space and converted to CO_2-equivalents using fuel carbon contents of 2,400.5 g/petrol liter and 2,667.3 g/diesel liter. These are the carbon contents assumed by Ricardo, Inc. in developing the modeling tool used for the 2014 ICCT study. This report presents all results in CO_2 space, but corresponding relationship parameters in fuel consumption space can be calculated precisely from the provided statistics.

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[44] Data transmitted from the New Zealand Ministry of Transport in two files. File “MLIT (Japan) new registration 2015-2018.xlsx” contains the MLIT 2015-2018 data. File “Japanese with Multiple Regimes_20200316.xlsx” contains the MLIT supplemental 10-15 Mode data.

[45] Data transmitted from the New Zealand Ministry of Transport. File “Japanese with Multiple Regimes_20200316.xlsx” contains the JSAE data.

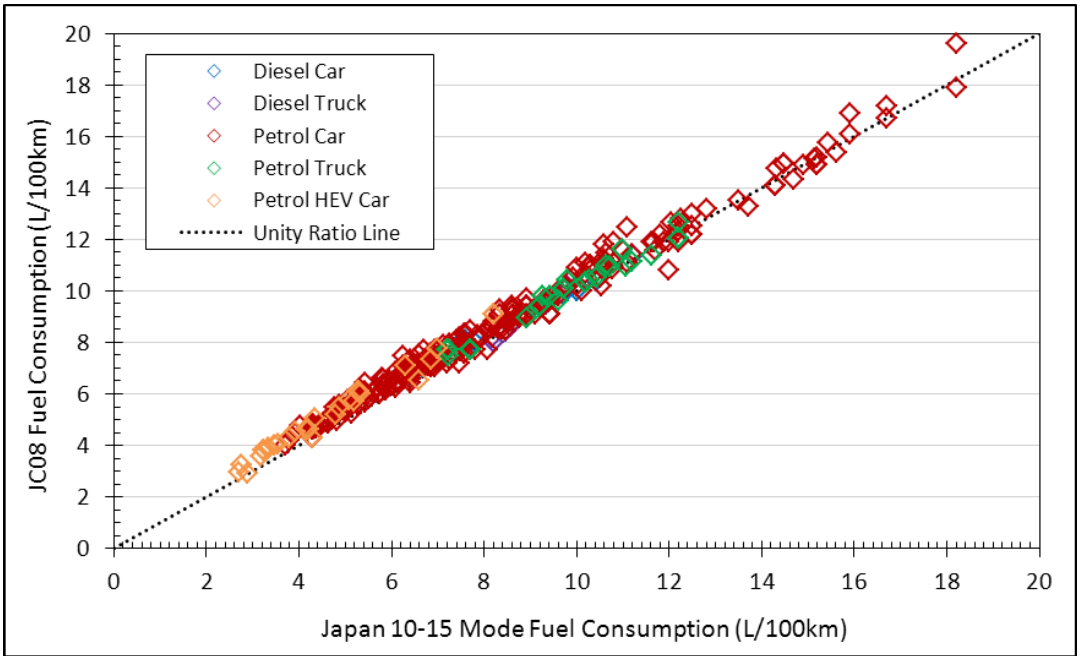

Figure 22. 10-15 Mode versus JC08 data from the MLIT and JSAE datasets

As presented in Figure 22, it is difficult to identify definitive trends across vehicle and technology types due to the relative sparsity of data for some vehicle segments and the general consistency of the data. This is consistent with similar observations for other cycles. Moreover, given the paucity of diesel data (8 car, 11 truck records) and the general consistency of diesel and petrol data, this analysis relies on a single 10-15 Mode to JC08 fuel consumption relation for all vehicles. This single "all vehicle" relation is converted to separate CO_2 relations for diesel and petrol vehicles, with the difference between the two reflecting only the differential fuel carbon contents of the fuels.[46] The resulting regression statistics for the 10-15 Mode to JC08 cycle were algebraically combined with JC08 to 3P-WLTP regression statistics with no loss in precision to derive an aggregate 10-15 Mode to 3P-WLTP relation.

Table 14 presents the resulting statistics. All regressions are of the form 3P-WLTP = *a*(10-15 Mode) + *b*, where *a* represents the rate of change (slope) of the relation and *b* represents a constant offset (intercept). Applicable units are gCO_2/km. Figure 23 provides a graphical depiction of the resulting relations.

Table 14. Parameters for converting 10-15 Mode data to 3P-WLTP equivalents

Data Description	Data Points	*a*	*b* (gCO_2/km)	r^2	Standard Error of Prediction (gCO_2/km)	Unity Relation Crossover (gCO_2/km)
MLIT & JSAE Data, Petrol, All Data Points	330	0.9353	39.7740	0.989	12.52	614.8
MLIT & JSAE Data, Diesel, All Data Points			44.1947		13.91	683.1

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[46] Given the diesel data, a separate diesel relation would differ from the "all vehicle" relation by just over 1 gCO_2/km at 50 gCO_2/km 10-15 Mode and less than 8 gCO_2/km at 500 gCO_2/km 10-15 Mode.

Relations are of the form: 3P-WLTP = *a*(10-15 Mode) + *b*, where both 3P-WLTP and 10-15 Mode are in units of gCO_2/km.

The data point and r^2 parameters indicate statistics for the underlying JC08 = a_1(10-15 Mode) + b_1 analysis, prior to algebraic aggregation with a separate 3P-WLTP = a_2(JC08) + b_2 analysis (the statistics for which are reported in Table 3 above). The aggregated statistics are developed as follows: *a* = $(a_1)(a_2)$, *b* = $(a_2)(b_1) + b_2$, and standard error = $[(\text{standard error}_1)^2 + (\text{standard error}_2)^2]^{0.5}$.

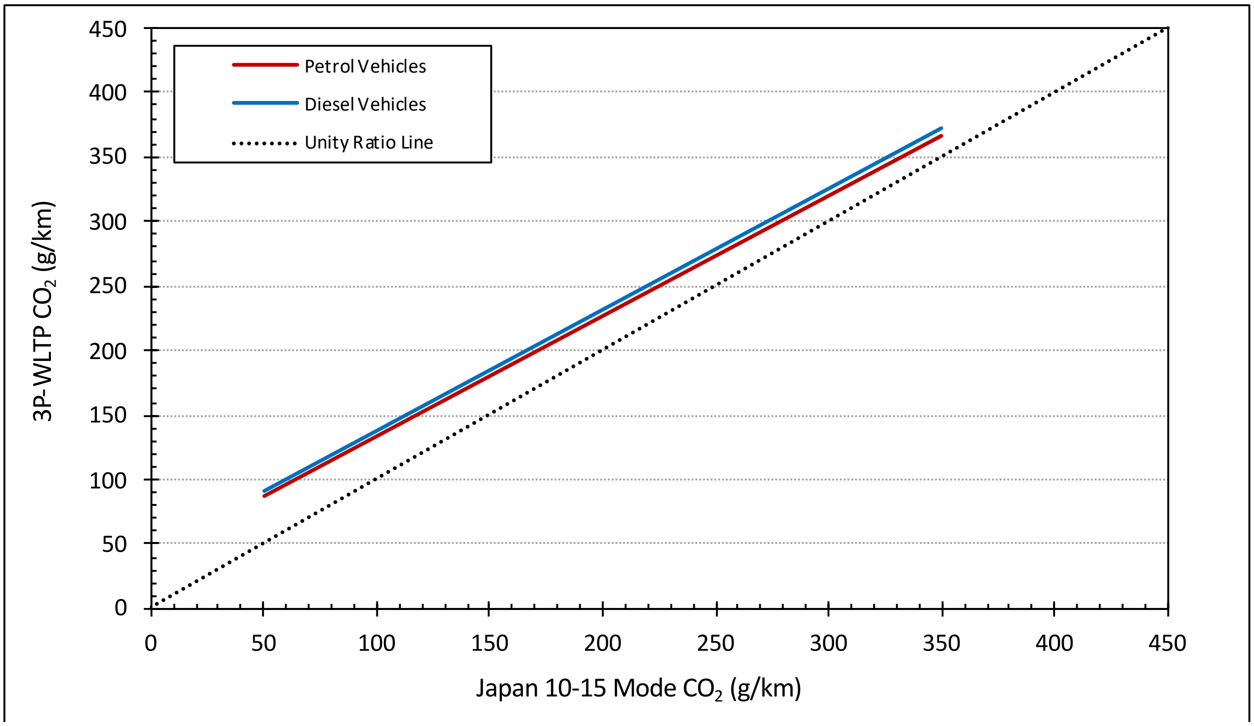

Figure 23. 10-15 Mode to 3P-WLTP conversion relations

Although the presented relations are consistent with those developed for other cycles, it is recommended that New Zealand stop accepting 10-15 Mode certification data at the earliest possible time. This cycle is already two generations and more than a decade out of date. All recent certifications should include data for a recent test cycle.

6.6 Summary of conversion factors

This analysis presents the relations recommended to convert certification test data from one test cycle to another. Table 15 provides a summary of the relations for all evaluated test cycles. In the case of the 4P-WLTP cycle, the conversion relation should only be used when phase specific data is not available and that should be rare. Instead, such data should be converted algebraically as follows:

$$3P\text{-}WLTP = 0.20614(P1) + 0.31680(P2) + 0.47706(P3)$$

where P1, P2, and P3 are the respective reported test results for phases 1 (low speed), 2 (medium speed), and 3 (high speed) of the WLTP cycle.

The algebraic conversion is precise for all vehicles. It includes no error.

Table 15. Summary of test cycle conversion parameters

From Cycle	To Cycle	Fuel	*a*	*b* (gCO_2/km)	Standard Error of Prediction (gCO_2/km)
4P-WLTP	3P-WLTP	Petrol	1.1569	-31.0519	6.35
NEDC			1.1194	-1.1618	13.12
JC08			0.9695	24.6742	10.08
CAFE			1.2094	-16.4856	7.95
10-15 Mode			0.9353	39.7740	12.52
4P-WLTP	3P-WLTP	Diesel	1.0497	-14.4674	4.49
NEDC			1.0871	12.7300	10.68
JC08			0.9695	27.4167	11.20
CAFE			1.1589	-16.5771	5.11
10-15 Mode			0.9353	44.1947	13.91

Relations are of the form: 3P-WLTP = *a*(From Cycle) + *b*
Both 3P-WLTP and From Cycle are in units of gCO_2/km.
4P-WLTP to 3P-WLTP relation should not be used unless data for an algebraic calculation is not available.

All of the relations carry inherent uncertainty (i.e., error). By definition, the relations are accurate on average. Thus, they will be precise only for the rare “average” vehicle. All other conversions will include an error. For normally distributed data, it is reasonable to assume that approximately 68% of vehicles will have an estimation error of no more than the standard error indicated in Table 15. Another 27% of vehicles will have an estimation error of no more than two times the standard error. The last 5% of vehicles can be assumed to have estimation errors larger than two times the standard error. Appendix F presents a series of residual statistics associated with the various relations as applied to the datasets from which they were developed. Although such statistics are informative, they should not be treated as representative of the specific distributions that will be observed in New Zealand. They reflect distributions applicable only to the datasets from which they were developed and thus reflect any and all inherent biases; in no case do they reflect either the New Zealand fleet or, more importantly, a sales-weighted New Zealand fleet. What the distributions provide is a glimpse into the degree of error that might reasonably be expected to be encountered in practice.

7 Robustness of testing results

To test the robustness of the derived conversion algorithms, estimated 3P-WLTP and 4P-WLTP emissions were compared to reported 3P-WLTP and 4P-WLTP emissions for a sampling of top-selling passenger vehicles in New Zealand. Appendix 1 of the New Zealand Ministry of Transport’s proposed LDV low-emission policies provides a list of 17 top-selling passenger vehicles.[47] To the extent practical, the residuals for these vehicles were estimated through comparable vehicles from the EU database used to support the analysis documented in this report.[48] As the Ministry of Transport rightly points out,

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[47] New Zealand Ministry of Transport, “Moving the light vehicle fleet to low-emissions: discussion paper on a Clean Car Standard and Clean Car Discount,” July 2019.
[48] The Japan and CAFE databases are not sufficiently detailed to allow distinct models and configurations to be easily identified.

there is no one-to-one relationship between the top-selling New Zealand vehicles and those included in the EU database. Nevertheless, representative counterparts can be identified, with varying degrees of precision. Table 16 presents the selected counterparts used for the examination of residuals herein. Table 17 presents associated residual statistics. As indicated, estimated CO_2 emissions are within one standard error for 75%–90% of the vehicles for all comparative cycles, and estimates for 100% of vehicles are within 1.6 standard errors. For the NEDC to 3P-WLTP conversion, estimates for 100% of vehicles are within 1.1 standard errors. Thus, although it is not possible to perform a precise one-to-one comparison given available data, it appears that the proposed conversions perform well for vehicles of the type being sold in New Zealand.

Table 16. Cross reference between EU database vehicles and top-selling New Zealand vehicles

New Zealand vehicle	EU database comparison
Toyota Corolla (1.8L Petrol HEV)	Toyota 1.798L (53kW Petrol HEV)
Toyota RAV4 (2.2L Diesel)	Toyota 1.997L (130 kW Diesel)
Toyota Yaris (1.3L Petrol)	Toyota 1.496L (82 kW Petrol)
Kia Sportage (2.0L Petrol)	Kia 1.591L (130 kW Petrol)
Mazda CX-5 (2.2L Diesel)	Mazda 2.191L (110 kW Diesel)
	Mazda 2.192L (110 kW Diesel)
	Mazda 2.193L (110 kW Diesel)
	Mazda 2.194L (110 kW Diesel)
	Mazda 2.195L (110 kW Diesel)
	Mazda 2.196L (110 kW Diesel)
Mazda 3 (2.0L Petrol)	Mazda 1.998L (90 kW Petrol)
Mitsubishi Outlander (88 kW PHEV)	Mitsubishi 1.998L (110 kW Petrol)
Suzuki Swift (1.2L Petrol)	Suzuki 1.242L (66 kW Petrol)
Suzuki Vitara (1.4L Petrol)	Suzuki 1.373L (103 kW Petrol)
Hyundai Tucson (2.0L Diesel)	Hyundai 1.995L (136 kW Diesel)
Hyundai i30 (1.6L Diesel)	Hyundai 1.598L (85 kW Diesel)
Hyundai Santa Fe (2.2L Diesel)	Hyundai 2.199L (147 kW Diesel)
Nissan Qashqai (2.0L Petrol)	Nissan 1.749L (110 kW Diesel)
Nissan X-Trail (2.5L Petrol)	Nissan 1.749L (150 kW Diesel)
	Nissan 1.332L (160 kW Petrol)
Ford Focus (2.0L Diesel)	Ford 1.995L (110 kW Diesel)
Subaru Outback (2.0L Diesel)	Subaru 2.498L (129 kW Petrol)
Honda HR-V (1.8L Petrol)	Honda 1.498L (96 kW Petrol)
	Honda 1.498L (134 kW Petrol)

Table 17. Portion of observations within standard error bounds for top-selling New Zealand vehicles

Metric	4P-WLTP from NEDC	3P-WLTP from 4P-WLTP	3P-WLTP from NEDC	4P-WLTP from NEDC	3P-WLTP from 4P-WLTP	3P-WLTP from NEDC
Vehicles	All Comparative Vehicles			One-to-One Comparison		
1 Standard Error	87.5%	83.3%	91.7%	76.5%	76.5%	88.2%
2 Standard Errors	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3 Standard Errors	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Maximum Ratio	1.60	1.45	1.10	1.60	1.45	1.10
Observations	24	24	24	17	17	17

The “All Comparative Vehicles” statistics include multiple comparatives for some New Zealand vehicles as listed in Table 16. The “One-to-One Comparison” statistics collapse all multiple comparatives into one. If any of the multiple comparatives are out of error bounds, the collapsed comparative is considered out of error bounds. The maximum ratio is the ratio of the largest residual to the standard error. Caution should be exercised in evaluating sparsely populated samples. Each vehicle in the “All Comparative Vehicles” statistics represents 4.2% (1/24) of the sample. Each vehicle in the “One-to-One Comparison” statistics represents 5.9% (1/17) of the sample.

