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TNO report

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Real-world fuel consumption of passenger cars and light commercial vehicles

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Samenvatting

Inleiding
Dit rapport over het brandstofverbruik in de praktijk van lichte wegvoertuigen is er één uit een serie rapporten die door de jaren heen door TNO zijn geschreven voor het Ministerie van Infrastructuur en Waterstaat. De analyse is gebaseerd op tankdata verkregen van Travelcard Nederland BV, en het geeft inzicht in praktijkverbruik en CO_2-emissies uit de uitlaat van personenauto's en, in dit rapport voor het eerst, bestelauto's, en de afwijking tot de officiële typekeurwaarden van de fabrikanten. Deze kloof is gegroeid over de afgelopen vijftien jaar, hetgeen betekent dat het werkelijke verbruik veel langzamer gedaald is dan het opgegeven verbruik. Dat heeft de effectiviteit van het Nederlandse en Europese klimaatbeleid, dat in belangrijke mate is gebaseerd op typekeuringswaarden, verminderd.

Verschillende nieuwe onderwerpen worden behandeld in dit rapport. Voor het eerst wordt het gemiddelde praktijk-elektriciteitsgebruik van volelektrische auto's (EV's) in Nederland gepresenteerd. Daarnaast is zoals genoemd het brandstofverbruik van bestelauto's geanalyseerd op een vergelijkbare manier als voor personenauto's al jaren gedaan is. Verder is het effect van de intrede van de Worldwide Harmonised Light vehicles Test Procedure (WLTP) onderzocht, door te kijken naar het verschil tussen praktijkverbruik en opgegeven waarden conform WLTP. Ook zijn resultaten gepresenteerd van de continue monitoring van drie plug-in hybrides in Vlaanderen. Tot slot zijn de effecten van E10-benzine en van veroudering van voertuigen onderzocht.

Dataset en representativiteit
De dataset bevat tankpasdata en laadpasdata, zoals verkregen van Travelcard Nederland BV. Na filtering op validiteit van de data, bevat de dataset gegevens voor 259.000 benzineauto's, waarvan 33.000 (plug-in) hybrides, 277.000 dieselauto's, waarvan 4.000 (plug-in) hybrides, en 54.000 bestelauto's. Het elektriciteitsgebruik kon worden vastgesteld voor 3.100 elektrische auto's.

Brandstofverbruiksdata dekt de periode januari 2004 - maart 2020.
Het jaarkilometrage van de voertuigen verschilt enorm, wat betekent dat de database niet alleen voertuigen van typische zakelijke veelrijders bevat, maar ook voertuigen van rijders die slechts een klein aantal kilometers per jaar afleggen. Rond de 45% van alle nieuw verkochte personenauto's in Nederland zijn leaseauto's. Omdat deze leaseauto's gemiddeld een hoger jaarkilometrage hebben dan auto's in particulier bezit, bepalen deze leaseauto's in grote mate het gemiddeld brandstofverbruik van de Nederlandse personenautovloot. De resultaten van de monitoring worden daarom representatief geacht voor een groot deel van de Nederlandse vloot. En omdat de database veel nieuwe voertuigen bevat, geeft het onderzoek vroege inzichten in de trend van brandstofverbruik van de Nederlandse vloot voor de komende jaren.

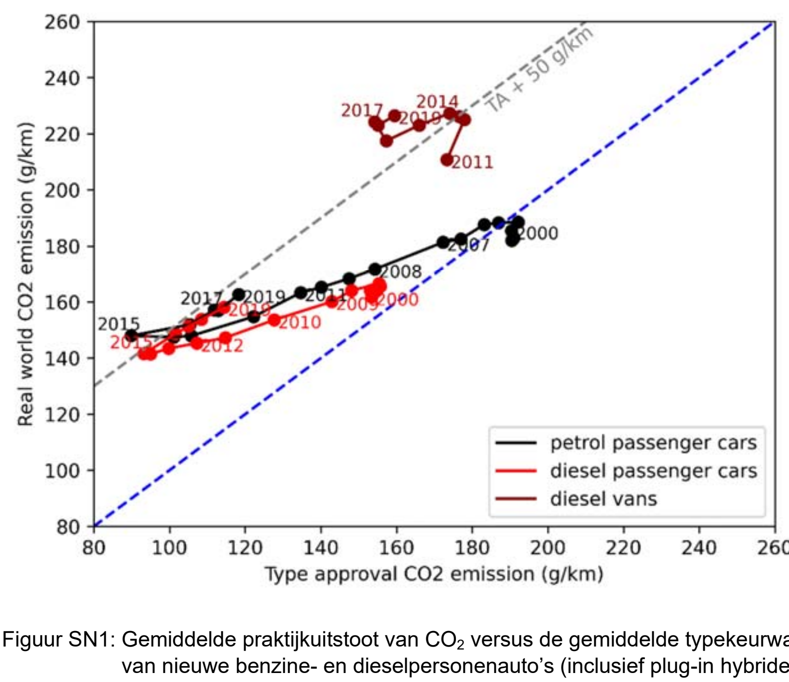
Omdat beleid gericht op het zuiniger maken van de voertuigvloot uiteindelijk tot doel heeft om de CO_2-emissies van mobiliteit te reduceren, worden alle resultaten in dit rapport uitgedrukt in CO_2-emissies uit de uitlaat. Ten behoeve van trendanalyses is een vaste CO_2-emissiefactor gebruikt voor de omrekening van brandstofverbruik naar CO_2, waarin het aandeel biobrandstof niet verdisconteerd is.

De in dit rapport gerapporteerde trends hebben daarom alleen betrekking op veranderingen in de vlootsamenstelling, voertuigen en hun inzet. De beperkte invloed van een klein aandeel bijgemengde biobrandstof op de energieinhoud per liter is daarbij vooralsnog verwaarloosd.

Resultaten
Nieuwe personenauto's hadden in 2019 een gemiddelde praktijkuitstoot van 163 g CO_2/km (benzine, inclusief (plug-in) hybrides) en 158 g CO_2/km (diesel, inclusief (plug-in) hybrides). De typekeurwaarden conform NEDC waren voor beide brandstoffen 44 g/km lager.Dat betekent dat de kloof ook na 2017 (waarden: 45 resp. 46 g/km) iets kleiner is geworden.Voor plug-in hybrides is het gat veel groter (150-300%), in het bijzonder voor plug-ins met benzinemotor.
De invloed van deze voertuigen op het gemiddelde voor 2019 is echter beperkt.
In piekjaar 2015 was er wél een grote invloed door plug-ins, en vanwege de weer stijgende verkoopaantallen valt het te verwachten dat dit opnieuw gebeurt in 2020.

Brandstofverbruiksdata voor bestelauto's is voor het eerst ook beschikbaar, met terugwerkende kracht vanaf 2014. In 2019 nieuw geregistreerde bestelauto's hadden een gemiddelde praktijkemissie van 226 g CO_2/km; dat is 42% hoger dan de bijbehorende gemiddelde typekeurwaarde van 159 g CO_2/km.
Voor bestelauto's die geregistreerd waren in 2014 is het gat tussen praktijkverbruik en typekeurverbruik met 31% verhoudingsgewijs beperkt, wellicht omdat de CO_2-normen voor bestelauto's destijds minder strict waren in vergelijking met die voor personenauto's.

De typekeurwaarden en praktijkwaarden zijn voor elk toelatingsjaar (~bouwjaar) tegen elkaar uitgezet in Figuur SN1.



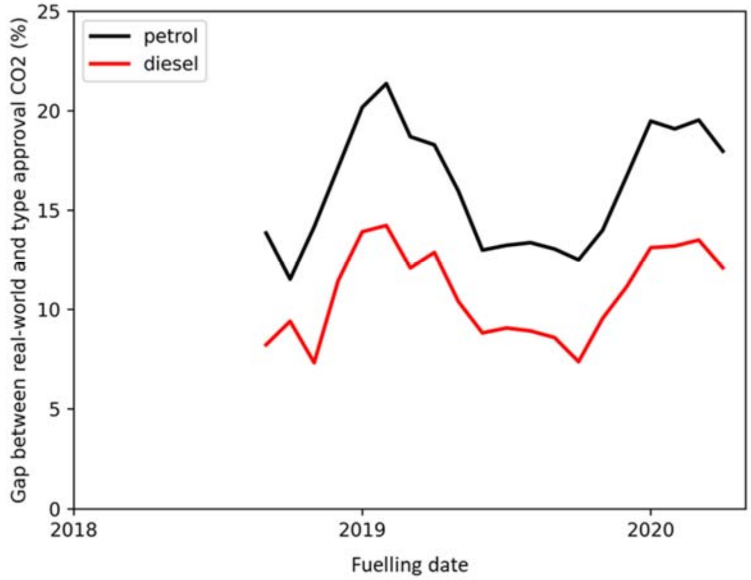
Figuur SN1: Gemiddelde praktijkuitstoot van CO_2 versus de gemiddelde typekeurwaarde voor CO_2 van nieuwe benzine- en dieselpersonenauto's (inclusief plug-in hybrides) en dieselbestelauto's, uitgesplitst naar toelatingsjaar.

Het gemiddelde elektriciteitsgebruik, berekend voor de ruim 3.000 elektrische auto's, waarvoor voldoende valide data aanwezig was in de database, bedraagt 20,4 kWh/100 km. Dit is inclusief laadverliezen. Gewogen naar de samenstelling van de totale Nederlandse EV-vloot verandert dit cijfer weinig: 20,2 kWh/100 km. Van model tot model varieert het gemiddelde gebruik tussen 16 en 29 kWh/100 km, waarbij de hogere waarden hoge auto's vertegenwoordigen met een groot frontaal oppervlak. Belangrijk om te weten is dat het gemiddelde elektriciteitsgebruik van individuele voertuigen sterk varieert. Voor EV's heeft het aandeel snelweg en de daar gereden snelheid een groot effect op het elektriciteitsgebruik (meer dan op het brandstofverbruik van auto's met verbrandingsmotor), en het gebruik van verwarming of koeling op korte ritten kan ook tot grote verschillen leiden.
De gemiddelden voor elk model vertonen, echter, een vergelijkbare spreiding als het brandstofverbruik van vergelijkbare brandstofmodellen. Gemiddeld genomen wijkt het praktijkelektriciteitsgebruik 18% naar boven af van de door fabrikanten opgegeven WLTP-waarde.

Voor plug-in hybride personenauto's is uit de tankdata het brandstofverbruik in hybridemodus (lege accu) afgeleid. Daarnaast is het aandeel elektrisch rijden geschat. Het brandstofverbruik is typisch 6-12 liter per 100 km, met uitzondering van de Toyota Prius Plug-in Hybrid, die 5 liter/100 km verbruikt in hybridemodus. Het geschatte aandeel elektrisch gereden kilometers varieert van model tot model tussen 14% en bijna 40%. Een uitzondering vormt de Porsche Panamera S E-hybrid met een aandeel elektrische kilometers van slechts 5%.

Het WLTP-praktijkgat is geanalyseerd voor personenauto's uit 2018 en 2019.
Een eerdere analyse[1] van de verschillen tussen NEDC- en WLTP-waarden voor dezelfde auto leidde tot de conclusie dat voor personenauto's een WLTP-waarde kan worden verwacht in de orde van 15 g/km + 10% hoger[2] dan de NEDC-waarde van hetzelfde type voertuig. Dat betekent dat de WLTP het gat tussen praktijk en typekeur gedeeltelijk zou dichten. Figuur SN2 toont de werkelijk gevonden afwijking voor benzine- en dieselpersonenauto's die onder WLTP-regime zijn toegelaten.
Het is nog te vroeg om conclusies te trekken over trends, en de hoeveelheid data is nog beperkt. Toch geven de resultaten aan dat het gat tussen praktijk en typekeuring iets verder gedicht lijkt dan op basis van de projecties gedacht werd.

[1] Aspects of the transition from NEDC to WLTP for CO_2 values of passenger cars – Phase 3: After the transition, TNO 2019 R10952, 2 July 2019.
[2] Dat wil zeggen: WLTP-waarde [g/km] = NEDC-waarde + 15 + 0,10 x NEDC-waarde [g/km]



Figuur SN2: Gat tussen praktijkuitstoot van CO_2 en opgegeven uitstoot van CO_2 conform WLTP bij benzine- en dieselpersonenauto's (grafiek start op het moment dat 100 volgens WLTP geteste voertuigen in de Travelcardvloot aanwezig zijn).