8 Additional insights for policymakers

Given the average nature of the developed relations, any policy that includes cross-cycle conversions is best designed on the basis of a continuous function. Under a continuous function, the inherent uncertainty associated with such conversions can shift a vehicle along the policy scale in either direction, but it cannot move a vehicle from one “bin” to another, as is the case with step function designs. It is also possible to include error expectations in function design if there is a policy preference for minimizing errors in one direction or the other. A policy scale that otherwise assumes precise knowledge of CO_2 emissions or fuel consumption can be shifted to accommodate an error expectation that allows for a certain percentage of errors without penalty to the vehicle owner. This is not meant to suggest that New Zealand should or should not undertake any particular policy or design, but rather to make sure that policy developers are aware of issues that should be considered.

If New Zealand adopts a set of conversion algorithms to determine compliance with low-emissions policies, it should also develop a mechanism to address instances where importers might dispute the estimated CO_2 data. For example, the Ministry of Transport could allow CO_2 test data under the 3P-WLTP to be measured at certified testing laboratories and used in place of the estimated equivalents.

Given that New Zealand will continue importing used vehicles that were first certified in other countries and under various test procedures, it is advisable to set a date by which all LDVs imported to New Zealand, both new and used vehicles, will need to report CO_2 emission values under the 3-phase WLTP using a reference fuel specified by New Zealand regulators. The introduction of emission factors for conversion from FE/FC to CO_2 emissions and conversion algorithms for conversion across different test procedures will always involve uncertainty. To eliminate these uncertainties and enhance LDV low-emission policies over the long term, New Zealand should consider setting a timeline (e.g., 2025 or 2030) to phase out the temporary solutions and require importers to prepare for a CO_2 emission type-approval procedure wherein only one test cycle with a specific reference fuel is accepted. This would standardize the compliance procedure and minimize both uncertainty and the potential for loopholes. We suggest New Zealand set up a system that requires importers to automatically provide both CO_2 values and the FE or FC for type-approval value for imported new vehicles. Because both Japan and EU are switching to 3P-WLTP and 4P-WLTP, there will be more and more used vehicles that are able to provide CO_2 values under 3P-WLTP directly in the next decade. Eventually, a unified CO_2 emission reporting mechanism could be required for imported used vehicles, as well.

Appendix A — Test cycle characteristics

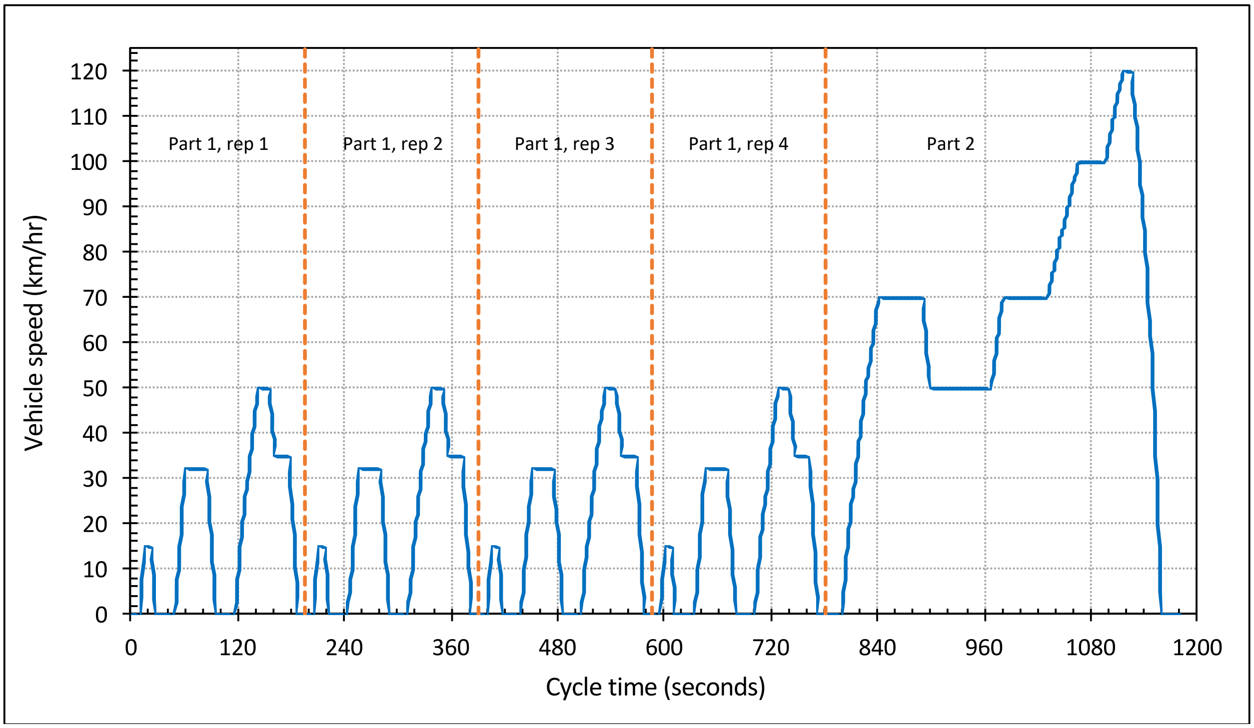

Figure A1. EU New European Driving Cycle (NEDC)

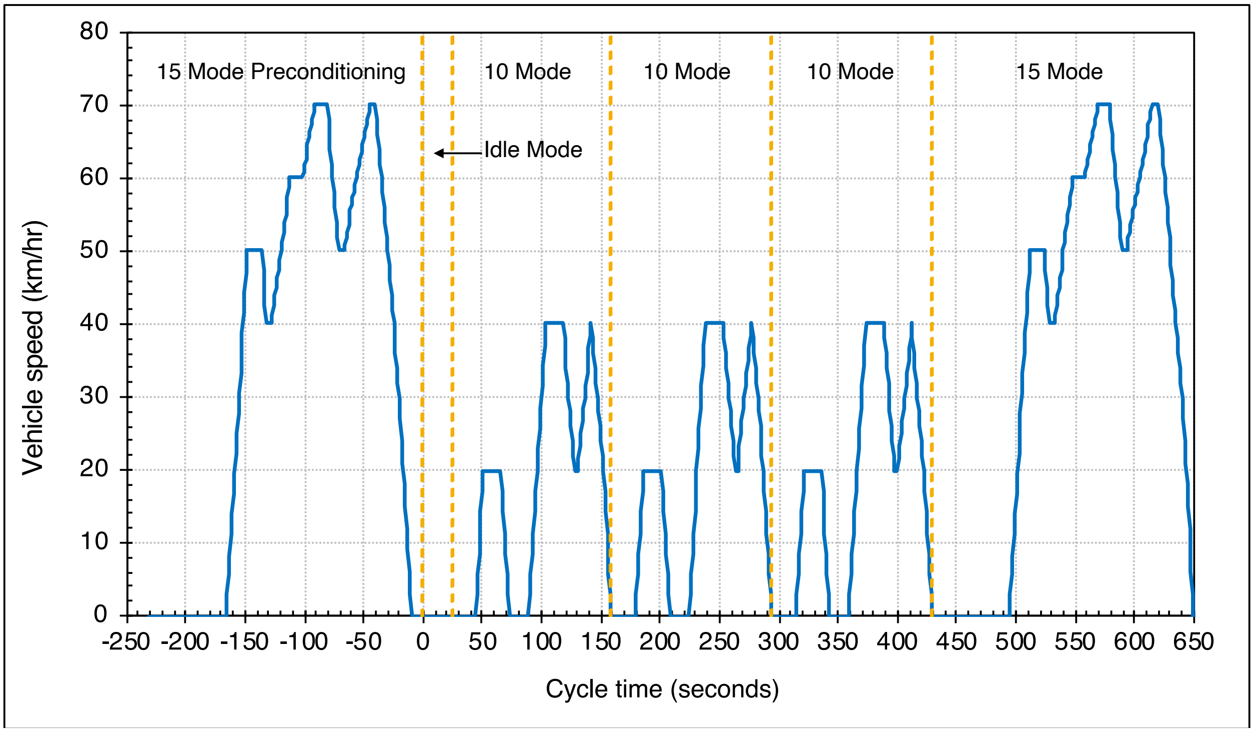

Figure A2. Japan 10-15 Mode driving cycle

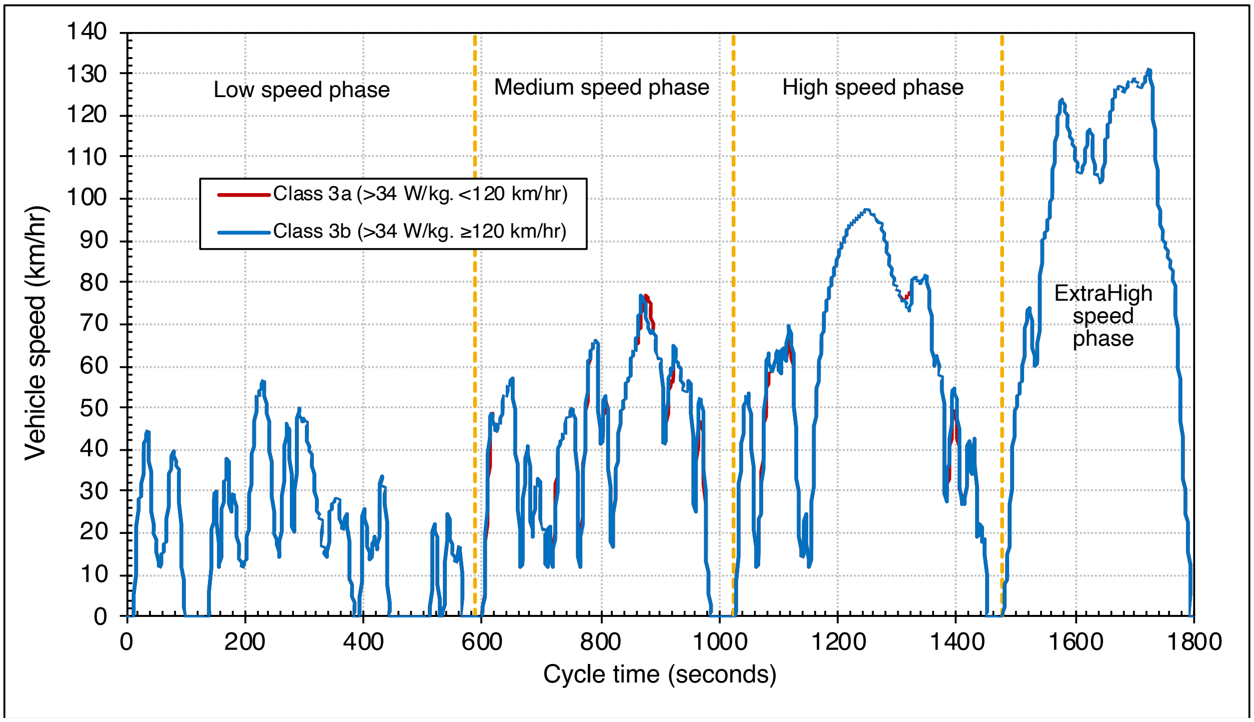

Figure A3. Worldwide Harmonized Light Vehicles Test Procedure (WLTP) for class 3 vehicles

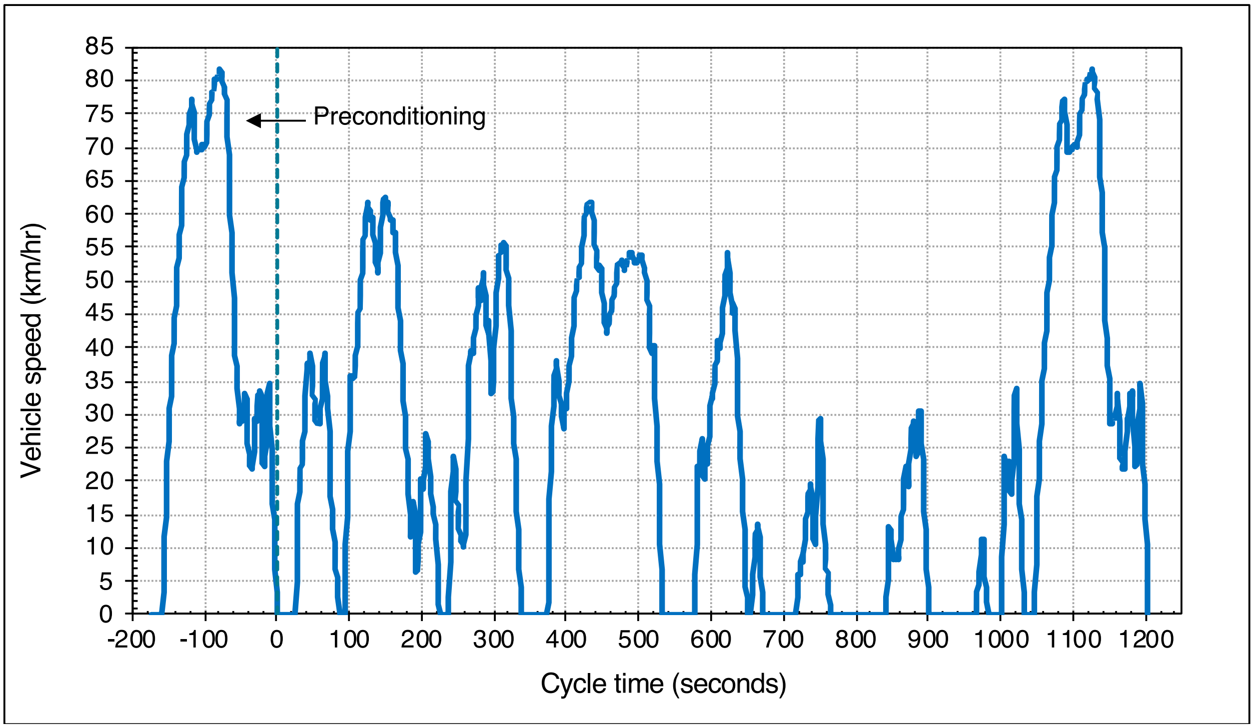

Figure A4. Japan JC08 driving cycle

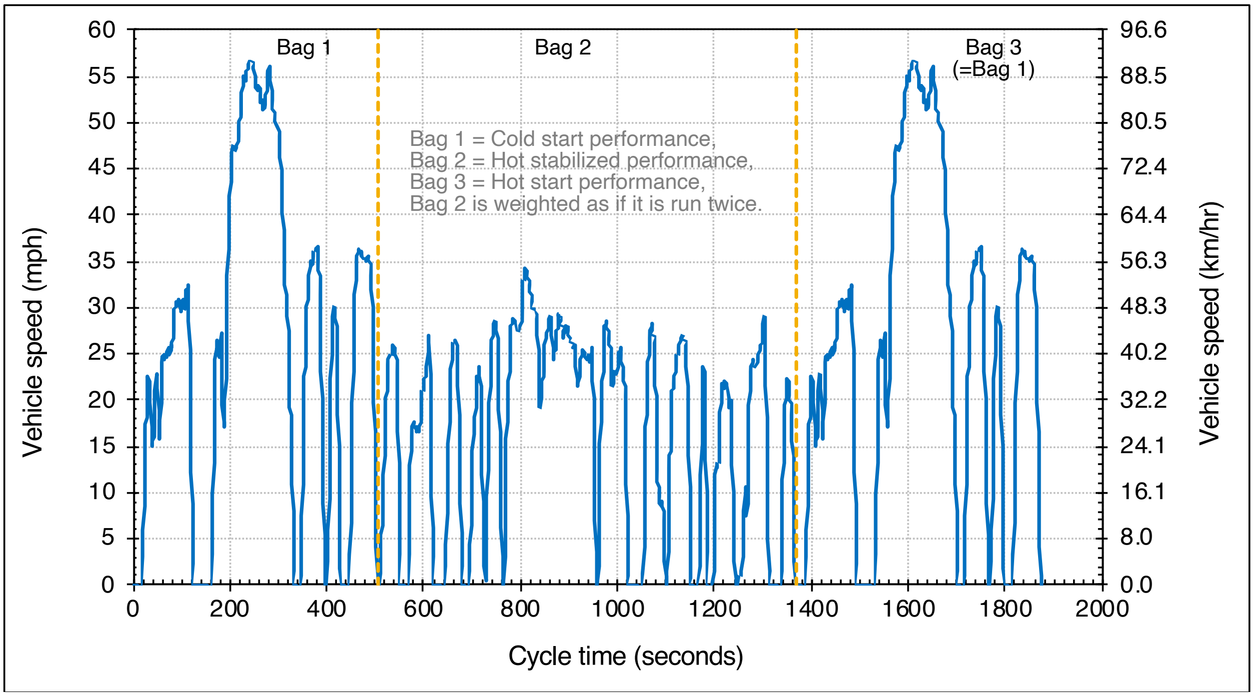

Figure A5. US CAFE cycle – FTP75, city driving portion (55% of overall CAFE fuel consumption)

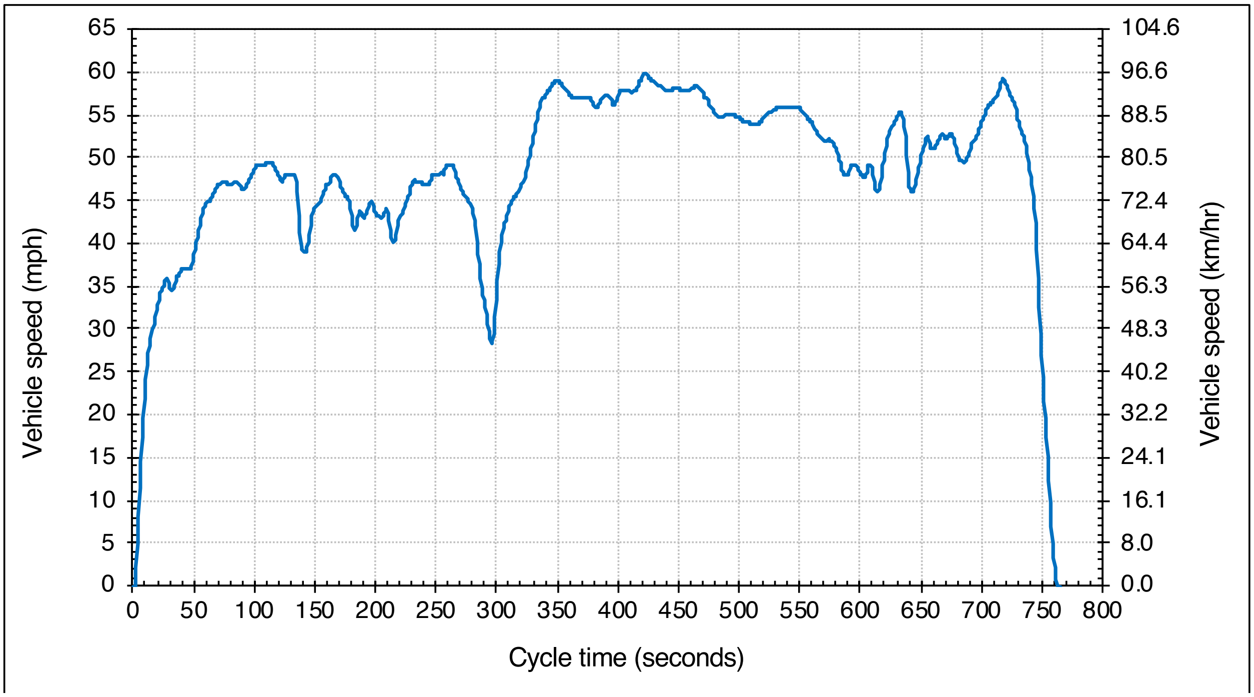

Figure A6. US CAFE cycle – HWFET, highway driving portion (45% of overall CAFE fuel consumption)

Appendix B — Worldwide Harmonized Light Vehicles Test Procedure (WLTP) for different classes of vehicles

Figure B1, B2, and B3 show the WLTP test cycles for all vehicle classes.

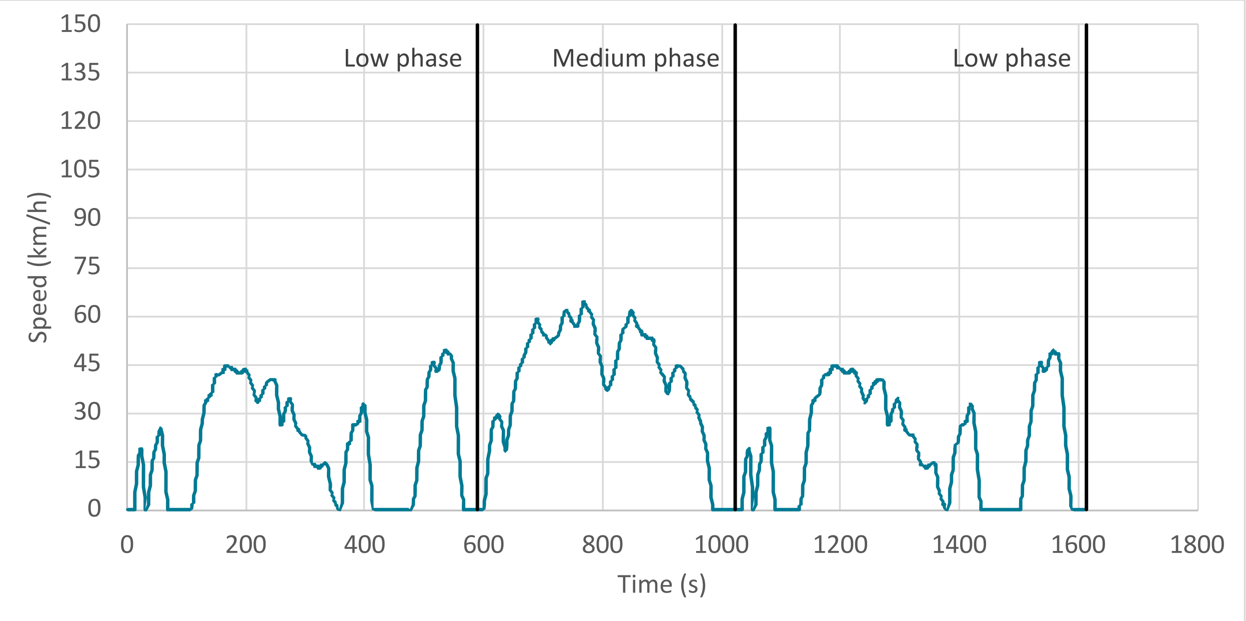

Figure B1. WLTC for Class 1 vehicles (only three phases)

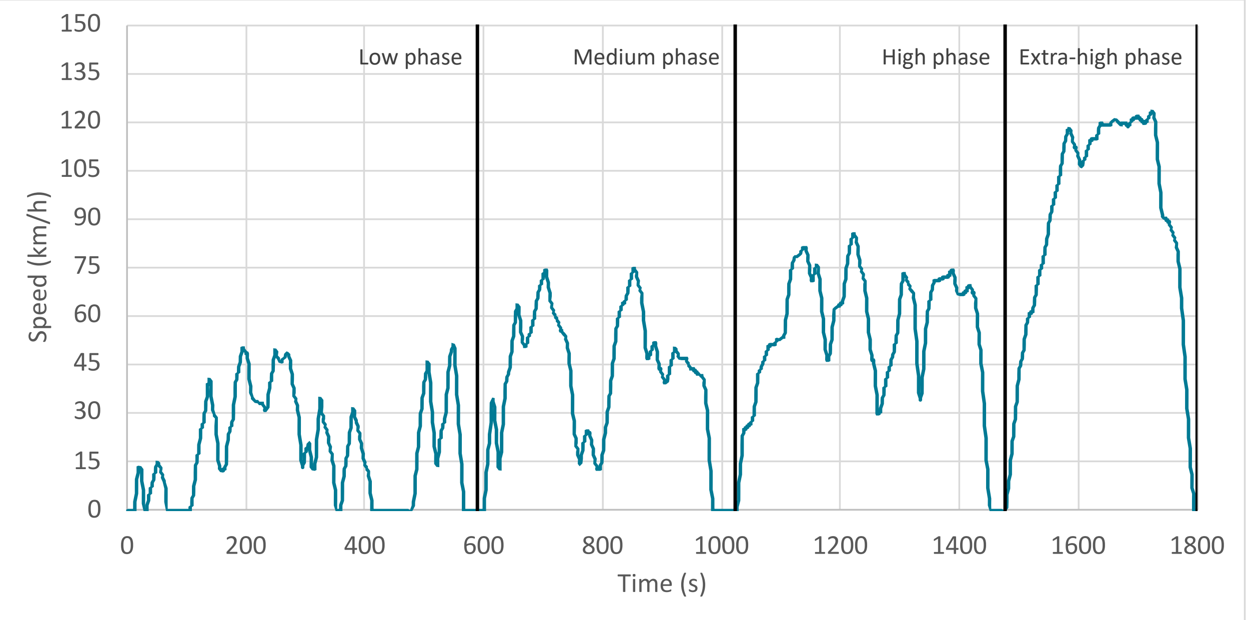

Figure B2. WLTC for Class 2 vehicles

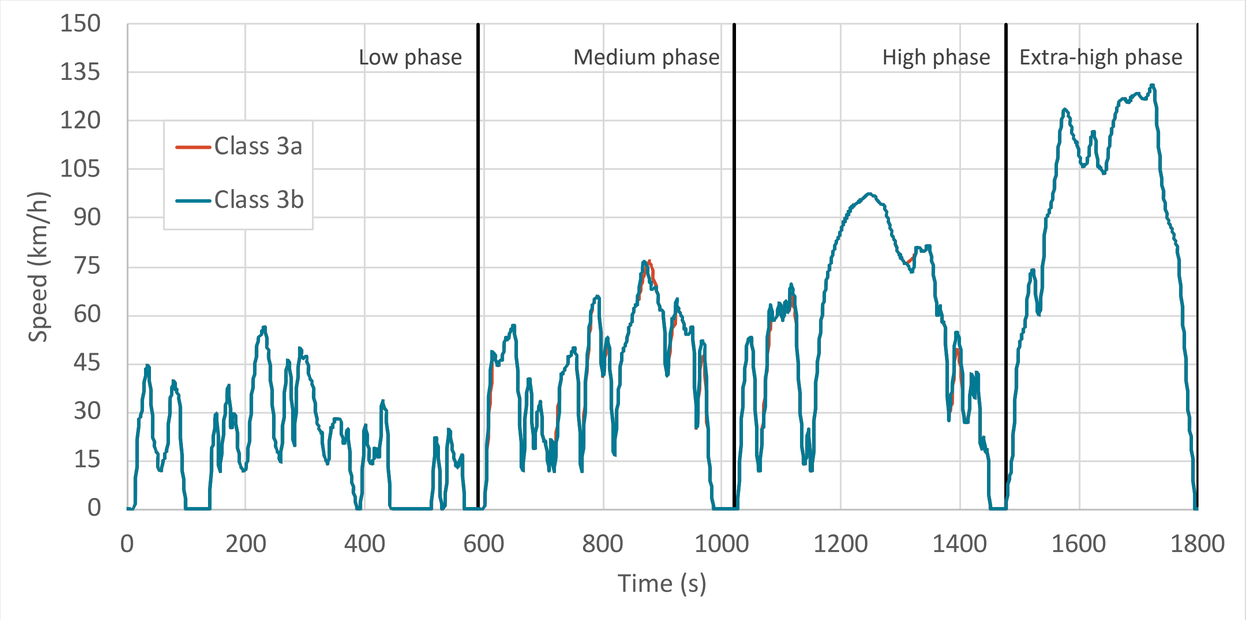

Figure B3. WLTC for Class 3a and Class 3b vehicles.

Appendix C — Discussion of alternative regression approaches

As detailed in the body of this report, the proposed cycle conversions are all expressed as linear relations that estimate 3P-WLTP emissions from emissions measured under another test cycle—specifically, the 4P-WLTP, NEDC, JC08, CAFE, and 10-15 Mode test cycles. Conversion parameters are specified separately for petrol and diesel vehicles. Other relations and relationship parameters were considered, but such alternatives do not significantly improve the predictability of desired 3P-WLTP emissions. Therefore, they are not documented in this report.

There is no question that vehicle technology and road load design parameters influence emissions over a given test cycle. Parameters such as vehicle mass, aerodynamic drag and rolling resistance characteristics, and engine and driveline technology combine to influence emissions performance, and emissions over a given test cycle can be expected to vary in accordance with variations in such parameters. However, the work documented in this report is not attempting to estimate emissions for a test cycle from first principles. Emissions data for a given cycle inherently includes the effects of all influencing parameters, and it is not necessary to isolate the component effect of each influence to estimate how the given emissions might change over a second cycle. To the extent that the magnitude of influence for any given parameter might change across two cycles, explicitly accounting for that parameter (to the extent possible given available data) may indeed add to the explanatory power of a cross-cycle relation. However, the degree to which such influence changes can be isolated is dependent on both the magnitude of the change and the degree to which it contributes to the unexplained “noise” of the cross-cycle relation.

Practical limitations also come into play. Obviously, data to quantify any particular parameter of influence must be available, both for relation development and for application in practice. Vehicle mass data, for example, is not included in the EU certification dataset that serves as the foundation for the NEDC and 4P-WLTP cross-cycle analysis documented in this report. In some cases, surrogate parameters are available, such as engine displacement for the EU database; but these introduce additional uncertainty and are thus less likely to enhance relationship performance. Most importantly, any parameter added to a relation must be quantifiable during application of the relation for it to be useful. A parameter that enhances relationship performance, but which cannot be readily quantified by a user attempting to evaluate the relationship, e.g., the presence or absence of a particular engine technology, serves little practical purpose.