Drie plug-in-hybrideauto's zijn over een gezamenlijke afstand van 13.000 km gemonitord, tijdens dagelijks gebruik in Vlaanderen. Gelogd zijn de accuspanning en laadtoestand van de accu, en de stroomsterkte van en naar de accu, naast andere voertuigparameters zoals snelheid en motortoerental. De CO_2-uitstoot uit de uitlaat werd berekend uit de hoeveelheid uitlaatgas en het zuurstofgehalte daarin. De twee benzineplug-ins hadden een gemiddelde uitstoot van 222 g CO_2 per km (9,3 liter/100 km), en de dieselplug-in 163 g CO_2 per km (6,2 liter/100 km). Daarbovenop werd 6,1 resp. 3,5 kWh/100 km gebruikt. De elektrisch afgelegde afstand was in alle drie de gevallen ongeveer 25% en daarmee hoger dan het voor deze automodellen gevonden gemiddelde voor de Nederlandse vloot.

Vanaf 1 oktober 2019 is het voor tankstations met minimaal twee benzine-tankinstallaties verplicht gesteld om E10 te voeren. Normaal gesproken vervangt deze E10 benzine daarmee de E5 Euro95 benzine. Er is onderzocht of een effect van de overgang van E5 naar E10 te ontdekken was in de tankdata. Vooral het seizoen beïnvloedt de brandstofverbruiksdata, en daarvoor diende gecorrigeerd te worden. Door gebruik te maken van de variatie voor dieselauto's (en een geconstateerd verschil in gevoeligheid van benzine- en dieselauto's voor seizoenseffecten) is geprobeerd om een trendbreuk te herkennen voor benzinevoertuigen. Er werd echter geen effect gevonden.

Met betrekking tot mogelijke effecten van veroudering van voertuigen is gekeken naar de trend in brandstofverbruik bij auto's in de vloot met hoge kilometerstanden. Het laagste verbruik lijkt op te treden bij een kilometerstand tussen 50.000 en 100.000 km. De effecten van veroudering waren klein, +1% bij 250.000 km voor benzineauto's en +0,5% voor diesels bij 300.000 km.

Summary

Introduction
This report on real-world fuel consumption of light vehicles is one in a series written by TNO for the Dutch Ministry of Infrastructure and Water management.
The analysis is based on fuelling data obtained from Travelcard Nederland BV, and provides insight in real-world fuel consumption and tailpipe CO_2 emissions of passenger cars and, for the first time, vans, and the gap with official type approval figures provided by the manufacturers. The gap has grown over the last decades, meaning that real-world fuel consumption and CO_2 emissions have decreased much more slowly than the average type approval values. This significantly reduces the effectiveness of greenhouse gas policies for cars based on the type approval values.

Several new topics are covered in this report. For the first time, real-world average electricity consumption values are presented for full electric vehicles in the Netherlands. Also, as mentioned, the fuel consumption of a fleet of 50,000 light commercial vehicles was analysed, in a way similar to passenger cars. Next, the effect of the Worldwide Harmonised Light vehicles Test Procedure (WLTP) was investigated, by comparing WLTP type approval fuel consumption values with real-world values. Furthermore, results from second-by-second monitoring of three plug-in hybrids are presented. Lastly the effects of E10 petrol and vehicle aging are investigated.

Dataset and representativeness
The dataset includes tank pass data and charge pass data, as obtained from Travelcard Nederland BV. After filtering for valid data, the dataset encompasses 259,000 petrol passenger cars, of which 33,000 (plug-in) hybrids, 277,000 diesel passenger cars, of which 4,000 (plug-in) hybrids, and 54,000 vans. The electricity consumption could be determined for 3,100 electric passenger cars.

Fuel consumption data covers the period of January 2004 up to March 2020.
The annual mileage of the vehicles in the fleet varies greatly, which means that the database does not only contain vehicles of business drivers with high annual mileage, but also vehicles of drivers that cover a relatively small mileage each year. Around 45% of all new cars sold in the Netherlands are leased vehicles. As these leased vehicles on average also have higher annual mileages than privately owned vehicles, their effect on the average real-world fuel consumption across the Dutch fleet is large. The results of the monitoring are therefore considered meaningful for the Dutch passenger car fleet.

As the objective of policies for improving the fuel efficiency of the fleet is to reduce the CO_2 emissions from mobility, all results in this report are expressed in terms of CO_2 emissions from the exhaust. For that reason, for the purpose of trend analysis, a fixed CO_2 emission factor was used, in which the share of biofuel in the delivered blend is not accounted for. Observed trends in CO_2 emissions in this report, therefore, solely relate to developments in the fleet composition, the vehicles and their use. The limited impact of a small share of blended biofuel on the energy content per liter of fuel has up to now been ignored.

Results

New passenger cars in 2019 had an average real-world CO_2 emission of 163 g/km (petrol, including (plug-in) hybrids) and 158 g/km (diesel, including (plug-in) hybrids). The type approval values according to NEDC were 44 g/km lower in both cases.This means that the gap has further decreased since 2017 (when the gap was 45 and 46 g/km). For plug-in hybrids the gap is much larger (150-300%), especially for petrol. However, their influence on the averages is limited in 2019. Plug-ins did significantly increase the average gap in peak year 2015, and, due to increasing sales numbers, will probably in 2020 as well.

For the first time, also fuel consumption data of vans was available, retroactively from the year 2014 onwards. New vans in the year 2019 had an average real-world CO_2 emission of 226 g/km, which is 42% higher than the corresponding average type approval CO_2 emission of 159 g/km. For vans registered in 2014 the gap between real-world and type approval was was relatively small at 31%, possibly because the regulations were not stringent at that time compared to those for passenger cars.

The type approval values and real-world values are plotted against each other for each registration year in Figure SE1.

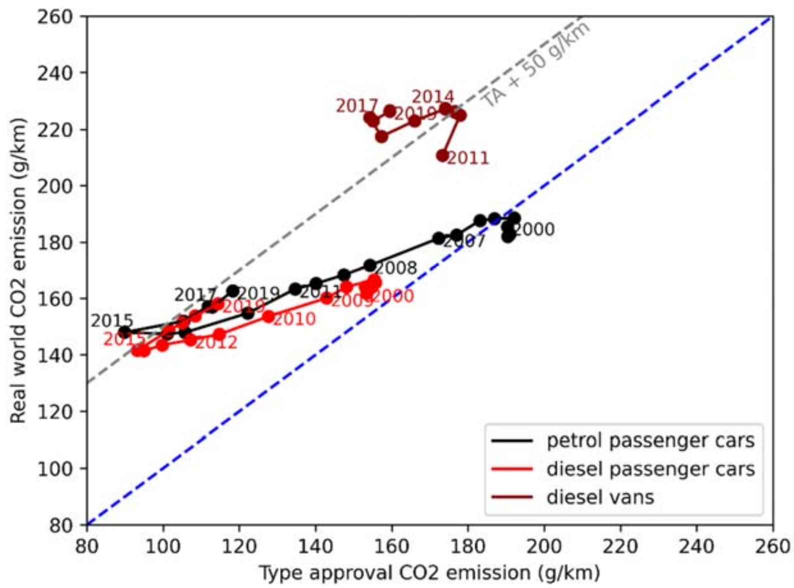


Figure SE1: Average real-world CO_2 emissions versus the average type approval value of new petrol and diesel cars (including plug-in hybrids) and diesel vans, differentiated by the year of first registration.

The average real-world electricity consumption of just over 3,000 electric vehicles in the database was found to be 20.4 kWh/100 km. This includes charging losses. Weighted to match the composition of the entire Dutch electric fleet this number remains almost the same: 20.2 kWh/100 km. From model to model the values vary between 16 and 29 kWh/100 km, where the higher values represent tall vehicles with a large drag area.

Note that the underlying data varies a lot for individual vehicles. For EVs the share of highway use and the speed driven on the highway have a large effect on the electricity consumption (more so than on fuel consumption for combustion engine vehicles), and the use of heating/cooling on short trips can lead to large differences as well. Averaged for each model, though, the spread in energy consumption is not notably larger or smaller than the spread in fuel consumption among similar combustion engine vehicles. On average the real-world electricity consumption is 18% higher than the WLTP value declared by the manufacturers.

For plug-in hybrid passenger cars fuelling data was analysed to derive their fuel consumption in hybrid mode (empty battery) and to estimate the share of electric driving. The fuel consumption is typically 6-12 l/100 km, with the exception of the Toyota Prius Plug-in Hybrid, which consumes 5 l/100 km in hybrid mode.
The estimated fraction of kilometres driven electrically generally varies from 14% to almost 40%, with the exception of the Porsche Panamera S E-hybrid, which is driven in electric mode only 5% of the kilometres.

For passenger cars earlier analysis of the differences between the NEDC and WLTP declared values of the same car[3] led to the conclusion that for passenger cars the WLTP value is expected to be in the order of 15 g/km + 10% higher[4] than the NEDC value of the same car, meaning that WLTP closes the real-world vs. type approval gap at least partially. Figure SE2 shows the actual gap found for petrol and diesel passenger cars under WLTP regulations. It is too early to conclude on any trends, and the amount of data is limited yet. However, the results indicate that the WLTP closes the type approval vs. real-world gap slightly better than was expected from projections based on NEDC.

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[3] Aspects of the transition from NEDC to WLTP for CO_2 values of passenger cars – Phase 3: After the transition, TNO 2019 R10952, 2 July 2019.
[4] I.e.: WLTP value [g/km] = NEDC value + 15 + 0.10 x NEDC value [g/km]

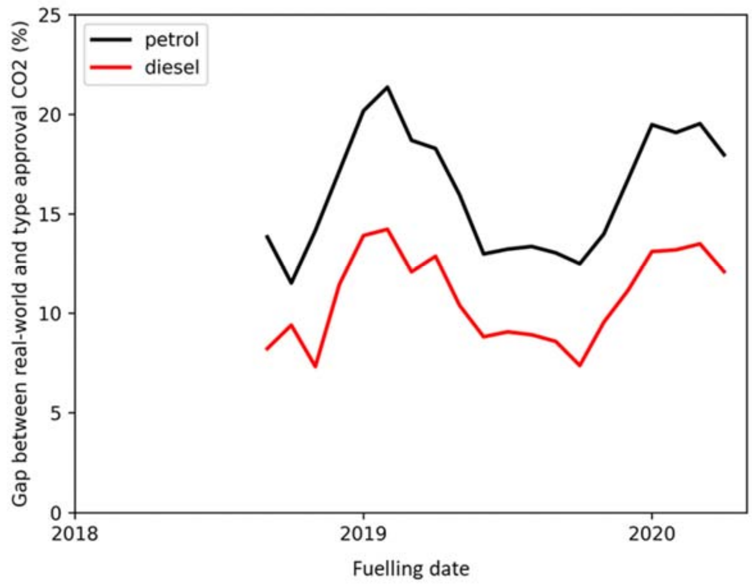

Figure SE2: Gap between real-world CO_2 emission and WLTP CO_2 value for petrol and diesel passenger cars (graph starts when >100 vehicles in the Travelcard fleet were admitted under WLTP regulations).

Three plug-in hybrid vehicles were monitored in daily use in Flanders, Belgium, over a total distance of 13,000 km. The state of charge of the battery as well as the current to and from the battery and the battery voltage were monitored, besides vehicle parameters such as speed and engine speed. The tailpipe CO_2 emissions were calculated from the amount of exhaust gas and the oxygen level in it.
The two petrol plug-ins averaged 222 g CO_2/km (9.3 l/100 km), the diesel plug-in 163 g/km (6.2 l/100 km). On top of that, 6.1 kWh/100 km and 3.5 kWh/100 km were consumed by the petrol and diesel plug-ins respectively. The distance driven electrically was around 25% for each of the three vehicles, which is actually higher than the average in the Dutch data for the models involved.

From October 1, 2019, it was made obligatory to sell E10 at all tank stations that have at least two petrol pumps. This E10 petrol most commonly replaced E5 Euro95 petrol. The effect of the transition from E5 to E10 petrol was analysed. In particular seasonal variation affects the fuel consumption data and therefore requires to be corrected for. Using the seasonal variation observed in diesel vehicles, for which the fuel composition should not have changed as much, it was attempted to find a trend breach for petrol vehicles. Yet, no effect of the introduction of E10 was observed.

To determine if the fuel consumption of passenger cars changes when their mileage increases, the fuel consumption trend of high mileage vehicles was analysed. The lowest fuel consumption occurs at 50,000-100,000 km. The effects of aging were found to be minor only, +1.0% at 250,000 km for petrol vehicles and +0.5% at 300,000 km for diesel vehicles.

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1 Introduction

At the request of the Ministry of Infrastructure and Water management, TNO performs regular studies on the fuel and energy consumption of vehicles based on data that is made available by Travelcard Nederland BV. Already for many years the official fuel consumption number of vehicles has a complex and tenuous relation with the real-world fuel consumption. This study, like the TNO studies before, provides insight into general trends and into specific new effects that are observed in the most recent data.