As stated above, none of the proposed relations include explicit treatment of influencing parameters other than vehicle fuel type and emissions from a given test cycle. Although this simplifies relationship application, the main drivers of this approach are the statistics for the derived relations. All proposed relations exhibit a coefficient of determination (r^2) of at least 0.9–0.95 or greater for all but the NEDC diesel relation and 0.98 or 0.99 for most of the relations. Thus, in all cases, the relations account for at least 90% of the total variability exhibited in the data samples from which they are derived. As a result, the potential improvement available through the addition of a secondary parameter of influence is modest. For example, some, but not all, of the Japanese 10-15 Mode, JC08, and 3P-WLTP data analyzed included vehicle mass data. When these data are analyzed with and without a mass parameter, the average residual for the sample data changes by 0.1 gCO_2/km relative to a standard residual of 11.5 gCO_2/km for the 10-15 Mode to JC08 relation and 0.2 gCO_2/km relative to a standard residual of 7.0 gCO_2/km for the JC08 to 3P-WLTP relation. This yields only marginal additional explanatory power when considered in conjunction with the exclusion of analysis records without mass data and the added complexity of introducing mass into the application of the relation. Thus, treating it is not recommended.[49]

It is generally true that vehicle technology and road load design parameters play key roles in determining fuel consumption and CO_2 emissions for a given test cycle, but this analysis is not focused on estimating independent performance for a given cycle. Rather, the intent is to estimate performance for a given cycle from performance measured over another. Because technology and design parameters influence performance over both cycles, it is only the differential influences, if any, that will be important in assessing cross-cycle relations. The cycles in question are all designed to estimate performance over a range of operating conditions reflecting low, intermediate, and high speed operations—albeit with differing levels of complexity—so it is reasonable to expect that the influence of vehicle technology and road load design will be similar and will thus, to a significant extent, “cancel out” when cross-cycle relations are investigated.[50]

Similarly, other forms of relations were considered but abandoned, as it is visually evident that the fundamental relations are linear in linear space. This is shown in the various charts presented in the body of this report. Additionally, Figures C1 through C3 depict the data for the 3P-WLTP from 4P-WLTP relation. As Figure C1 shows, the data are clearly linear in linear space. This is confirmed when the data are plotted in ln-linear space, as shown in Figure C2, where an upward sloping curve is clearly evident.

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[49] The application of relationship parameters is not trivial. For example, the mass data used in the example are certification mass values, which may or may not match the actual mass values available for a given vehicle. Thus, even for a hypothetically perfect (zero residual) relation, estimated emissions will not be precise if the mass value input into the relation is not the same as that used for certification. Because this latter value is not likely to be known with any degree of certainty, the inclusion of the parameter could actually lead in practice to unexpected and unquantifiable error.

[50] The exceptions to this expectation for the evaluated cycles are the U.S. City and Highway cycles, which differ dramatically in terms of cycle-average vehicle road load influences and vehicle operating characteristics. The average speed and acceleration of the Highway cycle are more than twice and only one-half those of the City cycle, respectively, and the idle time share of the Highway cycle is reduced by 97%. As a result, vehicle technology and design strongly influence the relation between Highway and City cycle performance. Although the tractive energy required to execute the Highway cycle is generally as great or greater than that required to execute the City cycle, fuel consumption over the Highway cycle is on the order of 25%–40% lower. However, these contrasting cycles are aggregated into a composite CAFE “cycle” for the analysis underlying this report; the composite is, like the other addressed cycles, more or less reflective of a full range of operating conditions.

Logarithmic relations can nonetheless be developed as shown in Figure C2, but when depicted in linear space, as shown in Figure C3, these regressions are clearly biased for low and high fuel consumption vehicles. Power-based relations can also be investigated, but such work is unwarranted given the clear linearity of the data.

Linear relations based on the ratio of cycle emissions were also investigated, i.e., relations of the form $\text{cycle}_2/\text{cycle}_1 = a \times \text{cycle}_1 + b$. These relations showed considerable weakness relative to the absolute emissions relations and thus were not pursued. For example, Figure C4 depicts the same data as Figure C1, but plotted in relative, i.e., 3P-WLTP/4P-WLTP ratio, space. The increased scatter is readily apparent, and regression determination coefficients drop to 0.65 for petrol and even lower for diesel vehicles.

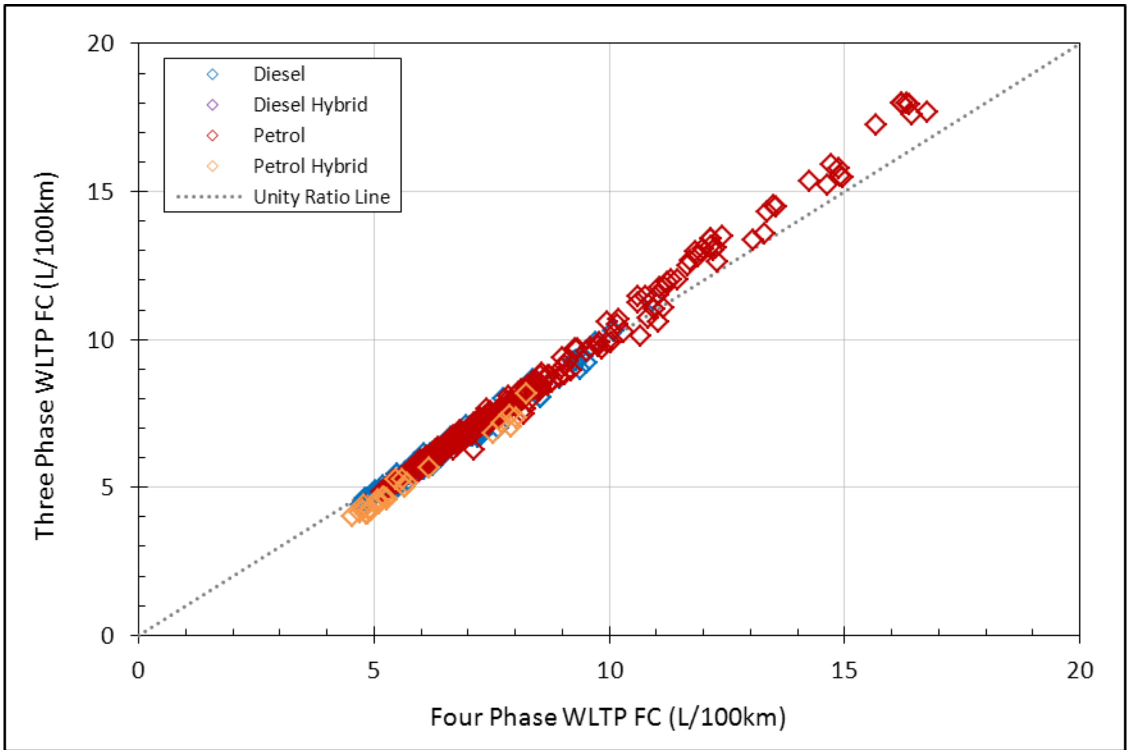

Figure C1. 3P-WLTP versus 4P-WLTP data in linear space

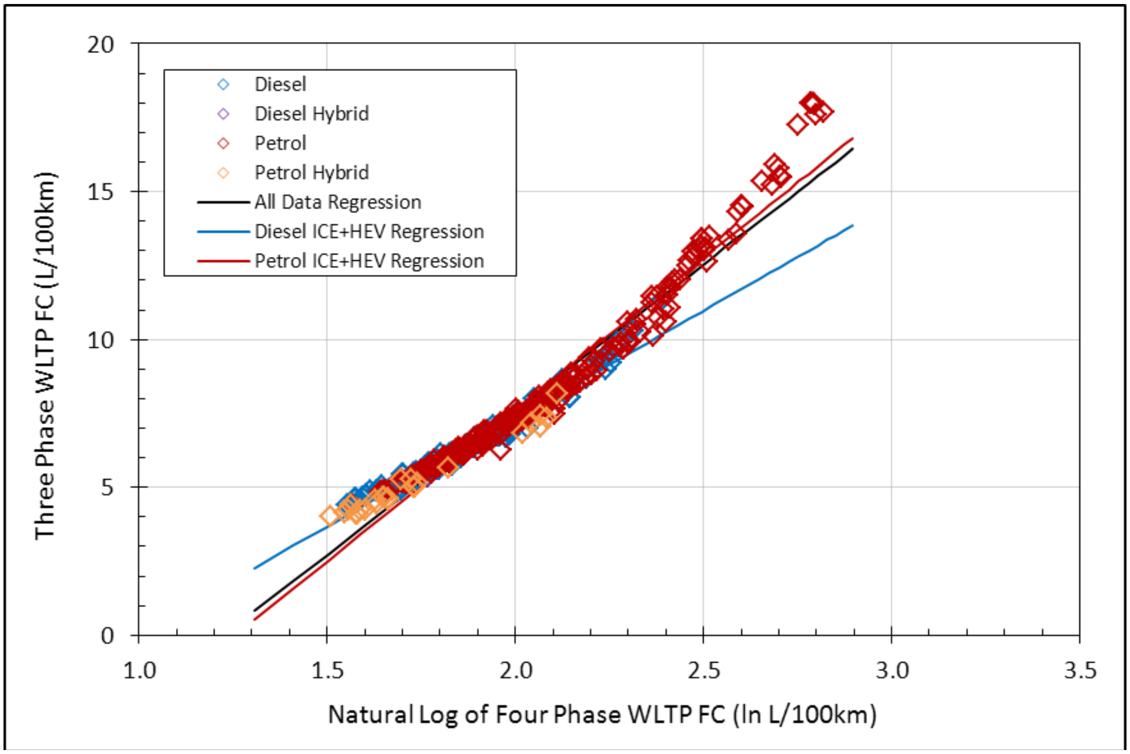

Figure C2. 3P-WLTP versus 4P-WLTP data in ln-linear space

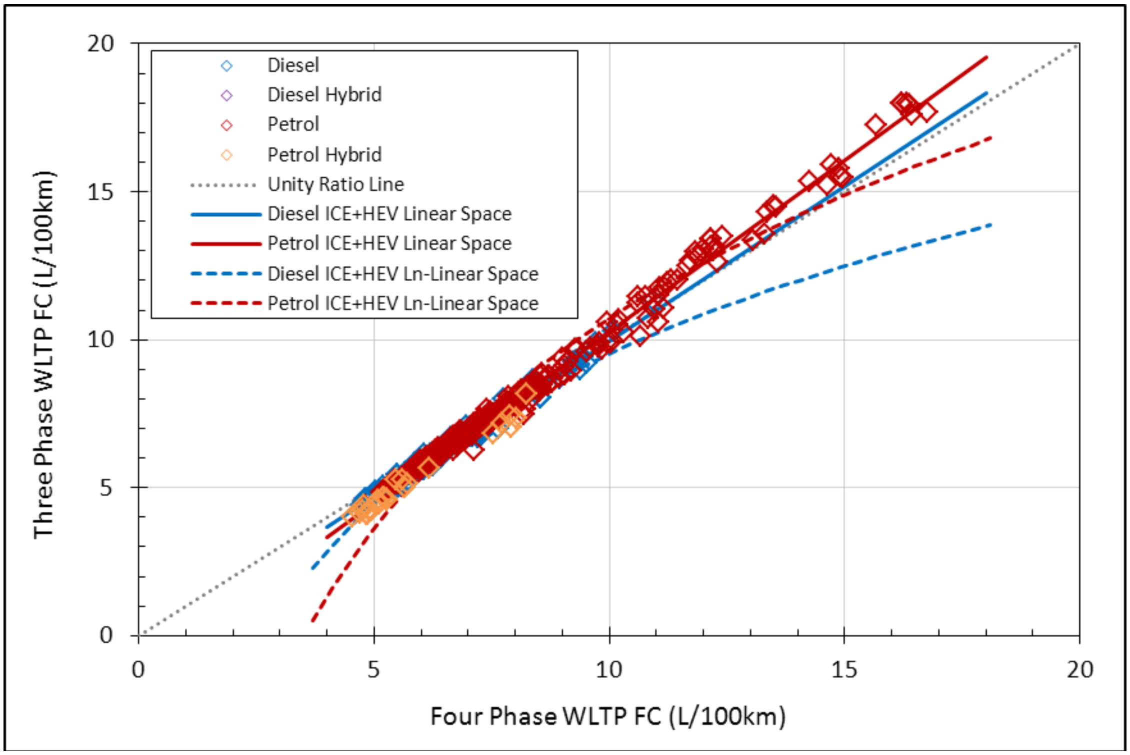

Figure C3. Regressions for 3P-WLTP versus 4P-WLTP data

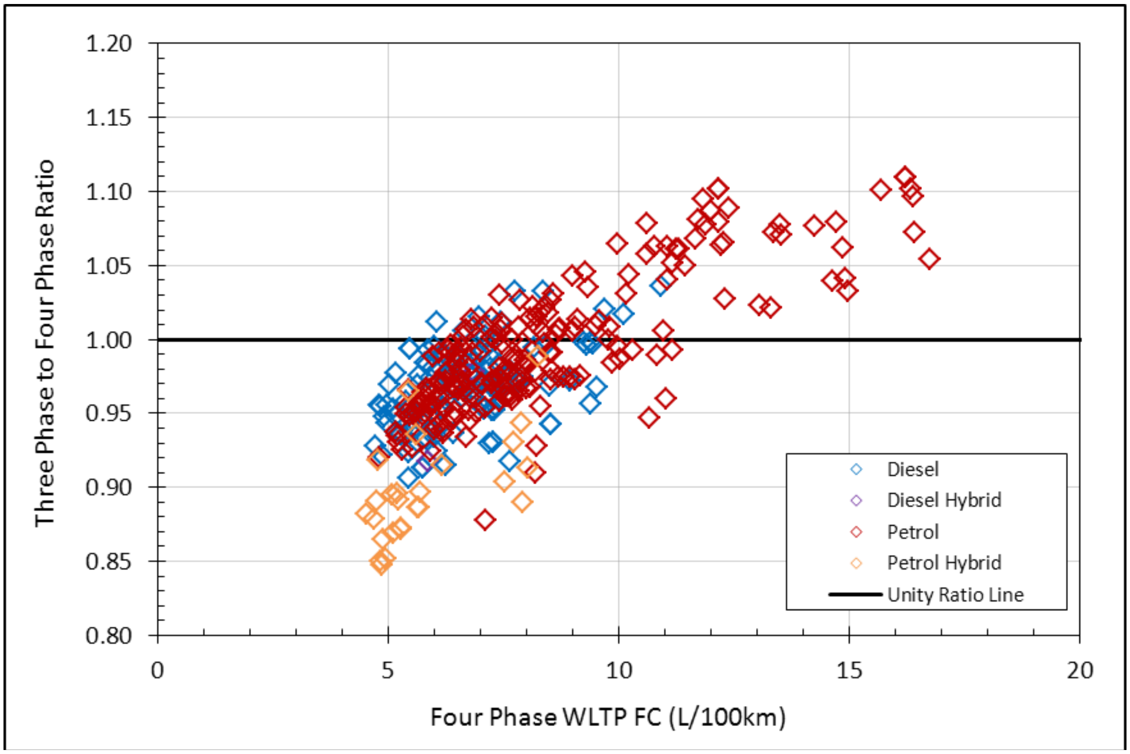

Figure C4. 3P-WLTP/4P-WLTP ratio versus 4P-WLTP data

Appendix D — Residual distributions

All regression-based relations carry inherent uncertainty, or error. By definition, the relations are accurate on average and will be precise only for the rare “average” vehicle. All other conversions will include an error, or residual. Assuming normal distribution characteristics for both the regression sample and the overall vehicle population, approximately 68% of vehicles will have an estimation error of no more than the standard error of the applicable regression. Another 27% of vehicles will have an estimation error of no more than two times the standard error, while the last 5% of vehicles will have estimation errors larger than two times the standard error.

In an effort to quantify the extent to which the regressions might be biased against certain vehicle types, the fraction of vehicles within various error ranges was calculated for:

- The regression samples as a whole
- Where distinguishing data exists within the regression samples, internal combustion engine (ICE) and hybrid vehicles separately to investigate potential technology bias
- The larger, unstratified datasets from which the regression samples were extracted

Regression samples as a whole and stratified by ICE and HEV technology.

Tables D1 through D6 present residual statistics for the regression samples. The statistics are generally in line with expectations and demonstrate that ICE and HEV vehicles are well represented by single “all technology” relations. In some cases, sample sizes are small and care must be taken to avoid applying false precision to presented distribution fractions. Single vehicles can represent 5% or more—and in the extreme case of diesel HEVs, 50%—of the sample population. Nonetheless, limited sample sizes support the development of aggregated relations when such relations can adequately represent all component segments, as appears to be the case for ICE and HEV vehicles given the data available. This is especially true when available data for one or more component segments span a relatively narrow range of the independent regression parameter, which is generally the case for HEVs; this forces the use of highly uncertain extrapolation to estimate the performance of vehicles beyond that range. It would be worthwhile to revisit such a determination should more extensive data become available, but aggregate relations appear to be the most appropriate given the data resources available for this analysis.

Note that Tables D1 through D6 include only sample data for which both the independent and dependent regression parameters are known; this is because both are required to calculate a residual. Thus, 10-15 Mode and CAFE data are provided relative to known JC08 and 4P-WLTP data, respectively. 3P-WLTP data can be estimated, but actual values are not known. The performance of the JC08 to 3P-WLTP relation that is applied as a secondary relation to the 10-15 Mode data is identical to that shown in Table D5 for the JC08 cycle. The performance of the 4P-WLTP to 3P-WLTP relation that is applied as a secondary relation to the CAFE data is identical to that shown in Table D2 for the EU 4P-WLPT cycle.

Table D1. Fraction of observations within standard error bounds for the 4P-WLTP to 3P-WLTP data sample

Metric	All Sample Data	Diesel ICE Data	Petrol ICE Data	Diesel HEV Data	Petrol HEV Data
1 Standard Error	75.2%	73.7%	75.6%	50.0%	80.8%
2 Standard Errors	94.6%	94.9%	95.2%	100.0%	88.5%
3 Standard Errors	99.2%	100.0%	99.0%	100.0%	96.2%
Maximum Ratio	3.59	2.79	3.59	1.38	3.11
Observations	355	118	209	2	26

The maximum ratio is the ratio of the largest residual to the standard error. Caution should be exercised in evaluating sparsely populated samples. For example, each petrol HEV represents 3.8% (1/26) of the petrol HEV sample, so the population “out of bounds” at three standard errors is one vehicle.

Table D2. Fraction of observations within standard error bounds for the NEDC to 4P-WLTP data sample

Metric	All Sample Data	Diesel ICE Data	Petrol ICE Data	Diesel HEV Data	Petrol HEV Data
1 Standard Error	70.4%	67.8%	71.3%	100.0%	73.1%
2 Standard Errors	94.6%	96.6%	94.7%	100.0%	84.6%
3 Standard Errors	99.7%	99.2%	100.0%	100.0%	100.0%
Maximum Ratio	3.11	3.11	2.84	0.61	2.54
Observations	355	118	209	2	26

The maximum ratio is the ratio of the largest residual to the standard error. Caution should be exercised in evaluating sparsely populated samples. For example, each petrol HEV represents 3.8% (1/26) of the petrol HEV sample.

Table D3. Fraction of observations within standard error bounds for the NEDC to 3P-WLTP data sample

Metric	All Sample Data	Diesel ICE Data	Petrol ICE Data	Diesel HEV Data	Petrol HEV Data
1 Standard Error	76.6%	80.5%	72.2%	100.0%	92.3%
2 Standard Errors	96.9%	97.5%	96.2%	100.0%	100.0%
3 Standard Errors	100.0%	100.0%	100.0%	100.0%	100.0%
Maximum Ratio	2.92	2.83	2.92	0.72	1.24
Observations	355	118	209	2	26

The maximum ratio is the ratio of the largest residual to the standard error. Caution should be exercised in evaluating sparsely populated samples. For example, each petrol HEV represents 3.8% (1/26) of the petrol HEV sample.

Table D4. Fraction of observations within standard error bounds for the JC08 to 3P-WLTP data sample

Metric	All Sample Data	Diesel ICE Data	Petrol ICE Data	Diesel HEV Data	Petrol HEV Data
1 Standard Error	75.5%	100.0%	71.0%	No Data	81.3%
2 Standard Errors	93.9%	100.0%	93.5%		93.8%
3 Standard Errors	100.0%	100.0%	100.0%		100.0%
Maximum Ratio	2.92	0.92	2.92		2.00
Observations	49	2	31	0	16

The maximum ratio is the ratio of the largest residual to the standard error. Caution should be exercised in evaluating sparsely populated samples. For example, each vehicle represents 2% (1/49) of the overall sample, each petrol ICE represents 3.2% (1/31) of the petrol ICE sample, and each petrol HEV represents 6.3% (1/16) of the petrol HEV sample.

Table D5. Fraction of observations within standard error bounds for the 10-15 Mode to JC08 data sample

Metric	All Sample Data	Diesel ICE Data	Petrol ICE Data	Diesel HEV Data	Petrol HEV Data
1 Standard Error	69.4%	73.7%	69.4%	No Data	66.7%
2 Standard Errors	96.4%	100.0%	95.7%		100.0%
3 Standard Errors	99.1%	100.0%	98.9%		100.0%
Maximum Ratio	4.62	1.76	4.62		1.77
Observations	330	19	281	0	30

The maximum ratio is the ratio of the largest residual to the standard error. Caution should be exercised in evaluating sparsely populated samples. For example, each diesel ICE represents 5.3% (1/19) of the diesel ICE sample and each petrol HEV represents 3.3% (1/30) of the petrol HEV sample.

Table D6. Fraction of observations within standard error bounds for the CAFE to 4P-WLTP data sample

Metric	All Sample Data	Diesel ICE Data	Petrol ICE Data	Diesel HEV Data	Petrol HEV Data
1 Standard Error	77.1%	79.4%	77.6%	No Data	75.7%
2 Standard Errors	93.6%	87.4%	95.0%		95.0%
3 Standard Errors	98.6%	100.0%	96.2%		100.0%
Maximum Ratio	4.17	2.69	4.17		2.82
Observations	938	175	343	0	420

The maximum ratio is the ratio of the largest residual to the standard error. Caution should be exercised in evaluating sparsely populated samples.

Residuals for the unstratified datasets from which the regression samples were extracted.

> Figures D1 through D12 present residual distributions for the raw datasets from which the stratified regression samples were developed. Distributions are presented for the datasets as a whole and for three emissions-based subsets, as requested by New Zealand regulators. The emissions subsets are specified on the basis of 3P-WLTP emissions, with emissions group one reflecting vehicles emitting 100 gCO_2/km or less, emissions group two reflecting vehicles emitting 100–200 gCO_2/km, and emissions group three reflecting vehicles emitting more than 200 gCO_2/km. Equivalent cutoffs for distributions not involving 3P-WLTP emissions are based on the cycle-specific emissions that would convert to 100 and 200 gCO_2/km 3P-WLTP emissions using the relationship parameters presented in the body of this report. For distributions based on JC08 emissions, the equivalent cutoffs are 78 and 181 gCO_2/km. For distributions based on 4P-WLTP emissions, the equivalent cutoffs are 113 and 200 gCO_2/km.

While these data are being published as requested, they are not reflective of relationships that would hold for New Zealand, or anywhere. The raw datasets are not sales weighted and are subject to any quirks associated with their assembly. As certification, test sample, and simulation modeling datasets, they reflect the nuances of their development and those nuances cannot be removed from any associated statistics. For example, although the raw EU certification database contains 5,492 records, 36% of those are for a single manufacturer, Volvo. Honda has the second highest total, at 12%. The other 52% of records are associated with 34 manufacturers. So, although the dataset is robust, it is also biased when treated on a record-by-record basis. When the EU dataset is properly stratified, the bias is reduced; Volvo, for example, constitutes 4% of the stratified records subjected to regression analysis.

Similar issues arise for the Japan datasets, where identical, or nearly identical, records appear year after year. Of the 6,490 records that include both 10-15 Mode and JC08 data, there are thousands of records that reflect identical, or nearly identical, emissions. Some are due to variants that are not sufficiently different from an emissions standpoint and some are due to multiple years of identical reporting. When properly stratified, the database contracts by about 95%. Statistics for the raw dataset will, however, reflect the described certification and reporting nuances. The same holds for the data that include both JC08 and 3P-WLTP data, as 505 raw data records collapse by about 90% to 49 properly stratified records.

The CAFE database, in the absence of alternative data, reflects simulation modeling data. As such, it is both limited to the vehicles and technologies included in the associated development study and subject to any bias inherent in simulation modeling assumptions or the simulation model itself. The vehicle and technology selection of the simulation modeling study is robust in that it spans the range of passenger vehicles and current generation technology, but without confirmatory testing, the precision of the data is unknown. Unlike the raw EU and Japan data, the CAFE data are reflective of a properly stratified data sample and are, therefore, not subject to the issues associated with multiplicative reporting.

Finally, for NEDC data, the raw EU dataset is also subject the nuances of the differing requirements of NEDC and WLTP testing. The EU requires WLTP testing to be performed for both high and low road load configurations. NEDC emissions are held constant for both WLTP tests. Thus, to the extent both WLTP tests appear in the EU database, regression estimates will necessarily reflect an average of the low and high measurements. In effect, the regression can never be “right” for the vehicles in the database. This essentially leads to a potential doubling of the number of vehicles within given error bounds and can greatly affect raw data performance statistics. It is not possible to identify precisely how many low/high combinations appear in the EU dataset without substantial effort, but it is clear that at least Volvo reports certification records in this manner as two records are included for every Volvo vehicle variant. For other manufacturers, this does not appear to be the case.

Given these issues, readers are strongly cautioned against inferring more than basic insights from the presented raw data distributions.

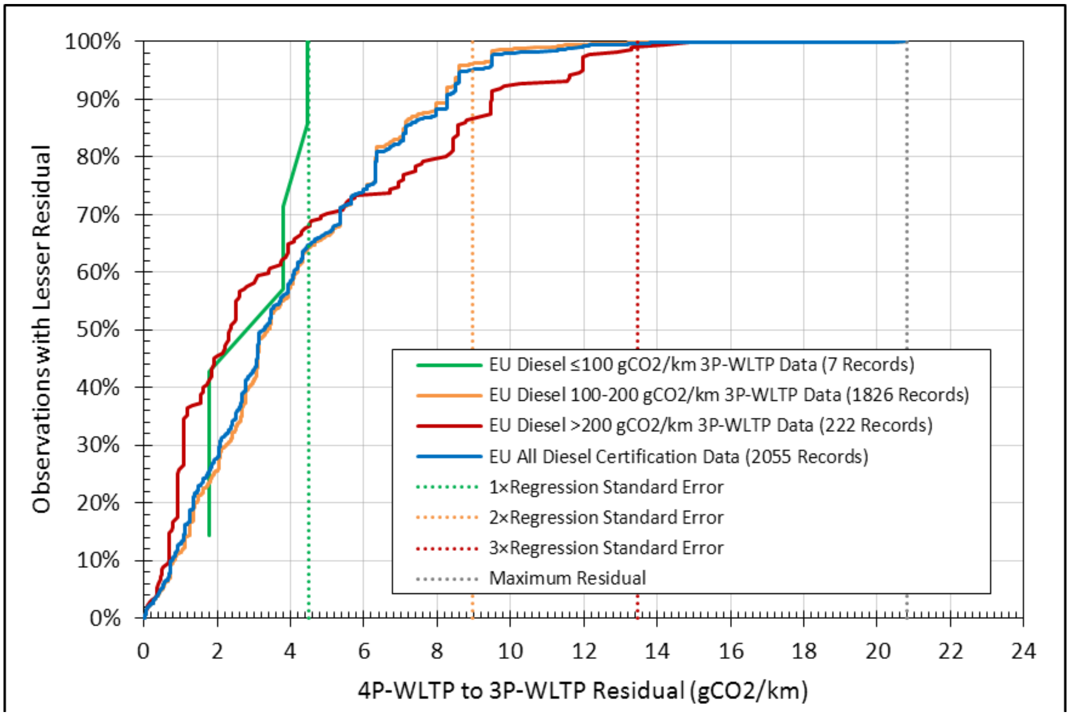

Figure D1. 4P-WLTP to 3P-WLTP residual distribution for diesel vehicles in the raw EU database

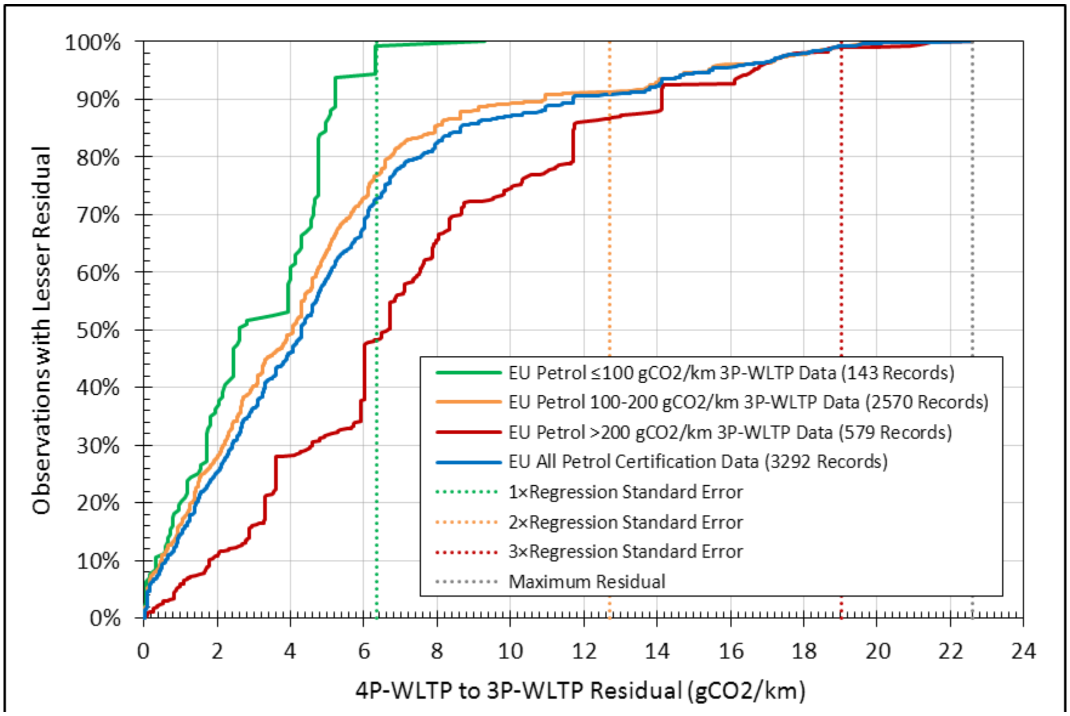

Figure D2. 4P-WLTP to 3P-WLTP residual distribution for petrol vehicles in the raw EU database