1.1 Context

Over recent years there have been many regulatory developments affecting the type approval as well as real-world CO_2 emissions and fuel / energy consumption of conventional vehicles, electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV, or OCV-HEV: off-vehicle charging hybrid electric vehicle). A new CO_2 test procedure was enforced: the Worldwide Harmonised Light Vehicles Test Procedure (WLTP). Also a transition is taking place from the EU 2021 CO_2 target for manufacturers, to the new targets for 2025 and 2030. The regulatory changes move manufacturers to modify their vehicles to meet the targets on a fleet level. This has a direct effect on the fuel consumption and CO_2 emission values as reported by the manufacturers. The intention of the regulations is to cause a decrease of the real-world fuel consumption and CO_2 emission. However whether these values decrease at an equal rate as the type approval values, after the introduction of the WLTP, remains to be seen.

Already for many years the CO_2 targets and the reduction of officially reported numbers have shown a limited impact on real-world CO_2 emission and fuel consumption of conventional vehicles. Additionally, there is a transition to PHEV and electric vehicles ongoing, which not only provides additional opportunities for the manufacturers to meet the CO_2 targets, but also affects trends with respect to the average gap between real-world and type approval. For PHEV the real-world fuel consumption reduction compared to similar non-plug-ins has been small in the Netherlands, because of the way the vehicles are used, with a large fraction of motorway driving for new vehicles, and a slack charging behaviour of many of the drivers.

This report is one in a long series of reports on the fuel consumption of light duty vehicles, but, with the current trends is extending the scope to include new topics. Firstly, as the electricity use of a household may double with the use of an electric car, it is relevant to consider the real-world energy consumption of electric vehicles. Secondly, the shift of petrol fuel from E5 to E10 has given concerns on the fuel efficiency of vehicles, i.e., the litres of petrol consumed per 100 kilometres. This is investigated. Thirdly, there has been a shift from diesel passenger cars to diesel vans, with an increasing number of vans on the Dutch roads. With the number of vans passing one million, it is relevant to know the real-world fuel consumption of these vehicles. Fourthly, PHEVs remain advertised as positive for environment and climate. The reality has been more diffuse. This is further investigated, to see if specific PHEV use may have more benefit than others.

Finally, the first WLTP vehicles have entered the market, so a first indication can be given if the transition to this new test procedure has had a positive effect on the real-world CO_2 emissions of passenger cars.

1.2 Vehicle database and filtering

For the purpose of this report, fuel and electricity transaction data was made available by Travelcard Nederland BV. For each fuelling event, the amount of tanked fuel, the odometer reading and the time and date were recorded.
For each charging event the kilowatt-hours and the time and date were recorded. After filtering for plausibility and completeness, the dataset encompasses 52 million fuel transactions and 1,8 million charging events. Rigorous filtering was necessary, because the odometer settings are entered manually by the drivers after fuelling and contain many errors and missing records. For more information on the methodology for data processing and analysis see for example reports TNO 2016 R11258 and TNO 2013 R11165.

For electric cars, odometer readings are generally not registered at charging events. Therefore odometer data, needed for the calculation of fuel consumption per kilometre, had to be sourced elsewhere. Information was exchanged with the data TNO collected for the Klimaat- en Energieverkenning (KEV) project for PBL. Just over 30,000 odometer readings were collected for the 14,000 electric vehicles in the dataset.

Real-world fuel consumption figures could be determined for 536,000 passenger cars: 259,000 petrol vehicles (of which around 33,000 (plug-in) hybrids) and 277,000 diesel vehicles (of which around 3,900 (plug-in) hybrids). Real-world electricity consumption figures could be determined for 3,100 full-electric passenger cars. The real-world diesel consumption could be determined for 54,000 vans.

Vehicles stay in the database for as long as they are present in the fleets that use Travelcard tank passes. Data is available since 2004, and for some vehicles indeed data is available over the entire period 2004-2020. The total mileage per vehicle therefore also varies from zero to over 200,000 km. Figure 1-1 shows the frequency distribution of the monitored mileage per vehicle. Compared to the 2018 report[5], for petrol the share of cars monitored over a large distance (>100,000 km) grew. The same happened for plug-ins, both petrol and diesel. This coincides with the increase in share in the (company car) fleet for these categories since 2015.

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[5] Real-world fuel consumption of passenger cars based on monitoring of Dutch fuel pass data 2017, TNO report 2018 R10371, 17 May 2018.

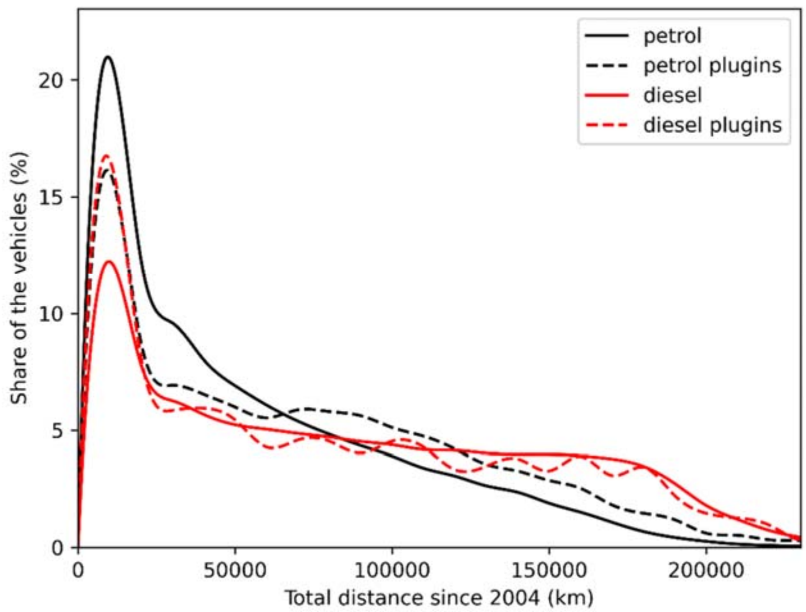

Figure 1-1: Histogram of the number of vehicles as a function of the total mileage over which the vehicle is monitored.

In the past vehicles were part of the lease fleet for a few years only. More recently, as a result of changes in tax benefits, vehicles remain somewhat longer in the lease fleet. In particular PHEVs, which have a tax benefit lasting till six years after introduction, tend to remain in the fleet for the full term of six years.

1.3 Methodology

Petrol/diesel

For petrol and diesel cars, consecutive fuelling events are combined with the distance driven in between these fuelling events. Fuel consumption is calculated by dividing the amount of total tanked litres by the total driven distance. The method used in this report is equal to the one used in 2018[6].

In short, the average fuel consumption for a selection of vehicles is determined by dividing the sum of all tanked litres by the sum of all kilometres driven for the selection of tank events of all vehicles for which the average is determined. This produces the average over a selection of vehicles whereby the results for individual fuel events or vehicles are weighted over the kilometres driven.

The ‘direct’ CO_2 emission, in other words the emission of CO_2 from the tailpipe, can be directly related to the fuel consumption. The amount of CO_2 emitted per litre of fuel is related to the carbon content of the fuel and more or less fixed. Per litre of petrol about 2370 grams of CO_2 are emitted, while for diesel this value is 2650 gram CO_2 per litre.

[6] Real-world fuel consumption of passenger cars based on monitoring of Dutch fuel pass data 2017, TNO report 2018 R10371, 17 May 2018.

These so-called emission factors are based on the relation between fuel consumption and CO_2 from the type-approval information, and are representative for 100% fossil petrol and diesel. The emission factors have been assumed constant for the period over which data is available. This is done to be able to monitor the efficiency of the fleet over time..

Impact of biofuels on calculated tailpipe CO_2 emissions
Caution needs to be taken when using the information in this report to calculate the CO_2 emissions of a fleet. Reported CO_2 figures are direct emissions from the vehicle's exhaust, estimated from consumed liters using a fixed CO_2 emission factor. For reporting of the direct emissions of transport according to IPCC guidelines the CO_2 emissions associated with biofuel use are counted as zero. If real-world CO_2 emission results from this report are used as input for official statistics or other assessments of the tank-to-wheel CO_2 emissions from transport, they need to be corrected for the share of biofuels, which increases over time.

Furthermore, an increasing biofuel share may affect the trends in consumed fuel. Biofuel blending generally lowers the CO_2 emissions per liter of fuel, but increases the vehicle's fuel consumption in liters per 100 km. The two effects largely cancel out in the net effect on the tailpipe CO_2 emissions per kilometre. If the CO_2 emissions are calculated with an emission factor that does not take account of the biofuel share (i.e. assuming the consumed fuel is 100% diesel), as is the case in this report, the tailpipe emissions per kilometre are somewhat overestimated. Based on the average biofuel content in 2018 this overestimation would amount to 2.3% for petrol and 0.3% for diesel. For 2019 the overestimation is larger because of E10 being compulsory from October 2019 onwards. The effect of the introduction of E10 on actually tanked liters is analysed from the data in chapter 9.

In previous reports on this topic, up to 2016, real-world fuel consumption and CO_2 emission were compared to type approval values as tested over the New European Driving Cycle (NEDC) to analyse trends in the real-world vs. type approval 'gap'. Since September 2017 (new vehicle models) and September 2018 (all new cars) the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) is in force, replacing the NEDC. For large vans the introduction dates are later. This report starts a new series, analysing the gap between real-world and WLTP-based fuel consumption and CO_2 emissions. Approximately 23,000 vehicles in the dataset have WLTP-based type approval values. However, the 2021 EU target of 95g CO_2 per kilometre is tied to the NEDC evaluation method. Therefore, for new vehicles the WLTP CO_2 values are transformed mathematically into a derived NEDC value, or are determined with double testing the vehicles on WLTP and NEDC, usually referred to as NEDC 2.0. For this report that gives the opportunity to continue the NEDC-based series, next to the new WLTP-based series. Also, possibly side effects of the introduction of the WLTP can be observed.

The real-world fuel consumption of petrol/diesel plug-in hybrid passenger cars was also calculated in the abovementioned way. Furthermore, fuelling data of PHEVs was arranged per vehicle model for further analysis. The "low end" of the distribution of fuel economy in km/l, achieved by sorting fuelling events for a particular model by fuel economy, reveals a fuel consumption value for hybrid mode ('empty battery' situation).

The difference between the mode (most common value) and the average can be used to deduce an average share of electric driving for that particular model.
A more detailed explanation can be found in chapter 5. The method is an extension of approaches reported in reports TNO 2013 R10703 and TNO 2016 2016 R10938.

Electric vehicles
For full electric cars, a new methodology was developed. The goal of the method is to calculate the electricity consumption per kilometre for each vehicle individually. This is done by matching charging data with odometer data. Charging data and odometer readings are obtained from two different sources and are generally not available on matching dates. Also, in some instances charging data is available intermittently, due to holidays, service, or possibly the temporary use of a different card or of unmetered charging points. All in all, extensive filtering and validity checking is necessary to select reliable series of data for the electricity consumption calculation.

The first step is to filter the electric vehicles in the database for the presence of at least two odometer readings.

Subsequently, implausible charging data are removed. To this end, for each vehicle brand, model and version ('uitvoering' in RDW vehicle registration data) a net usable battery capacity was determined. Data on battery capacity were retrieved from several sources (ev-database.nl, autoweek.nl, manufacturer specifications, RDW data, and Wikipedia). Considering charging losses, and taking an additional margin, charging events larger than 1.25 times the battery capacity of the car are removed. The correctness of the battery capacities was verified by checking the frequency of the occurrence of charging events exceeding the factor 1.25 rule for individual models/versions.

Starting point for determing the electricity consumption of individual EVs is clustering of the recorded charging events which are most likely subsequent, i.e. not interrupted by unregistered charging events. This is done by setting a maximum allowed gap between two charging events, which is dependent on the average charging frequency of the user and the length of the charging event sequence so far. Sequences are considered valid if they comply to two criteria: a) it spans a period of at least 14 days, b) it consists of at least 10 charging events.

The kilometres to be associated with the total electricity consumed in a sequence of charging events are then determined by matching odometer readings with the sequence. For this purpose a graph was plotted for each vehicle with at least two odometer readings (4,500). Two approaches are followed.

Approach 1 is illustrated in Figure 1-2, using a real-world case.
Two sets of odometer readings and -dates are used (orange in the graph), one close to the start date of a charging sequence, and one close to the end date of this charging sequence. In the illustration these are plotted as orange dots on the left bottom and right top of the graph. The charging sequence is plotted as a row of blue dots. To align the kWh-data and odometer data in time, the cumulative kilowatthour-level is predicted on the dates of the odometer readings. To this end, the two closest charging samples are extrapolated (or interpolated) towards the date of the odometer reading.