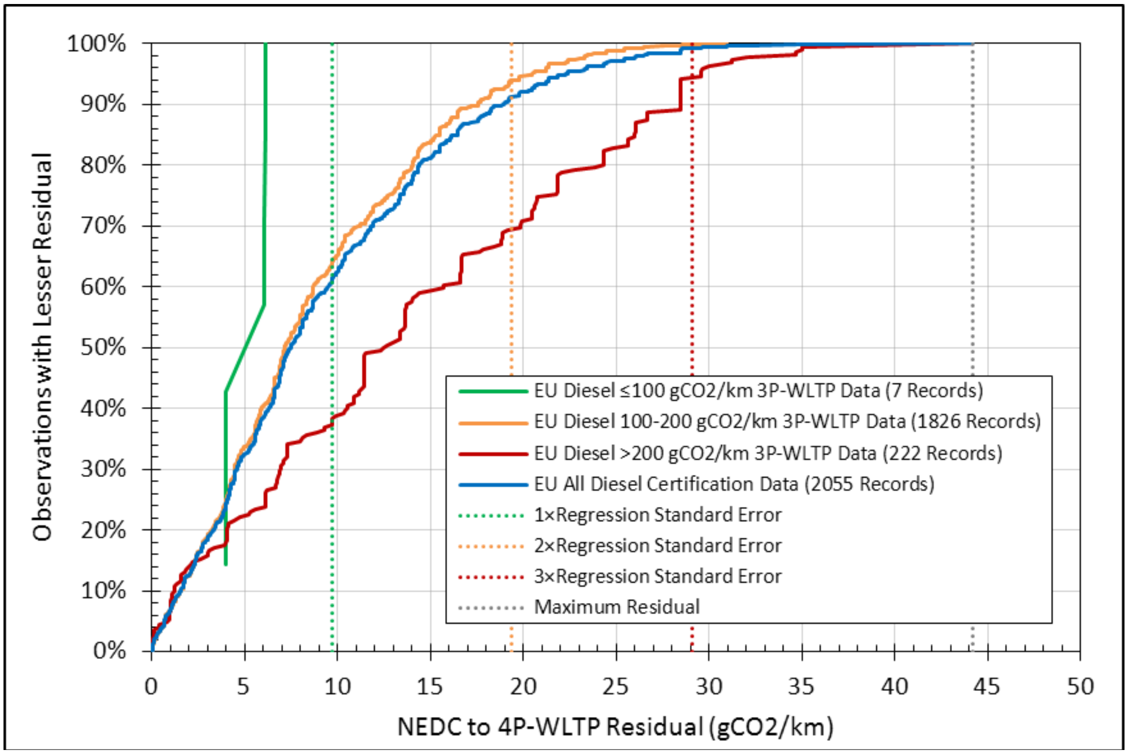

Figure D3. NEDC to 4P-WLTP residual distribution for diesel vehicles in the raw EU database

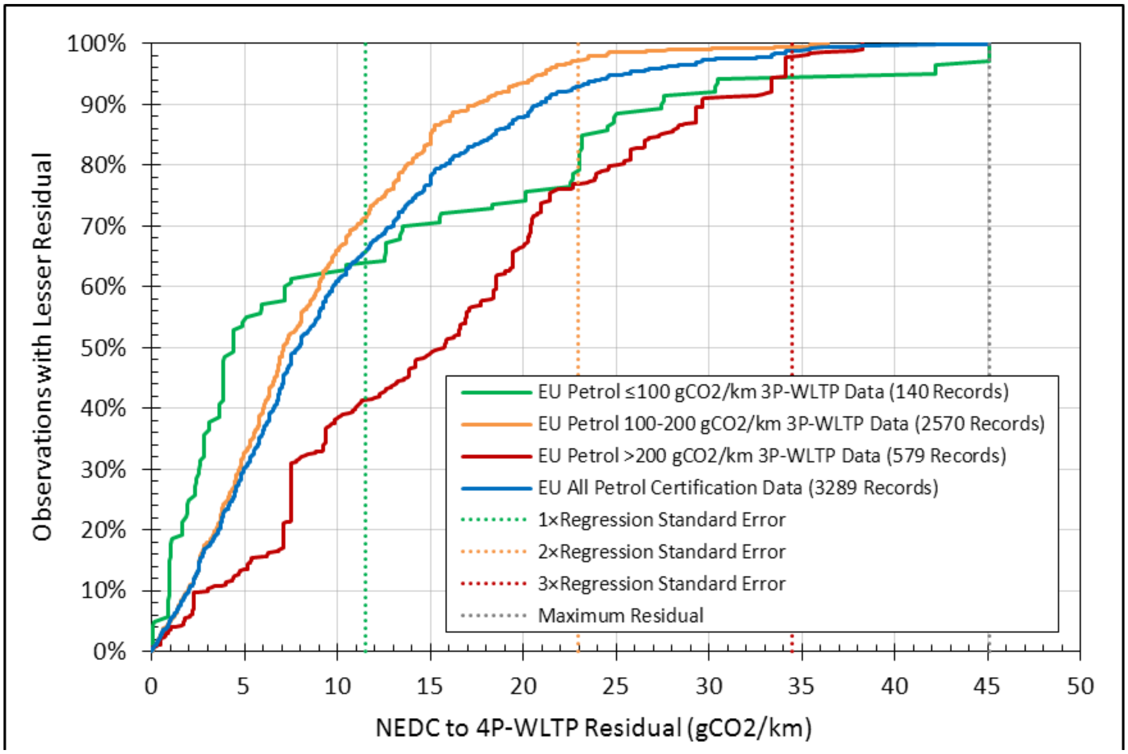

Figure D4. NEDC to 4P-WLTP residual distribution for petrol vehicles in the raw EU database

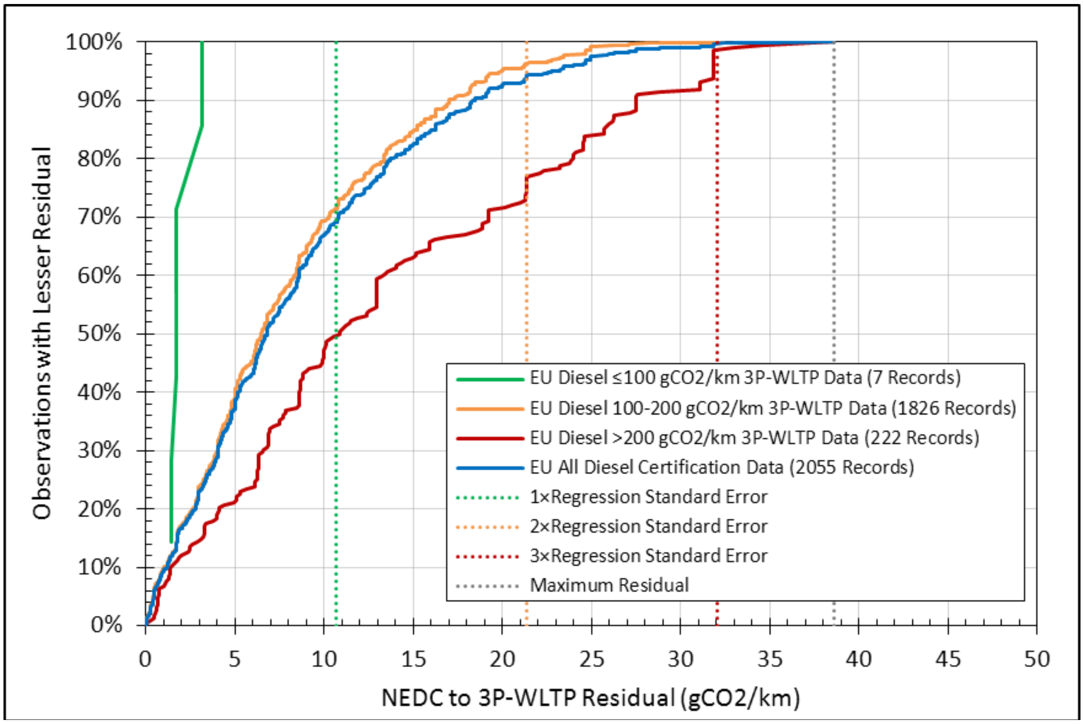

Figure D5. NEDC to 3P-WLTP residual distribution for diesel vehicles in the raw EU database

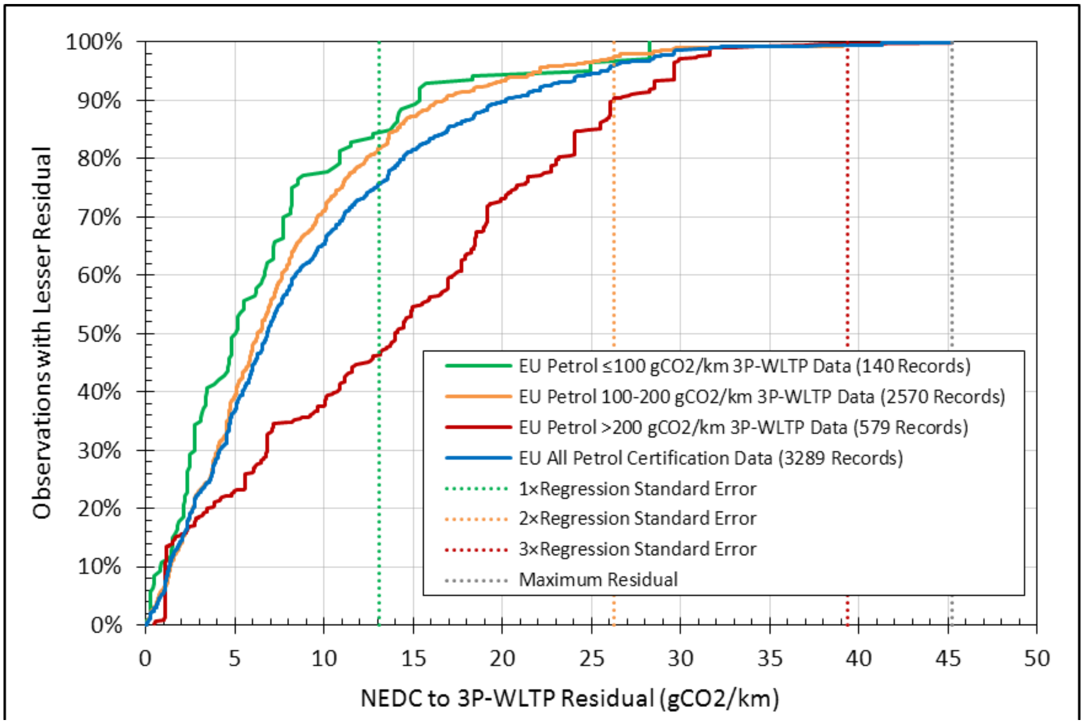

Figure D6. NEDC to 3P-WLTP residual distribution for petrol vehicles in the raw EU database

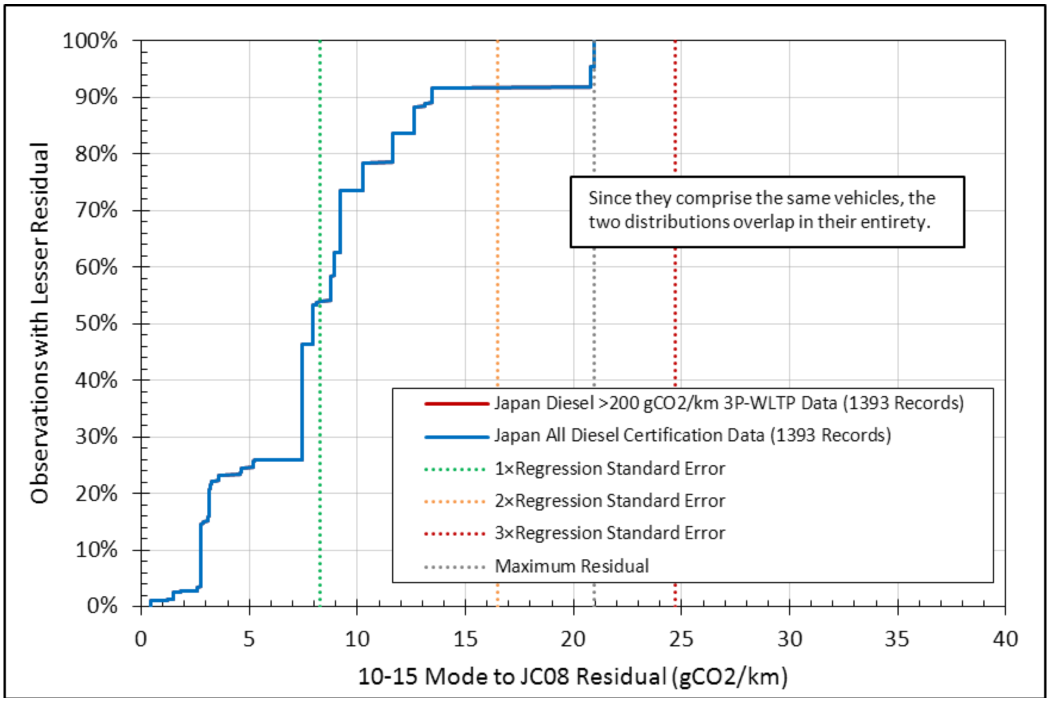

Figure D7. 10-15 Mode to JC08 residual distribution for diesel vehicles in the raw Japan database

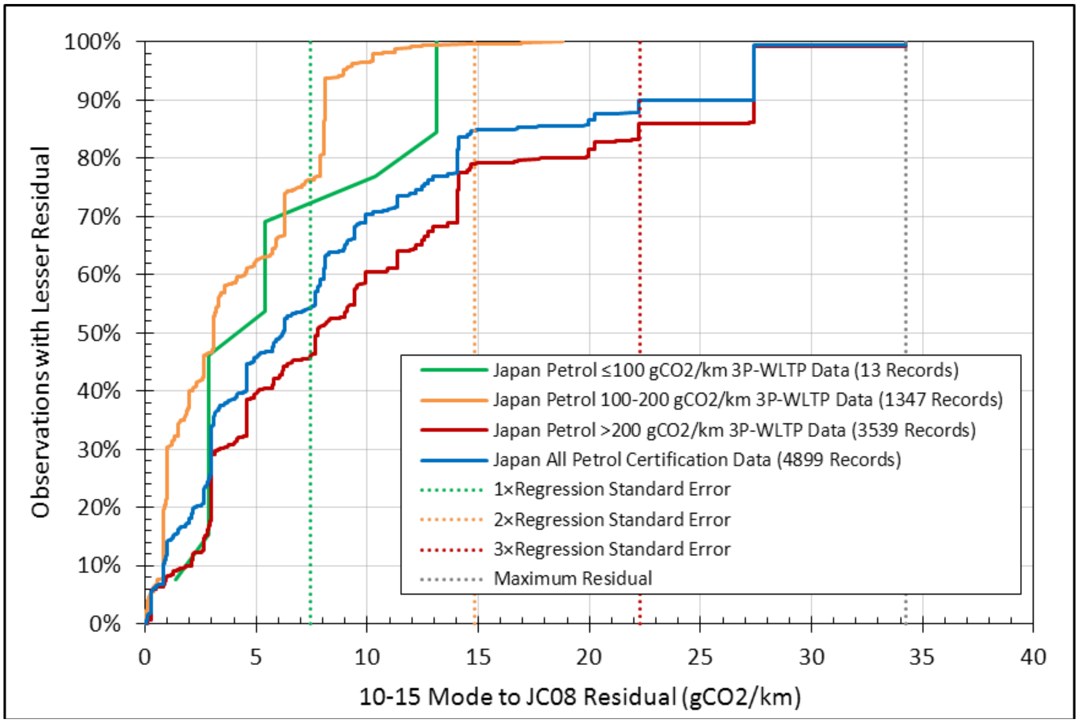

Figure D8. 10-15 Mode to JC08 residual distribution for petrol vehicles in the raw Japan database