In the illustrated case, extrapolation was needed, because the odometer reading dates were outside the date range of the charging sequence. The extrapolation is indicated by small green lines. Now the data are time aligned, the calculation is simple: the electricity consumption equals ΔkWh / Δkm.

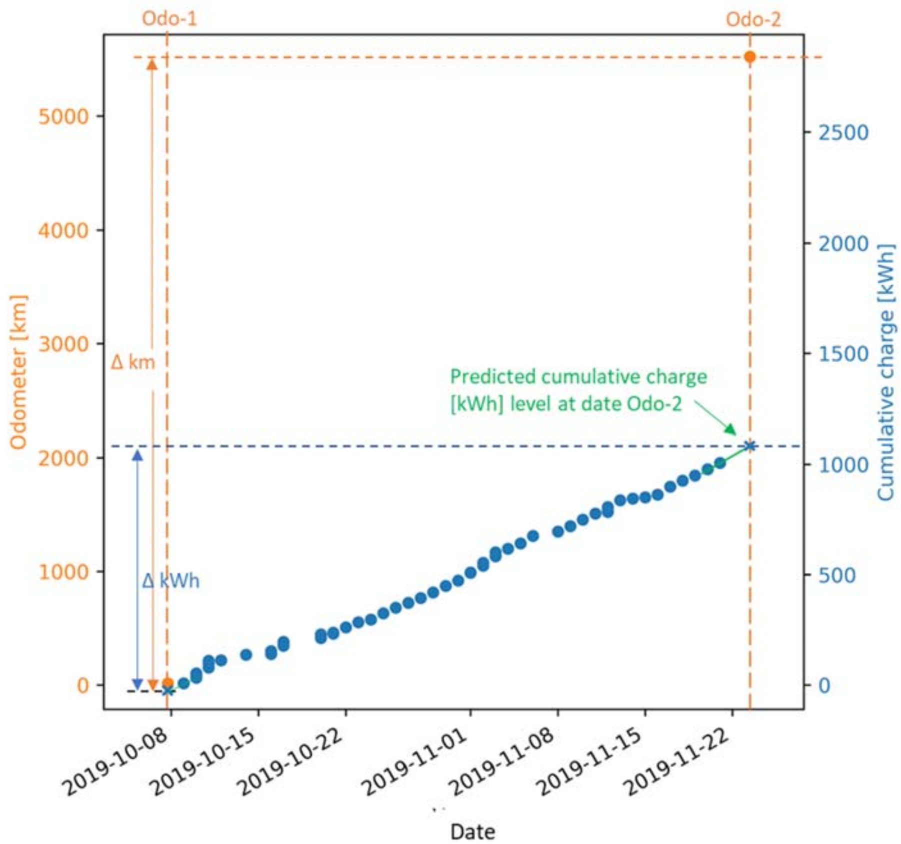

Figure 1-2: Example of approach 1 to determine electricity consumption per km.

If this approach does not succeed for a particular vehicle, for instance because the odometer readings are too few, approach 2 is attempted. Approach 2 determines the slope (in cumulative kWh) of the longest sequence of a vehicle and the slope of the odometer readings. For both the regression coefficient must be over 0.9 to be considered valid. In other words, if there are more than two odometer readings, the annual mileage of the vehicle has to have been more or less constant to be valid for this approach. Also, a minimum of 3000 km must be covered, and a minimum of 25 charging events.

Approach 2 is illustrated in Figure 1-3.

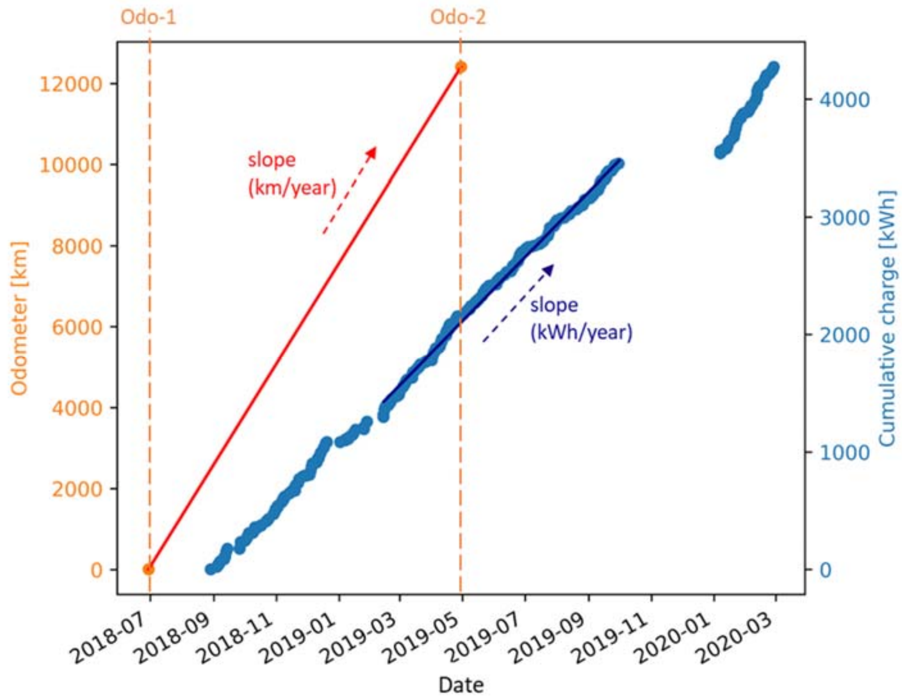

Figure 1-3: Example of approach 2 to determine electricity consumption per km.

The procedures described above yield 3,467 sets of charging data-distance combinations for 3,134 vehicles.

Further filtering is done in two steps. First, for each vehicle a lower limit of energy consumption was calculated, being 70% of a calculated kWh/100 km-value derived from the WLTP value of the vehicle. All results below this threshold are removed. Secondly, for each vehicle an initial average and standard deviation is calculated for its energy consumption. All results outside two times the standard deviation are removed. Also, results over 35 kWh/100 km are removed. The remaining results are averaged per vehicle brand and model, and for some vehicles the version as well. Only vehicles with ten sequences or more are considered valid. All other data is ignored as implausible or irrelevant.

1.4 Representativeness of the results

The suggestion is often made that the analyses based on tank pass data from Travelcard Nederland BV is biased for a particular group of users and a particular type of use. Tank passes are used by “business drivers” who mostly drive a leased car provided by their company. As their fuel bill is paid for by the company, these drivers are not considered to have an incentive to drive in a fuel efficient manner. Also company car drivers tend to have higher than average annual mileages, which are generally associated with a higher than average share of highway kilometres. So, some bias towards higher than average fuel consumption values may indeed be expected. However, an analysis of the annual mileages of vehicles in the database (see Figure 1-4) shows that the database does not only contain stereotypical business drivers.

Moreover, there is no systematic difference in the results between the typical vehicle brands and models used by business drivers, compared to the more family oriented brands and models. There is a large spread in annual mileages and the database also contains a significant share of vehicles with relatively low annual mileages.

The average annual mileage of the Dutch passenger fleet is 10,700 km/year for petrol and 23,800 km/year for diesel. Figure 1-4 shows the distribution of the annual mileage of the Travelcard dataset. The average mileage (see also Table 1-1) is well above the national average (petrol: 10,700 km/y; diesel: 23,800 km/y).
However, the monitored fleet is relatively young, and newer vehicles are known to have higher annual mileages than older vehicles. According to CBS vehicles of two years old drive 15,600 km (petrol) and 34,600 km (diesel) on average in the Netherlands.

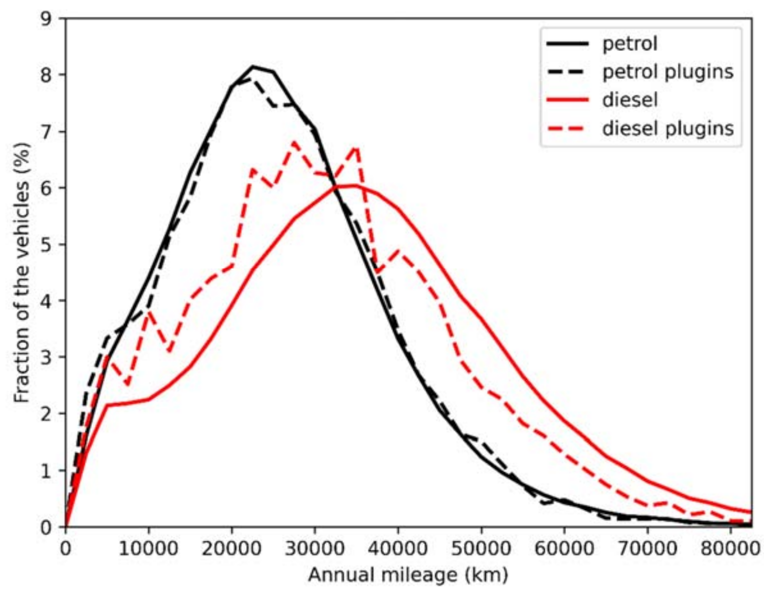

Figure 1-4: Distribution of the annual mileages of vehicles in the Travelcard database.

Table 1-1: Annual mileages per fuel/drivetrain-combination

	Most common, modal annual mileage (km)	**Average annual mileage (km)**	**Average annual mileage in 2018 report (km)**
Petrol	22,500	24,700	26,700
Petrol plug-in	22,500	24,700	33,900
Diesel	35,000	34,600	37,600
Diesel plug-in	27,500	30,100	40,200

Compared to the 2018 research the most significant change is the drop in average mileage of plug-in hybrids. The values today are much closer to those of non-plug-in cars.

2 Developments in Dutch vehicle market

With changing CO_2 emission regulations, changing fiscal incentives and changing preferences of car buyers, it is useful to first shed some light on trends in the Dutch vehicle fleet. Some of the following information was previously published by TNO in 2019[7].

Figure 2-1 shows the new vehicles sales in the Netherlands across the years. Commonly, in January of every year the number of new registrations is higher, while in December this number is low. The exception is 2015-2016, when the opposite happened, probably as a consequence of anticipation for a change in the tax regime for company cars. Notwithstanding the general annual trend, from 2013 the annual sales have dropped compared to the years 2010-2012.

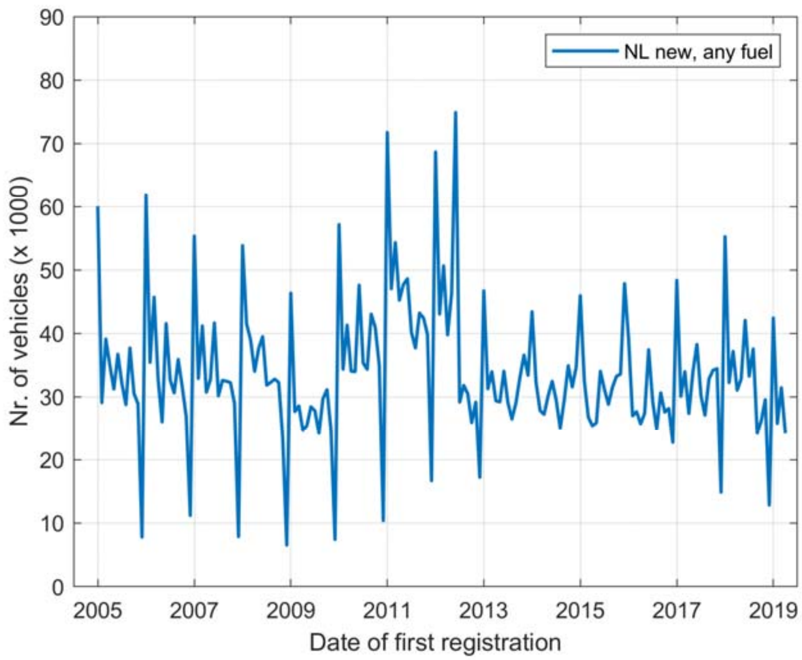

Figure 2-1: New passenger cars in the Netherlands, by registration month.

The average official CO_2 emission values of new cars show a downward trend, resulting from European targets. The current European target value amounts 95 g/km for the best 95% of the vehicles across all new registrations in Europe over the year 2020. In 2021 the new vehicle average should be below 95 g/km. The downward trend in the Netherlands is depicted in Figure 2-2. It can be seen that the new sales average (blue line, ‘any fuel’) is moving away from the course towards the 95 g/km target since 2016.

[7] Aspects of the transition from NEDC to WLTP for CO2 values of passenger cars – Phase 3: After the transition, TNO 2019 R10952, 2 July 2019.

This coincides with the increased austerity of fiscal incentivisation of conventional cars with a low CO_2 value, more particular with ending the company car tax liability discount for fuel-efficient cars without a plug (14% level). As a consequence the Dutch fleet is likely to follow more closely the average European fleet trends after 2015. Indeed the European average type approval values show a trend similar to the one shown in the graph. The drop in market share of diesel is one of the underlying factors.

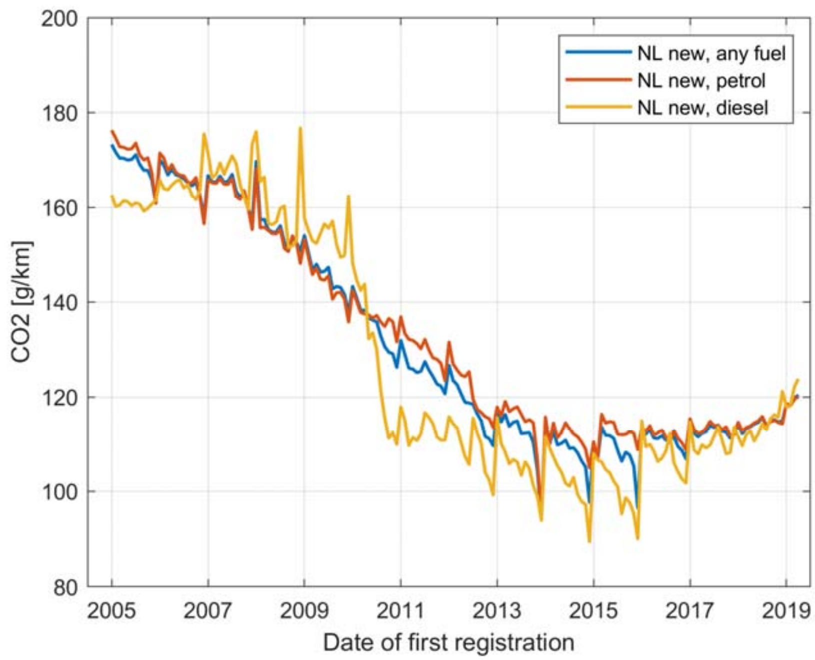

Figure 2-2: Monthly average NEDC CO_2 value for newly registered passenger cars. Based on the vehicle's first date of registration. From 2017 onwards, values are increasingly NEDC2.0 values, calculated from the WLTP type approval test result.

The transition from NEDC to WLTP, as described in paragraph 1.3, is shown for new registrations in the Netherlands in Figure 2-3. The transition mainly took place in the second half of 2018. Interestingly, even in March 2019 a significant percentage of the vehicles put on the road was still approved under NEDC regulations (end-of-series stock).

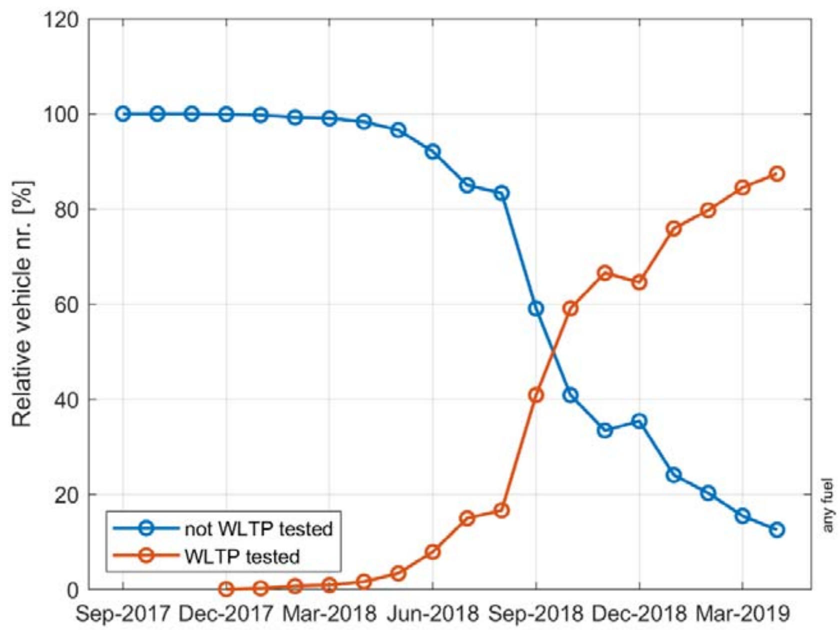

Figure 2-3: Transition from NEDC to WLTP type approved vehicles, expressed as a percentage of all registered new passenger cars.

The NEDC-WLTP transition was studied in detail, and described in the following reports:

- Report series “Aspects of the transition from NEDC to WLTP for CO_2 values of passenger cars”
  - Phase 1: problem definition; TNO 2018 R10732;
  - Phase 2: preliminary findings; TNO 2018 R11145;
  - Phase 3: after the transition; TNO 2019 R10952.

One of the focal points while studying the transition was to isolate the effect of the change of NEDC to WLTP from other trends, such as fleet composition, weight, engine power and transmission type of the vehicles, giving rise to trends as shown in Figure 2-2, which occur in the meantime and in particular at vehicle updates.

The average WLTP to real-world CO_2 emission gap for the Travelcard fleet is analysed in chapter 7.

3 Real-world fuel consumption of passenger cars on conventional fuels

The real-world fuel consumption and associated CO_2 emission was calculated for each of the vehicles in the Travelcard tank pass database. In this chapter the database is used to show trends in the fuel consumption/CO_2 emission. In the first part, data is grouped by fuelling year, meaning that the results are averages over the entire fleet of vehicles present in the database for that year. A second part shows trends that can be observed when vehicles are grouped by registration year of the vehicle.

The trend of the average real-world CO_2 emission per kilometre between 2004 and 2020 is shown in Figure 3-1.

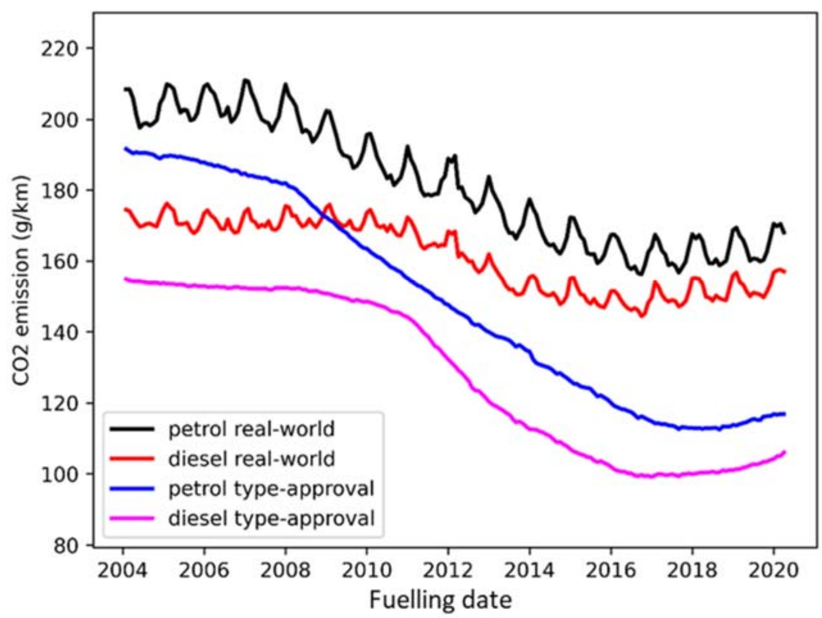

Figure 3-1: Average real-world and type approval tailpipe CO_2 emission of all conventional and non-plug-in hybrid petrol and diesel vehicles in the database. Both the real-world and the type-approval CO_2 emissions have decreased since 2004. The different rates of reduction result in an increasing gap up to 2018.

From 2018 onwards, the average type approval values of the vehicles in the Travelcard tank pass database increase again after a consistent decline.
This coincides with a similar trend in the whole Dutch new vehicle fleet described in chapter 2, and is most likely related to a combination of the cut in stimulation measures for low-CO_2 petrol and diesel cars, the waning popularity of diesel as a passenger car fuel and increased weight and/or engine power. The real-world emissions have increased at the same time, but to a lesser extent. Possibly the calculated NEDC 2.0 values (since December 2017) are inflated due to WLTP declared values.

The real-world lines show a clear seasonal effect. In the summer, the CO_2 emissions are several percent lower than in the winter.

The real-world CO_2 emissions of plug-in hybrids can be found in Figure 3-2. Also for plug-ins the gap is found to increase over time. The seasonal effects appear a bit more profound compared to conventional or hybrid vehicles without a plug.

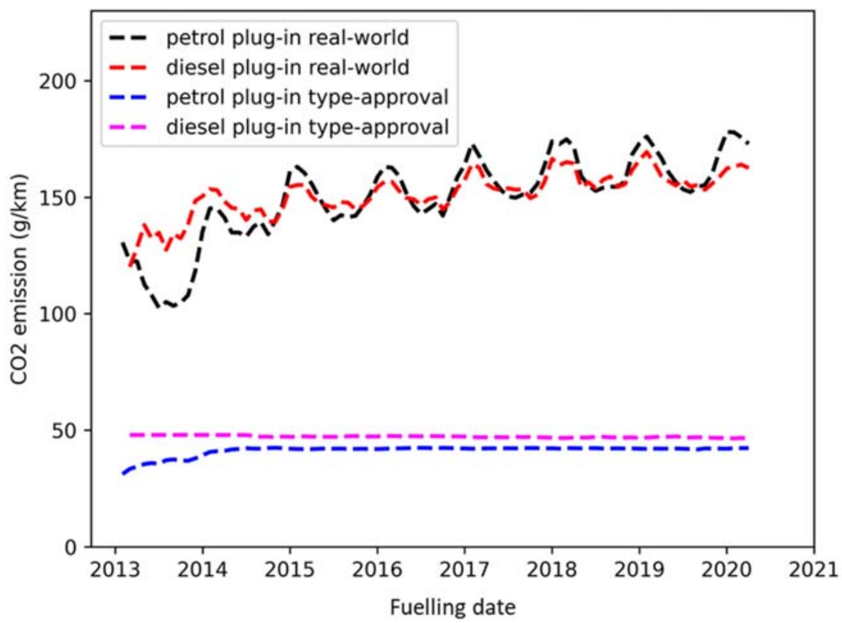

Figure 3-2: Average real-world and type approval tailpipe CO_2 emission of all plug-in hybrid vehicles on petrol and diesel in the database. The real-world CO_2 emissions have increased since 2013, while the type-approval CO_2 emissions remained relatively constant. The increasing real-world emissions lead to an increasing gap.

The trend in the average gap between real-world and type-approval CO_2 emissions is shown in Figure 3-3. As mentioned, the decrease in gap over the last years may be related to inflated NEDC 2.0 values as a result of WLTP declared values.

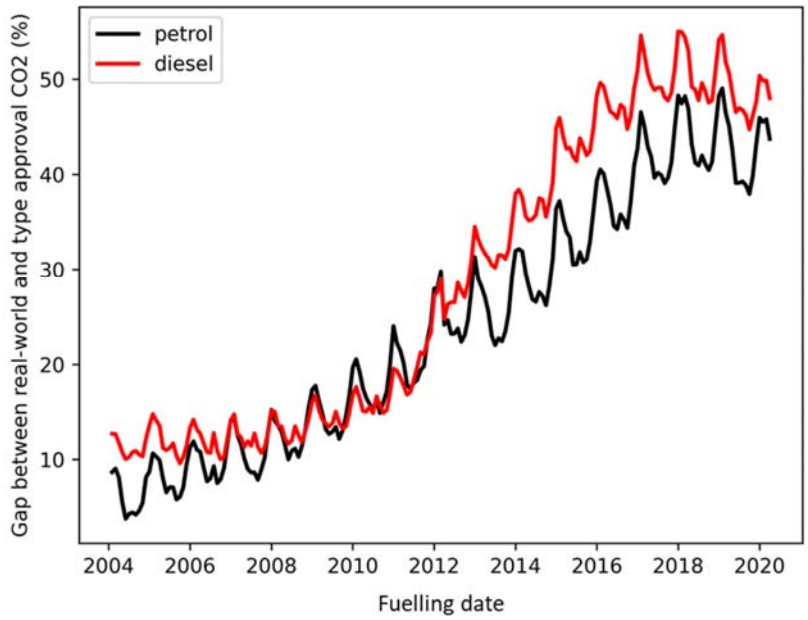

Figure 3-3: The evolution of the relative difference between the fleet average real-world fuel consumption and the average type-approval value, based on monthly averages of the fuelling data: the total amount of fuel and the total distance. This data is based on all vehicles in the Travelcard tank pass fleet. Plug-in hybrids are not included.