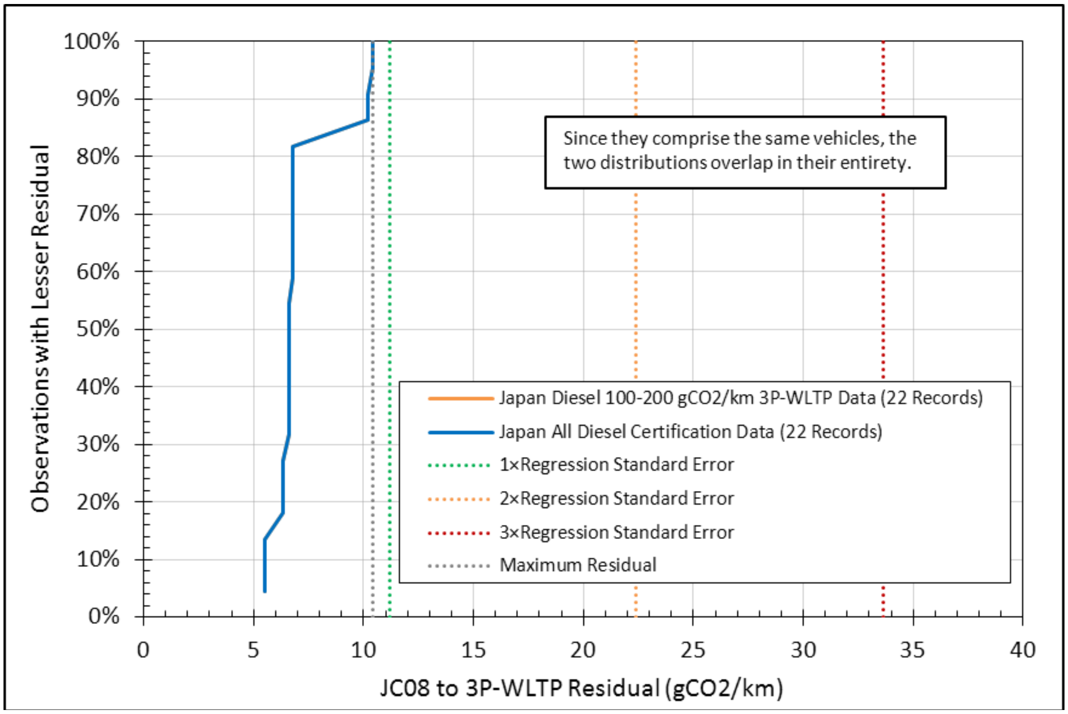

Figure D9. JC08 to 3P-WLTP residual distribution for diesel vehicles in the raw Japan database

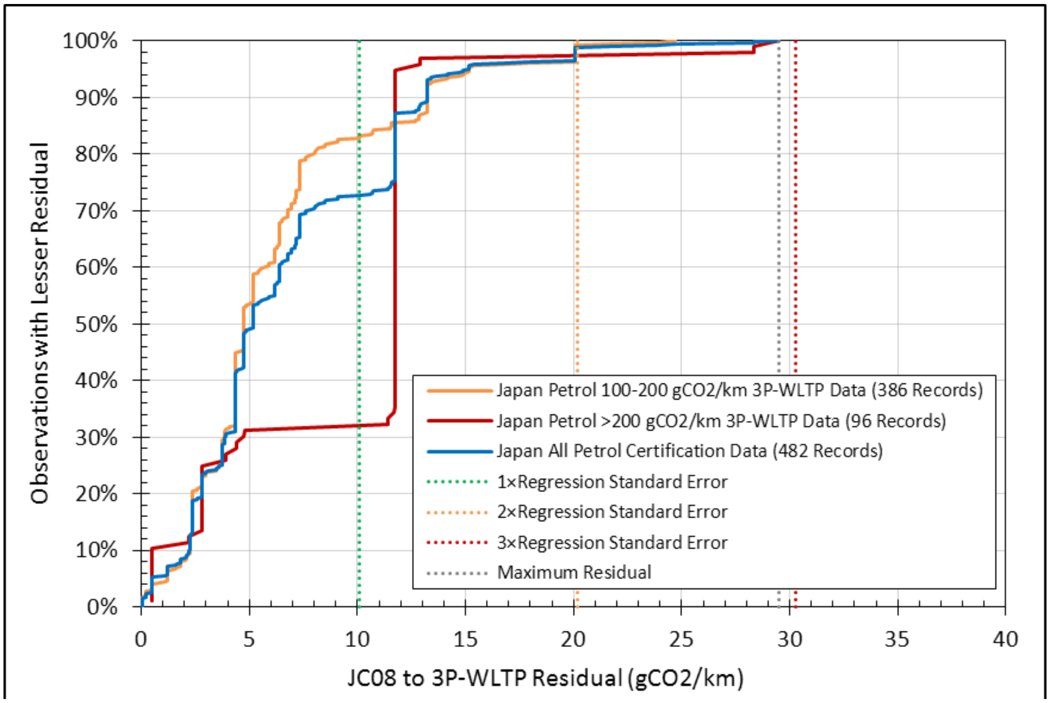

Figure D10. JC08 to 3P-WLTP residual distribution for petrol vehicles in the raw Japan database

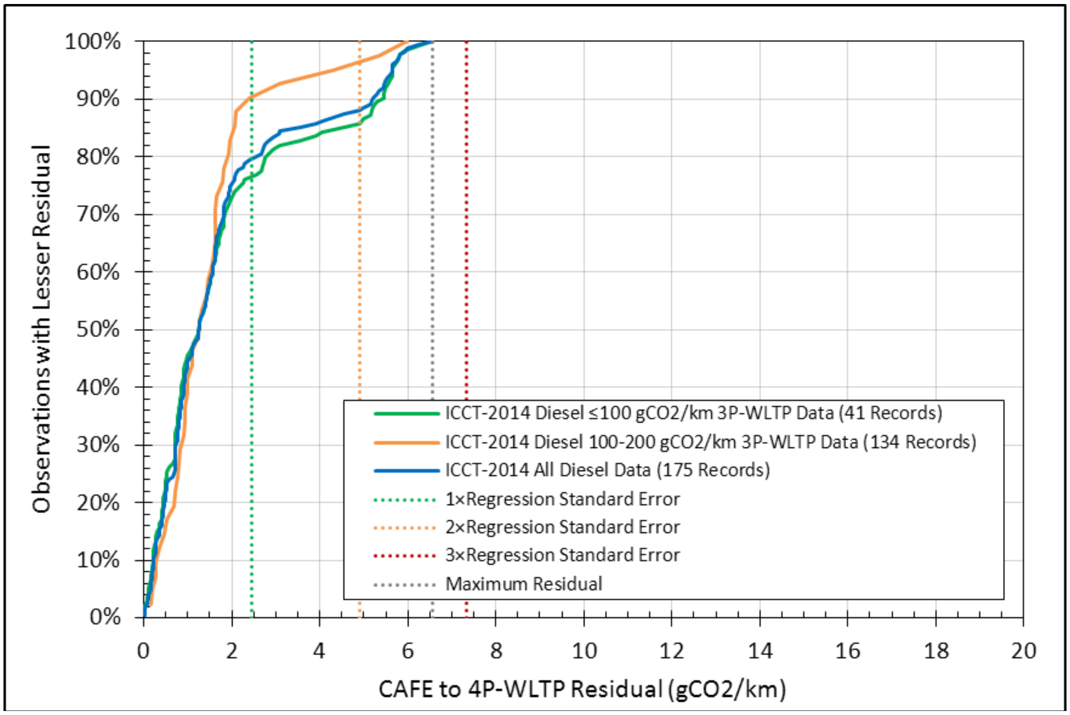

Figure D11. CAFE to 4P-WLTP residual distribution for diesel vehicles in the raw CAFE database

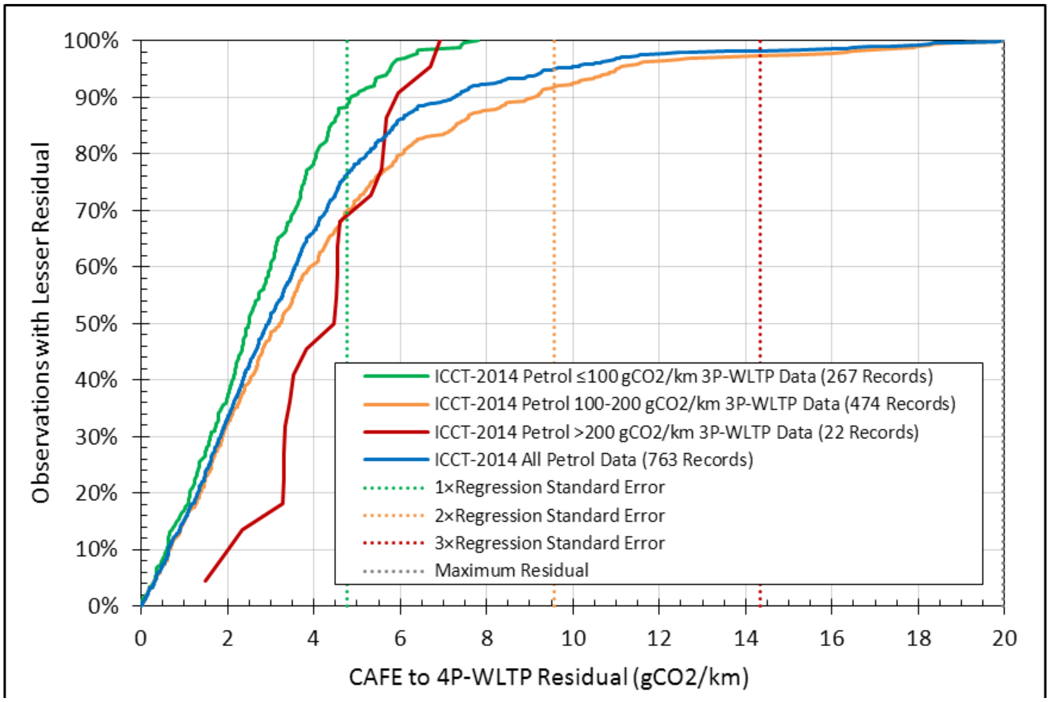

Figure D12. CAFE to 4P-WLTP residual distribution for petrol vehicles in the raw CAFE database

Appendix E — JC08 analysis using the MLIT 3/25/16 dataset

Prior to the receipt of the MLIT 2015–2018 dataset and the MLIT supplemental JC08 dataset from the New Zealand Ministry of Transport, the JC08 to 3P-WLTP relation was developed using an earlier dataset found via a literature review, the MLIT 3/25/16 dataset. Although it has been superseded, the analysis associated with the MLIT 3/25/16 dataset is included herein as it continues to provide insights into the behavior of specific technologies that are not available from other datasets.

As mentioned in the body of the report, the data included in the 2016 MLIT publication is reported only in graphical form and does not include regression statistics. The values associated with the data points depicted in the MLIT graphics were manually estimated based on their axis positions and relation to other data points. Figure E1 depicts both the original MLIT plot and an overlay of the replicated data. The overlaid data are represented by the "×" markers; the original data consist of all other markers (red triangles are minicars, purple squares are hybrids, blue diamonds are passenger cars other than minicars and hybrids, and gold circles are light trucks). To assist in interpreting the comparison and to allow for better resolution of the data points in the original graphic, Appendix F shows both the original graphic and the overlay separately.[51] There is good agreement between the original and replicated data, and it should be recognized that the precise estimation of individual values is not critical to accurately deriving a relation across the sample. As long as the data are sufficiently accurate to replicate the overall distribution of the sample, derived trends will be valid. Note that this analysis resolved 77 data points from the MLIT graphic, which agrees well with the 2016 MLIT publication's claim of "about 80" data points.

As indicated in Figure E1, the data from the 2016 MLIT publication is in fuel economy space. Because fuel economy is inversely related to CO_2, all analysis was conducted in fuel consumption (the inverse of fuel economy) space and converted to CO_2-equivalents using fuel carbon contents of 2,400.5 g/petrol liter and 2,667.3 g/diesel liter. The carbon contents are those assumed in the 2014 ICCT study and are used herein for consistency. For similar purposes of consistency, this analysis presents all results in CO_2 space, but equivalent results in fuel consumption space can be precisely calculated from the presented statistics.

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[51] The MLIT publication also included individual graphics for each of the different marked datasets. These graphics were helpful is resolving the position of data points that otherwise appear as "clutter" in the composite graphic depicted herein. This report does not reproduce the slate of individual graphics, but they are available in the referenced MLIT publication.

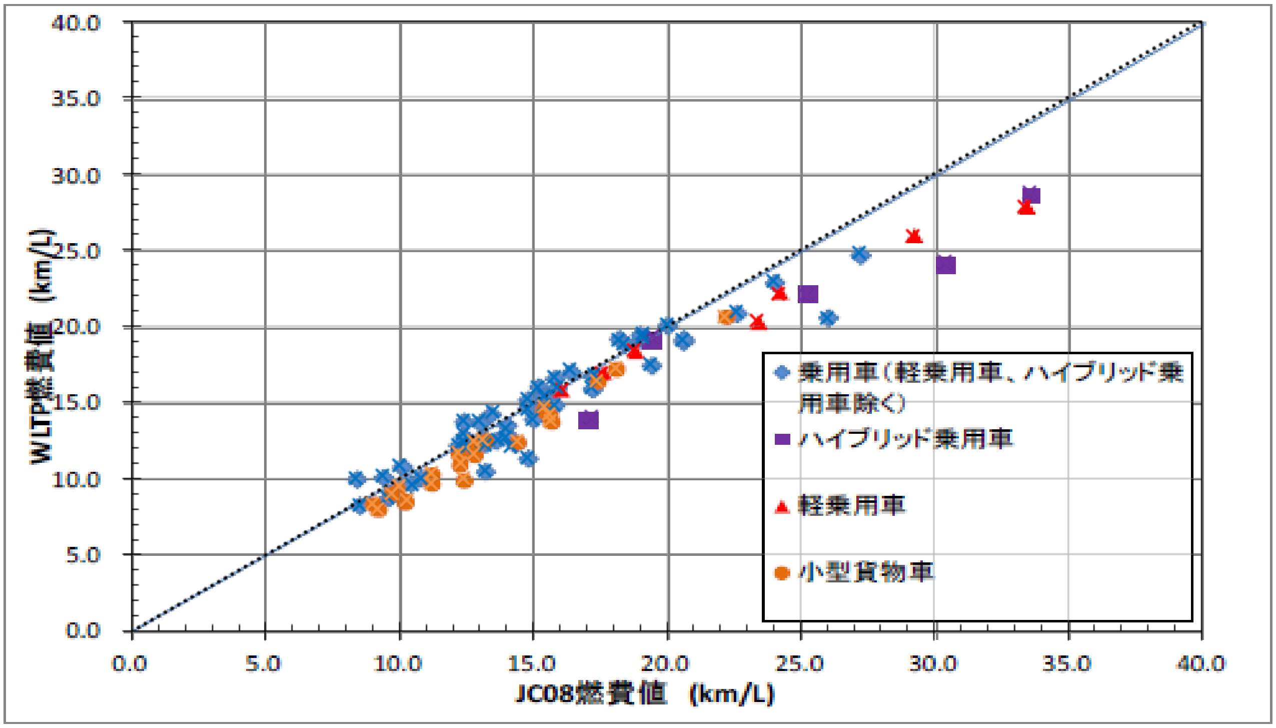

Figure E1. Graphical depiction of reported and replicated JC08 to 3P-WLTP data

The MLIT 3/25/16 dataset in terms of fuel consumption is presented in Figure E2. Here the data are further stratified by stop-start technology, which reflects the greatest level of resolution possible from the information in the MLIT report. While it is not possible to determine the fuel type associated with each data point, few light-duty diesel engines are sold in Japan and thus it is highly likely that most, if not all, of the data are for petrol vehicles. In keeping with the approach for all other test cycle conversions, the analysis provides separate relations for petrol and diesel vehicles, but these relations only reflect fuel carbon content differences for the JC08 cycle; both the petrol and diesel relations are based on the same underlying data points, i.e., the complete MLIT 3/25/16 dataset undistinguished by fuel type. In other words, one fuel consumption relation is converted into two CO_2 relations that differ only in terms of their respective carbon content assumptions.