Figure 3-4 shows the same graph including plug-in hybrid vehicles. Despite type approval CO_2 values of below 50 g/km, the real-world CO_2 emissions are in the range of those of non-plug-ins, translating into a large relative gap. Interestingly the gap for diesel plug-ins is slightly smaller than for petrol plug-ins. This might be related to the relative efficiency of diesel engines on the highway.

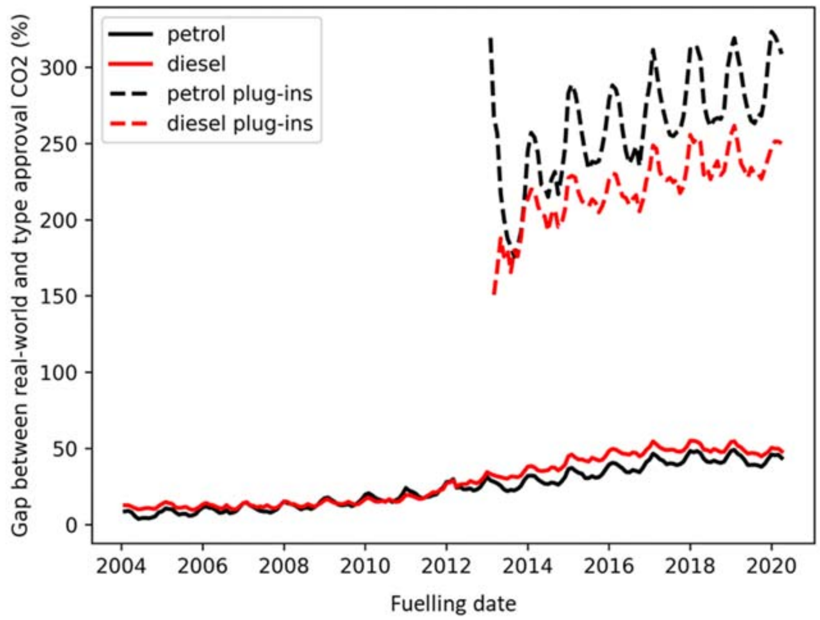

Figure 3-4: The evolution of the relative difference between the fleet average real-world fuel consumption and the average type-approval value, based on monthly averages of the fuelling data: the total amount of fuel and the total distance. This data is based on the vehicles in the Travelcard tank pass fleet with NEDC type approval.

WLTP-based CO_2 values are available only for new vehicles since 2017/2018. An analysis of the gap between WLTP-based and real-world CO_2 values is made in chapter 7.

The developments on the level of the complete fleet as described above are closely related to developments in new vehicles. To analyse these developments, the fuel consumption data was regrouped by the registration year of the vehicles. For each vehicle the fuel consumption was averaged over the entire duration it was part of the Travelcard fleet, and the value was attributed to its year of first registration. Vehicles that are presently no longer in the fleet were included as well.

New passenger cars in the year 2019 had an average real-world CO_2 emission of 163 g CO_2/km (petrol, including (plug-in) hybrids) and 158 g CO_2/km (diesel, including (plug-in) hybrids). The type approval values according to NEDC were 44 g/km lower for both fuels, which translates to a relative real-world - type approval gap of 37% for petrol and 38% for diesel.

In Figure 3-5 the evolution of the gap between real-world and type approval CO_2 emissions is shown across the registration years. Per year of registration, the average CO_2 emission values of all vehicles were averaged. In other words, every vehicle has equal weight. This approach differs from the one in the previous report in this series, where results were weighted by vehicle usage.

In the previous report the reduction of the gap after 2015 was already observed for both petrol and diesel passenger cars. Figure 3-5 shows that the reduction continues between 2017 and 2019 as well, from 49 to 44 g/km for petrol (black line) and from 50 to 44 g/km for diesel.

The graph shows also that in general the downward trend of real-world CO_2 as well as type approval values has turned in 2015. For four years now the average CO_2 emissions gradually increase. As stated in the previous report, the reasons can probably be found in the cutback on fiscal advantages for plug-in hybrids, anticipation on (tuning for) WLTP based targets after 2021, and a trend towards heavier and larger cars.

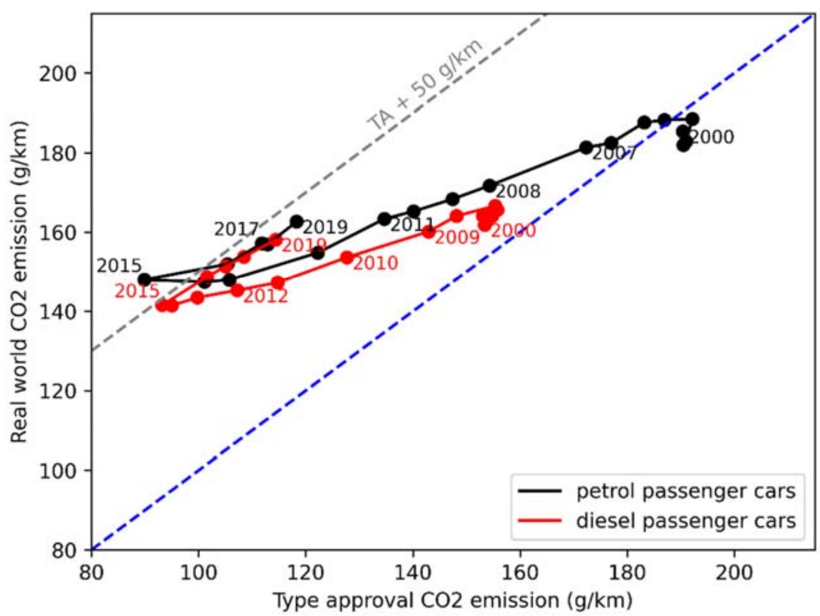

Figure 3-5: Average real-world CO_2 emissions versus the average type approval values of new petrol and diesel cars, including plug-in hybrids, differentiated by the year of registration.

Zooming in on the period 2013-2015, the strong increase of the real-world vs. type approval gap for petrol vehicles can be attributed to the introduction of a large amount of petrol plug-in hybrids in the fleet. Figure 3-6 shows the same results excluding plug-ins. Comparing the two graphs it is seen that the plug-in effect is very small after 2015. This is likely going to change in 2020, as manufacturers are increasing their efforts to sell plug-in hybrids in order to meet the 95 g/km-target by 2021.

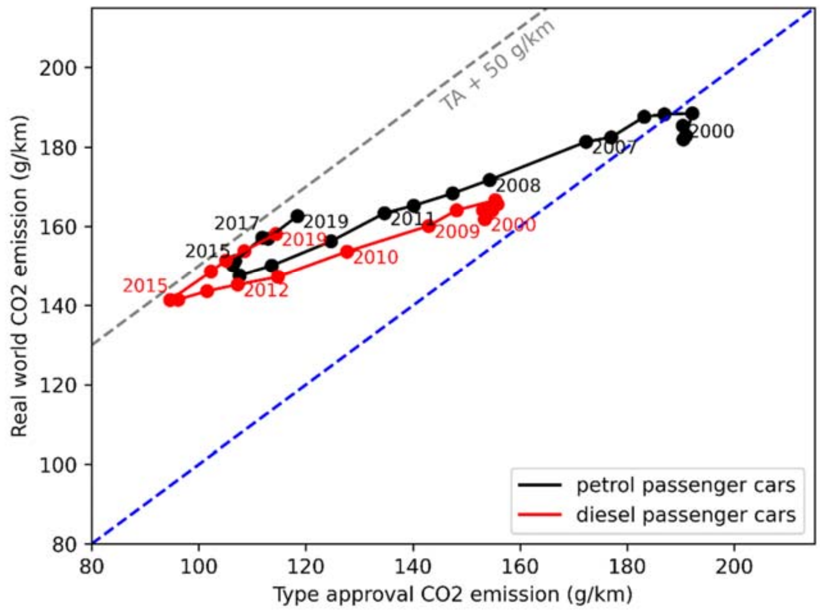

Figure 3-6: Average real-world CO_2 emissions versus the average type approval value of new petrol and diesel cars, excluding plug-in hybrids, differentiated by the year of registration (world).

4 Electricity consumption of full electric passenger cars

4.1 Introduction

As described in paragraph 1.3, charging sessions data was combined with odometer readings for each full electric car in the Travelcard fleet. In total 3,467 series of charging events of 3,134 unique vehicles were available for deriving the electricity consumption per vehicle model. Charging data were available up to 31 December 2019 and are paid kilowatt hours (kWh). This means that charging losses are included in the data. These may vary from model to model and from charger to charger. The 3,467 series were further filtered for outliers (see paragraph 1.3), after which 2,411 series of charging events were considered valid and used for further analysis.

4.2 Average electricity consumption per model

Table 4-1 shows for each model the number of observations (series of charging events), the average electricity consumption and the standard deviation. Vehicle models having less than 10 observations were not further analysed.

Table 4-1: Average electricity consumption per brand and type.

Brand	**Type**	**Series of charging events**	**Average [kWh/100 km]**	**Standard deviation**
Audi	E-Tron	34	29.0	3.9
Azure Dynamics	Transit Connect Electric	≤10		
Bmw	I3	165	19.7	5.2
Bmw	I3S	31	18.0	5.0
Citroen	C-Zero	≤10		
Fiat	500E	≤10		
Ford	Focus Electric	≤10		
Hyundai	Ioniq	248	20.0	6.2
Hyundai	Kona	132	17.5	3.7
Jaguar	I-Pace	89	26.4	6.4
Kia	Niro	64	16.2	3.8
Kia	Soul	10	22.8	5.5
Maxus	Maxus V80	≤10		
Mercedes-Benz	B 250 E	41	17.5	9.2
Mercedes-Benz	EQC 400 4Matic	≤10		
Mercedes-Benz	Evito	≤10		
Nissan	Nissan E-NV200	21	23.2	5.7
Nissan	Nissan Leaf	85	20.5	7.3
Nissan	Nissan Leaf 40kWh	130	18.6	4.5
Nissan	Nissan Leaf 62kWh	≤10		
Opel	Ampera-E	61	18.6	4.9

Brand	Type	Series of charging events	Average [kWh/100 km]	Standard deviation
Peugeot	Ion	≤10		
Peugeot	Partner	≤10		
Renault	Kangoo Express Z.E	13	24.2	8.3
Renault	Zoe	188	22.4	5.4
Smart	Fortwo ED	≤10		
Smart	EQ Forfour	≤10		
Smart	EQ Fortwo Coupe	≤10		
Smart	Forfour ED	≤10		
Tesla	Model 3	196	19.5	4.7
Tesla	Model S	303	22.1	5.3
Tesla	Model X	39	22.2	6.9
Volkswagen	Golf	412	17.8	4.2
Volkswagen	Up	25	16.7	8.6

The standard deviations are often large, which means that the variation among vehicles of the same model is large. For electric vehicles the energy consumption per kilometre is relatively independent of speed for lower speeds but increases with the square of the speed above 100 km/h, due to higher air drag at higher velocities. Therefore, a large share of highway driving can seriously increase the average energy consumption. Furthermore, brake energy recovery helps reducing the urban energy consumption. However, losses do occur, and frequent and heavy braking on any road type can still increase the energy consumption. Also, the use of air-conditioning and heater influences the energy consumption, especially over short trips and at low speeds (more time per km). Another factor that may play a role is differences in efficiency between fast and slow charging.

Sorted by average consumption, the data looks as displayed in Figure 4-1.

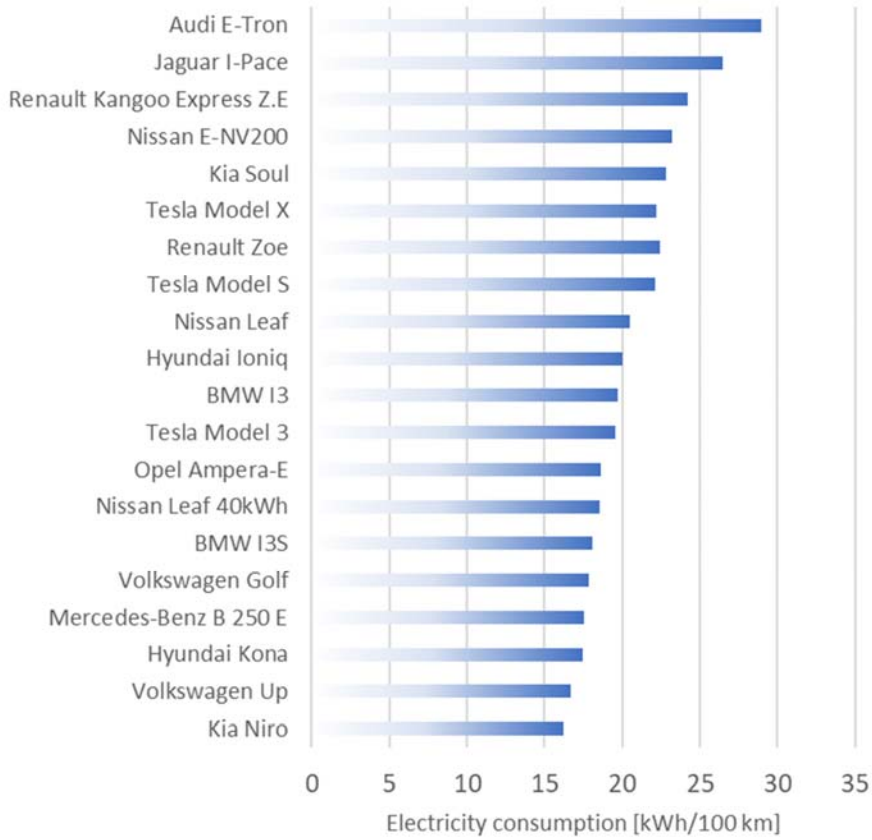

Figure 4-1: Average real-world electricity consumption per vehicle model.

Aerodynamic vehicles and vehicles used predominantly on shorter distances have an advantage. The large SUV-type EVs (Audi E-tron and Jaguar I-Pace) and vans (Renault Kangoo and Nissan E-NV200), with larger frontal area and usually less favourable drag coefficients compared to the average passenger car, fill the top of the list. This is likely related to air-drag on the motorway.

The average electricity consumption of the 19 passenger car models in the graph is 20.3 kWh/100 km (weighted across the models). If accounted for the number of vehicles of each model on the road, the average for the present Dutch fleet is 20.2 kWh/100 km. The 19 models constitute 93% of all models in the whole Dutch electric vehicle fleet.

Given the above derived average, an electric car that typically drives 15,000 km per year has an annual electricity consumption of 3000 kWh. This is roughly equal to the annual electricity consumption of an average Dutch household. Most company cars, however, drive even more kilometres per year.

The presented values are generally higher than the values declared by the manufacturer under the WLTP regime. For the models for which we could obtain a WLTP declared value (in Wh/km), a comparison is made in
Figure 4-2.

For the Tesla Model S and the Nissan Leaf no WLTP values are available, only NEDC values.

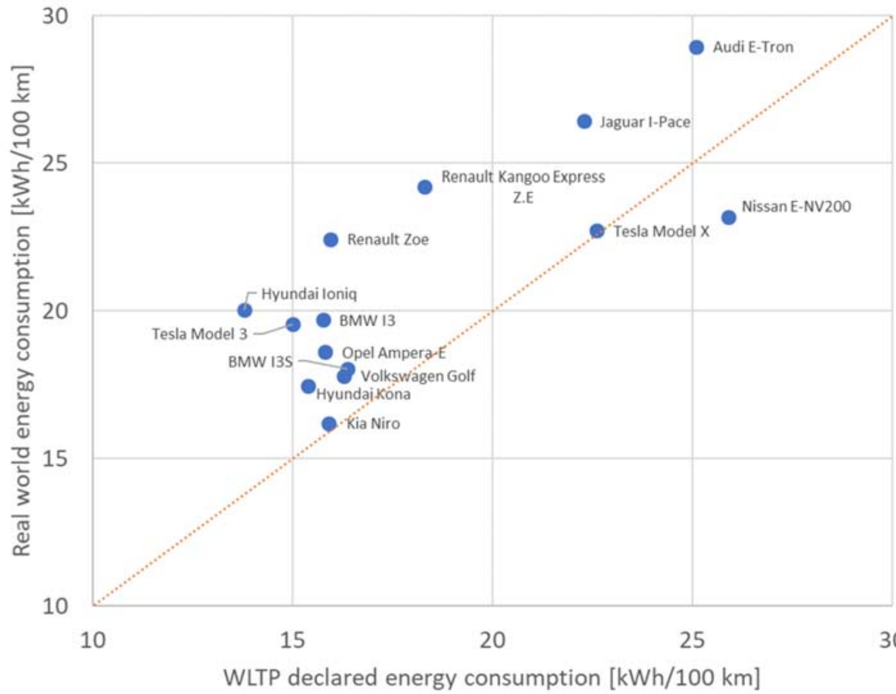

Figure 4-2: Comparison of real-world energy consumption and WLTP declared values for full electric vehicles.

On average, the real-world value equals 1.18 times the WLTP declared value. This result is in line with the deviation between WLTP and real-world energy use of conventional cars, but probably caused by different underlying issues. As the graph shows, the gap between real-world and type approval varies to a large extent from model to model. The Tesla Model X and Kia Niro stay closest to the declared value, while the real-world energy consumption of the Nissan E-NV200 is lower than the WLTP value. However the WLTP value for the Nissan E-NV200 seems relatively high for this type of vehicle (see, e.g., Renault Kangoo Z.E which is only slightly smaller).

Among the non-SUV passenger cars, the Renault Zoe and Hyundai Ioniq show the highest deviation in an upward direction. A comparison of these two models with other models in terms of e.g. aerodynamic properties or mass, does not yield plausible causes for this deviating behaviour.

Regenerative braking reduces the influence of one of the two main factors in a vehicle's energy consumption: weight. This could lead to a reduction in the spread in energy consumption between different models of electric cars compared to that of petrol or diesel fueled cars. Figure 4-3, however, shows no signs of electric vehicles with differing mass being closer together in terms of energy consumption than a similar group of diesel cars.

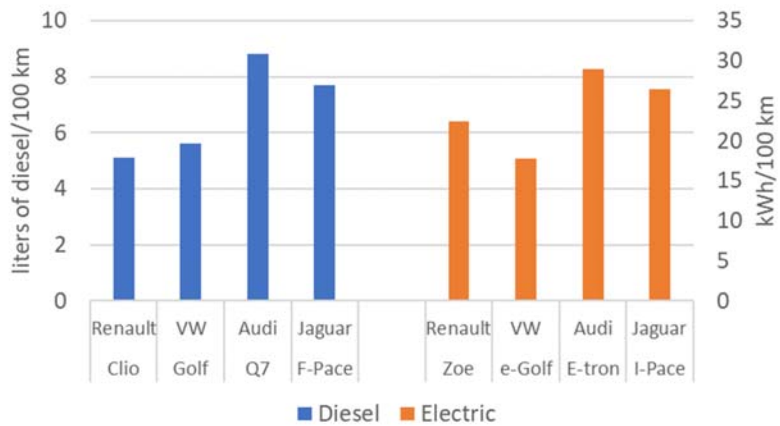

Figure 4-3: Energy consumption of a selection of models with different mass. The spread in average electricity consumption is not significantly smaller than the spread in average fuel consumption between similarly sized diesel-fuelled models of the same manufacturers.

For three vehicle models a more detailed analysis was made of the spread in energy consumption among vehicles of the same model. The first thing that is clear from Figure 4-4 is that the applied filtering, removing charging sequences with energy consumption values differing more than two times the standard deviation from the average (see paragraph 1.3), still allows some implausible values to remain in data. The graph also shows that there is a large spread in energy consumption for each of the models, and for the Hyundai in particular. For future research it would be interesting to link these variations to the actual use pattern, to the outside temperature and to charging speed. This, however, requires instrumentation of the monitored vehicles.

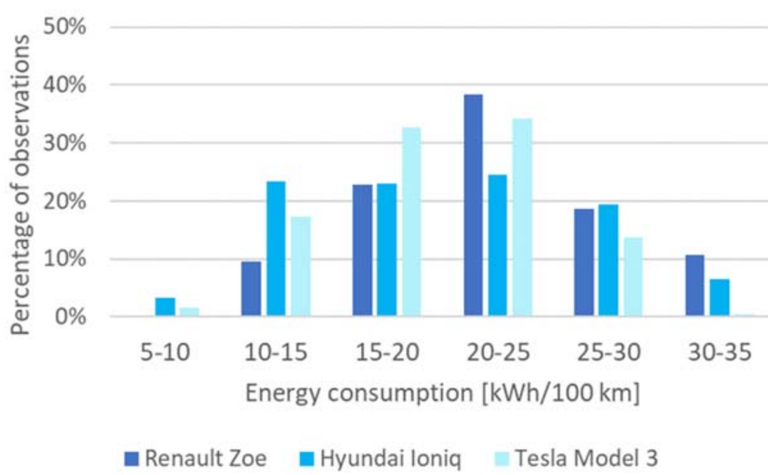

Figure 4-4: The spread in average electricity consumption per charging sequence for three electric vehicle models.

5 Real-world fuel consumption of plug-in hybrid passenger cars

Plug-in hybrids operate in different modes, which are normally chosen by the vehicle's software, although a preference can be selected by the user via a button. The different modes are explained in a slightly simplified way in Table 5-1.

Table 5-1: Modes of operation of plug-in hybrid vehicles (simplified).

Mode	Brief explanation	Battery	Description
EV mode	Full electric	Charge depleting	Vehicle is propelled by the electric motor only, and behaves like a full-electric vehicle. All consumed energy is derived from the battery.
Hybrid mode	Petrol/diesel, part of the time with support of electric motor	Charge depleting (blended)	The blended CD strategy gradually depletes the battery, ideally choosing the best combination of electricity and fuel to make optimal use of the engine when it is needed. The engine assists the electric motor when power demand exceeds the limits of the electric motor or when the control strategy deems the use of the engine more efficient.
		Charge sustaining	After reaching the end of its charge depleting range, a plug-in hybrid vehicle will switch to charge sustaining mode. The mode can also be selected by the user. In this mode the vehicle uses regenerative braking and power from the engine to keep the battery state of charge constant. The switch to charge sustaining operation is triggered by the battery reaching a specific state of charge (usually ~20%).This behaviour is similar to that of a hybrid vehicle without a plug.

All modes lead to a reduced tailpipe CO_2 emission compared to traditional combustion engine vehicles. The use of energy from the battery, which is charged from the grid, avoids the use of fuel, thereby avoiding tailpipe CO_2 emission. This happens in EV mode, but also in charge depleting hybrid mode. Furthermore, in all hybrid modes, the combustion engine can operate in a more efficient way than normal because of the interaction with the electric motor/generator. Lastly, brake energy is recovered in both EV and hybrid mode. However, from the fuelling data available, it appears that these mechanisms do not lead to markedly low fuel consumption and CO_2 emissions for most of the current plug-ins monitored.

From the fuel consumption of plug-in hybrid electric vehicles (PHEV) already much can be deduced. If the distribution is plotted of the fuel consumption across all fuelling events of a particular model (see Figure 5-1 and Figure 5-2), the shortest distance driven per litre is related to driving on the combustion engine.

Many PHEVs have a typical engine-only fuel consumption between 8 and 16 kilometres per litre (12 to 6 litres per 100 km). The exception is the Toyota Prius Plug-in Hybrid with 20 kilometres per litre.

On the other hand, the tail of the distribution, i.e., the large distances per litre, is related to substantial amounts of electric driving. The longer the tail, and the more skewed the distribution, the more electric driving can be assumed.

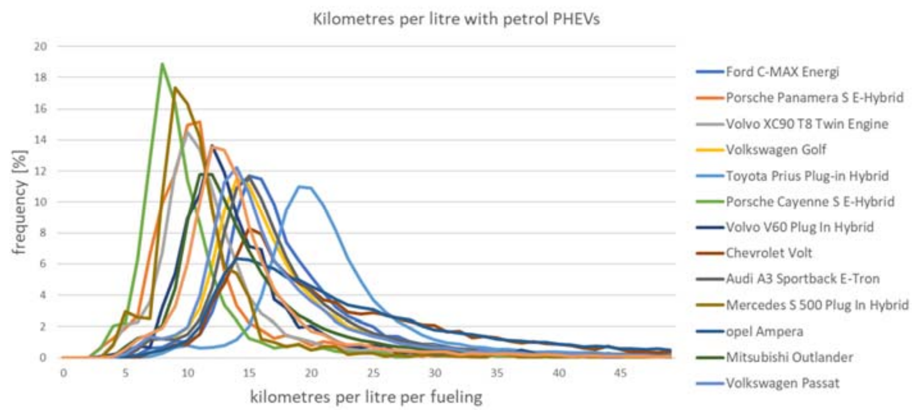

Figure 5-1: The frequency distribution of the distance driven per fuelling event expressed in kilometres per litre of all petrol PHEV models with data of more than 1000 fuelling events.