In reviewing the data depicted in Figure E2, it is tempting to try to visualize relations that vary either by stop-start technology or vehicle type. However, upon close inspection, such stratification is not warranted. All of the data straddles the one-to-one ratio line and although some of the data seem to “prefer” one side of the line or the other, there are enough opposing data points to make such an assumption risky. Minicars constitute a total of seven data points, which are further reduced when viewed in terms of stop-start technology. Similarly, there are only five HEV data points. About 60% of the data are for “other” (non-mini, non-HEV) passenger cars and these data generally tend toward 3P-WLTP/JC08 ratios above one. For “other” vehicles with fuel consumption between about 6 and 8 l/100km, vehicles without stop-start technology generally tend toward ratios above one, whereas vehicles with stop-start technology generally exhibit the opposite. However, for lower fuel consumption vehicles the ratios for vehicles with and without stop-start technology are generally similar, and for higher fuel consumption vehicles the ratios between the two technology subsets actually reverse. Per-km idle time over the JC08 cycle, 42.4 sec/km, is nearly three times that of the 3P-WLTP cycle, 14.7 sec/km. If stop-start systems have a significant effect on the 3P-WLTP/JC08 ratio, vehicles with such systems should have higher ratios than vehicles without stop-start technology; this opposite is true for the data of vehicles with JC08 fuel consumption between 6 and 8 l/100km. Thus, the data suggest that any impacts of stop-start technology are too small to have a statistically significant impact on cycle ratios. Trucks are universally on the “above one” ratio side of the line, but not in a way that is significantly different from the overall trend for the dataset. Given these observations and the overall size of the dataset, this analysis treats the data in the aggregate. Moreover, this similarity across technology types provides important confirmation for similar assumptions made for other test cycle data. Of course, that does not mean that those assumptions are proven, but rather that they remain consistent with available data and thus the assumptions are not disproven.

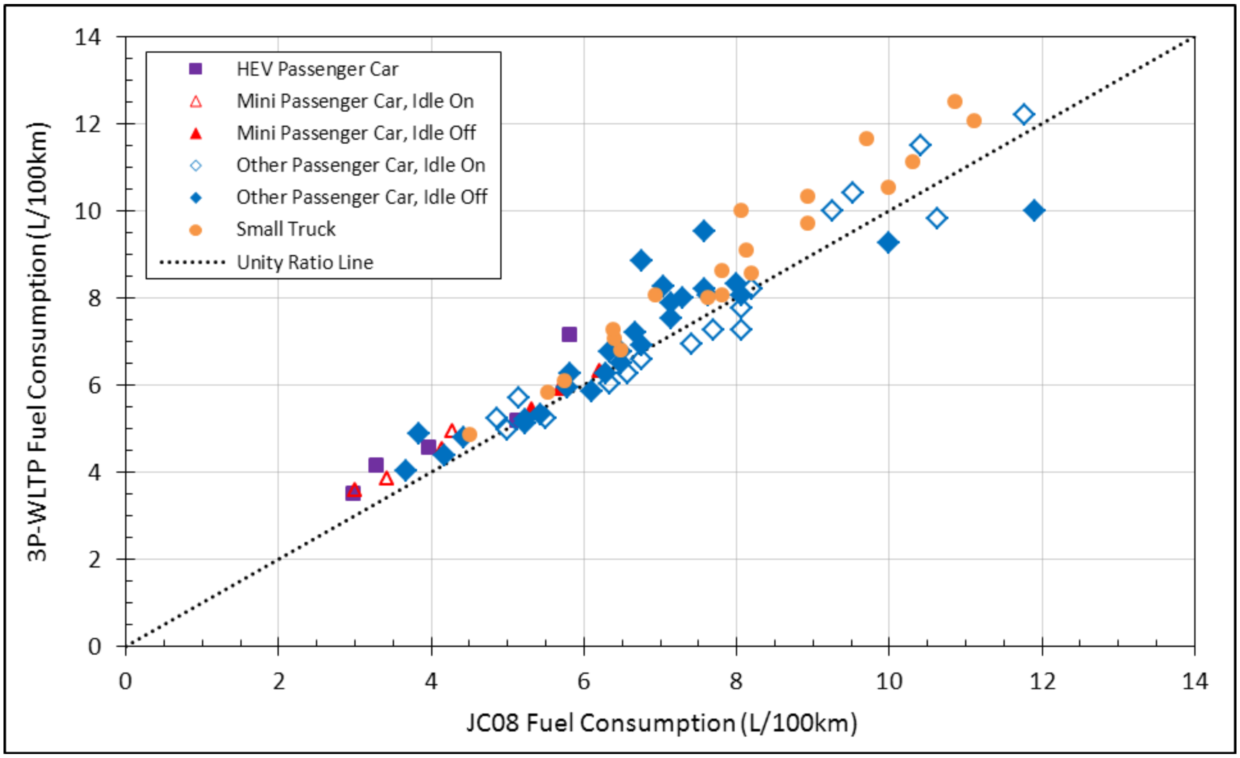

Figure E2. MLIT JC08 versus 3P-WLTP data in fuel consumption terms

Although the relation developed from the MLIT 3/25/16 dataset has been superseded by more recent MLIT data, it is informative to compare the MLIT 3/25/16 relation to the corresponding relation developed from the MLIT 2015–2018 and supplemental JC08 datasets. Figure E3 graphically depicts the comparison, where the MLIT 3/25/16 dataset relation is shown alongside the data points and relation from the MLIT 2015–2018 and supplemental JC08 datasets. Although the two relations are similarly sloped, the newer relation consistently predicts greater 3P-WLTP to JC08 ratios. Estimated 3P-WLTP emissions are approximately 4% (9 gCO_2) higher at 200 gCO_2/km JC08 (about 8.4 l/100km), about 10% (12.0 gCO_2) higher at 100 gCO_2/km JC08 (about 4.2 l/100km), and about 24% (13.7 gCO_2) higher at 50 gCO_2/km JC08 (about 2.1 /100km).

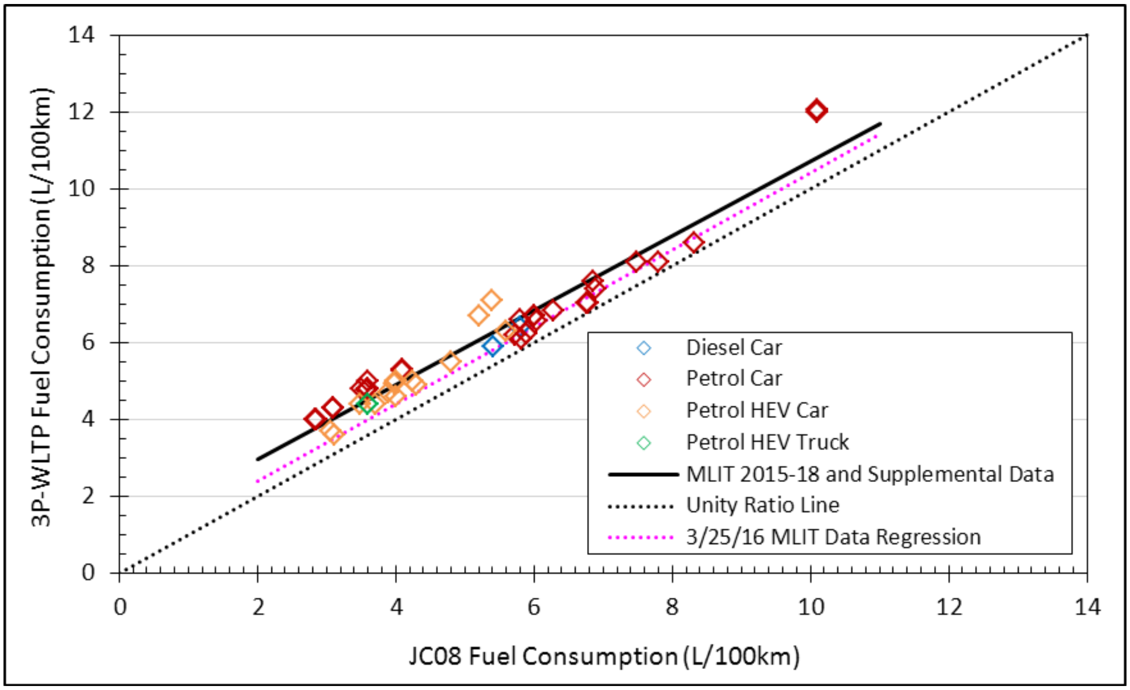

Figure E3. MLIT 3/25/16 relation versus the MLIT 2015-2018 and supplemental JC08 data relation

Appendix F — JC08 data reproduction (MLIT 3/25/16 dataset)

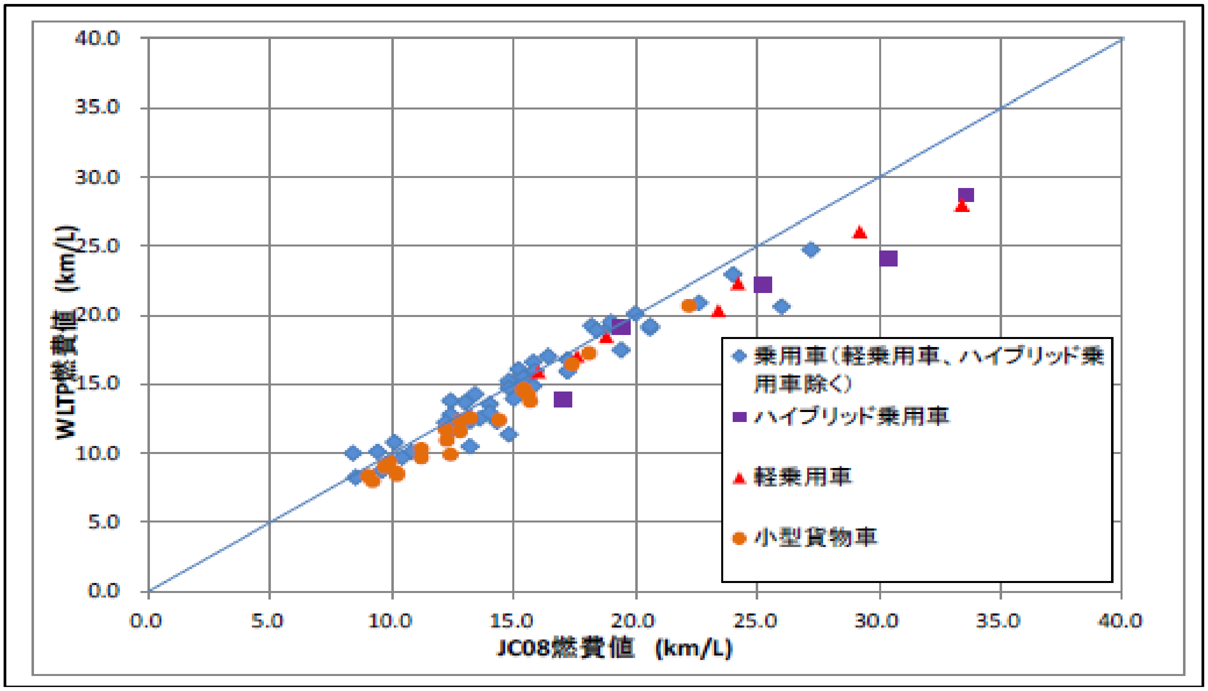

Figure F1. Published JC08 to 3P-WLTP data

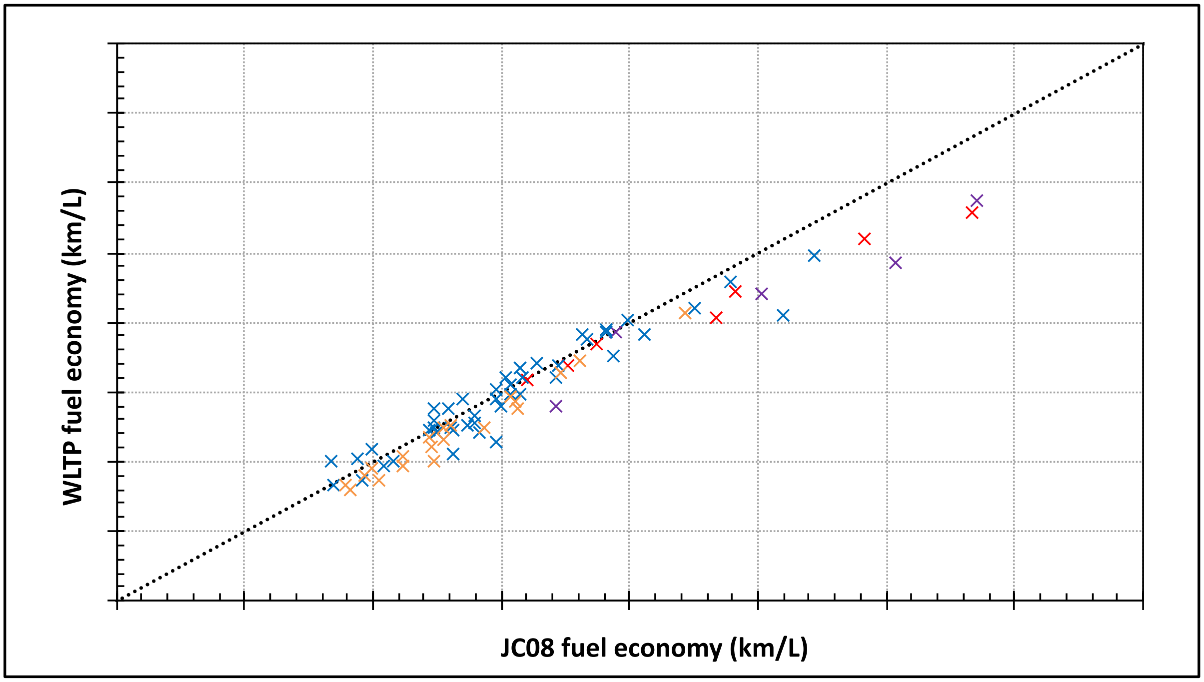

Figure F2. Constructed JC08 to 3P-WLTP data