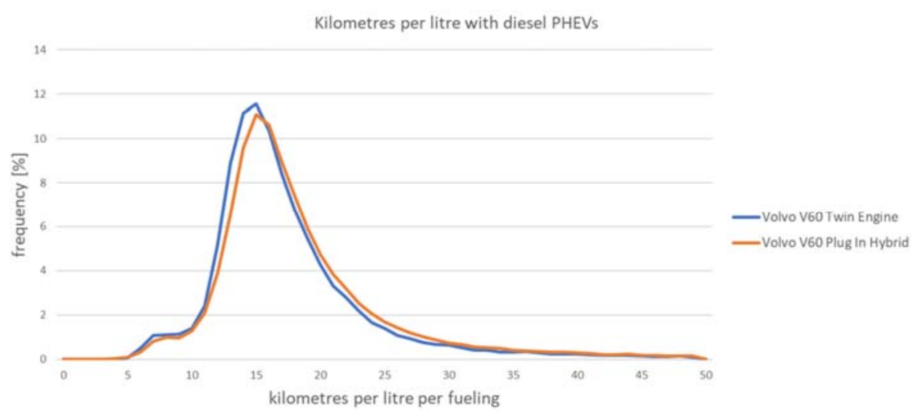

Figure 5-2: The frequency distribution of the distance driven per fuelling event expressed in kilometres per litre of the diesel PHEV models with data of more than 1000 fuelling events.

The position of the peak is a good indication of the fuel consumption on the combustion engine while the total average fuel consumption is derived from the combined data. From these two results the share of electric driving is deduced. For the different models the electric share ranges from 5% to 39% of the driven kilometres.

Table 5-2: The fuel consumption and share of distance driven electrically, deduced from the distribution of fuel consumption.

Make and model	km/liter combustion engine	km/liter average	Fraction electric distance
Petrol models			
Ford C-Max Energi	14.6	18.7	22.2%
Porsche Panamera S E-hybrid	11.5	12.0	4.7%
Volvo XC90 T8 Twin Engine	9.8	12.6	22.2%
Volkswagen Golf	13.7	17.6	22.5%
Toyota Prius Plug-in hybrid	18.5	22.1	16.1%
Porsche Cayenne S E-hybrid	7.8	10.6	26.2%
Chevrolet Volt	14.7	22.0	33.4%
Audi A3 Sportback E-tron	15.2	17.9	15.6%
Opel Ampera	13.6	22.3	39.2%
Mitsubishi Outlander	12.5	15.3	18.5%
Volkswagen Passat	14.1	17.3	18.1%
Mercedes C 350 E	11.6	15.0	22.9%
Diesel models			
Volvo V60 Twin Engine	15.2	17.7	13.8%
Volvo V60 Plug in hybrid	14.7	18.6	20.8%

6 Real-world fuel consumption of vans on conventional fuels

The average fuel consumption has been calculated for 53,920 light commercial diesel vehicles. Note that for the years 2014, 2015 and 2016 fuelling data is available for only a limited fleet of vans (~7700 vehicles). Therefore the fuelling year-oriented results for these years are less stable than the results for the more recent years, and may not have the same market coverage.
The annual mileage of the vehicles is distributed as shown in Figure 6-1.

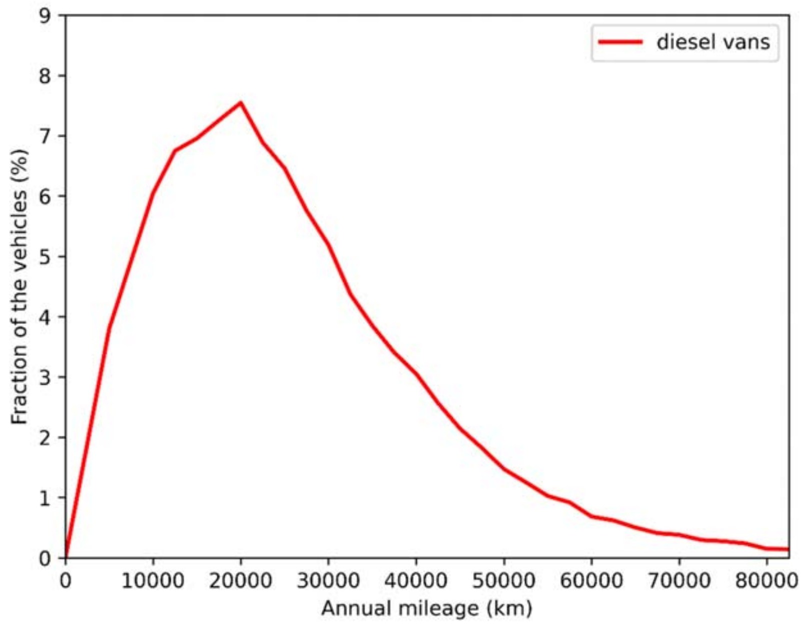

Figure 6-1: Distribution of the annual mileage of vans in the Travelcard database.

The most common, modal annual mileage is 20,000 km, the average 25,100 km.

For the first time, also fuel consumption data of vans was available, retroactively from the year 2011 and onwards. However, the sparse fuellings dated prior to 2014 were removed, so 2014 is the first year in the analysis,

From a regulatory perspective, vans are different from passenger cars. Meeting the first CO_2 emission target for light commercial vehicles (EU regulation EC/510/2011), of 175 grams per kilometre in 2017, required a relatively limited reduction compared to, e.g., the effort needed to meet the 2015-target for passenger cars.
The 175 g/km-target had already been met in 2014. The 2020-target of 147 g/km will be more challenging, given the current fleet.

As shown in Figure 6-2, the vans in the Travelcard fleet that tanked in 2014 have an average type-approval CO_2 emission of 175 g/km.

In the years after, the type approval values slightly decreased, moving towards the 2020 target. In the meantime the real-world CO_2 emissions increased.

Over the year 2019, the fleet average real-world CO_2 emission was 237 g/km, the average type-approval value was 167 g/km. This corresponds to 8.9 and 6.3 litres of diesel per 100 km respectively.

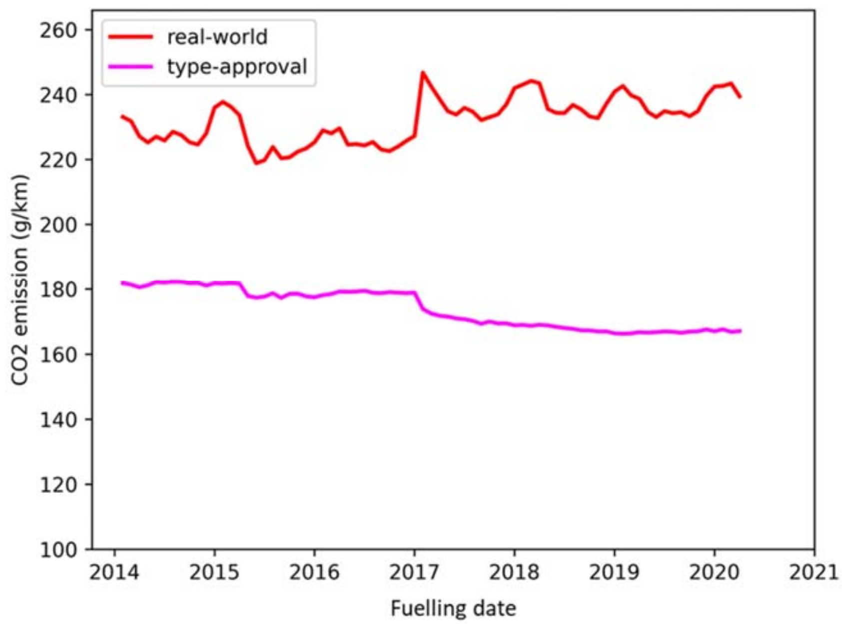

Figure 6-2: Average real-world and type approval tailpipe CO_2 emission of light commercial vehicles in the Travelcard fleet. The real-world emissions have gradually increased since 2014, the type approval values gradually decreased in the same time. The distinct drop in 2017 coincides with a step increase in the size of the monitored fleet.

Figure 6-2 and Figure 6-3 also show that the gap between type approval and real-world CO_2 emissions used to be smaller than for passenger cars, but is now (almost) similar to that of passenger cars after a clear trend breach at the beginning of the year 2017. This step change in January 2017 can be observed in both the type approval data and the real-world data. The reason for the change is that at that point in time the monitored fleet was enlarged by a factor of six. Furthermore, the vehicles added to the fleet were relatively new. The type approval values have decreased for newer vehicles. The increased real-world CO_2 emissions can be caused by a different usage of the new vehicles in the fleet. Also, the average vehicle mass over the build years shows a weak upward trend, which may have had a contribution to the change in real-world fuel consumption (see Figure 6-4).

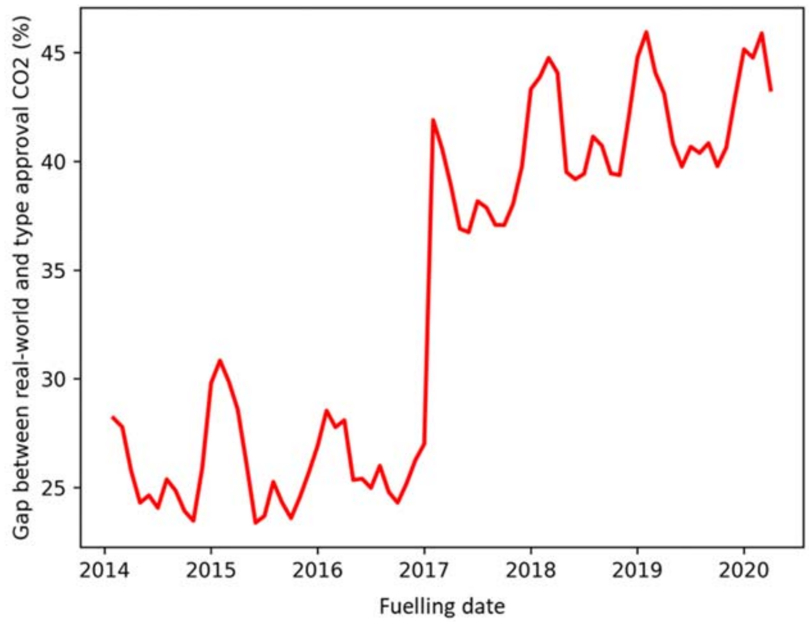

Figure 6-3: The evolution of the relative difference between the fleet average real-world fuel consumption and the average type-approval value for light commercial vehicles, based on monthly averages of the fuelling data: the total amount of fuel and the total distance. This data is based on the vehicles in the Travelcard tank pass fleet.

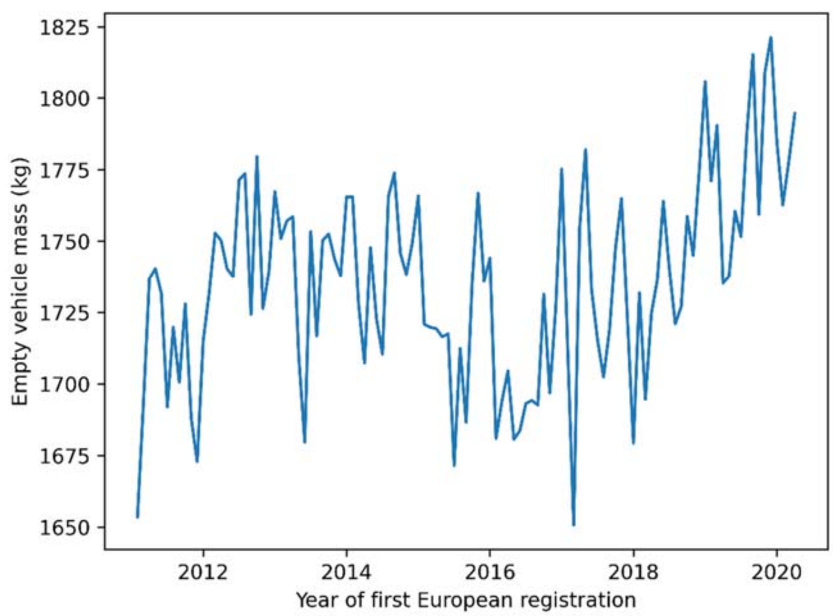

Figure 6-4: Evolution of empty vehicle mass of newly registered vans in the Travelcard fleet.

For further analysis, the fuel consumption data for vans is regrouped by the registration year of the vehicles. For each vehicle the fuel consumption was averaged over the entire duration it was part of the Travelcard fleet, and the value was attributed to its year of first registration.

New vans in the year 2019 had an average real-world CO_2 emission of 226 g/km, which is 42% higher than the corresponding average type approval CO_2 emission 159 g/km, For vans registered in 2011 real-world and type approval CO_2 emission values amounted 216 g/km and 173 g/km, respectively, a gap of 22%.

Figure 6-5 shows the evolution of the gap between real-world and type approval CO_2 emissions across the registration years. After years of increase, the gap for vans decreased again slightly after 2017.

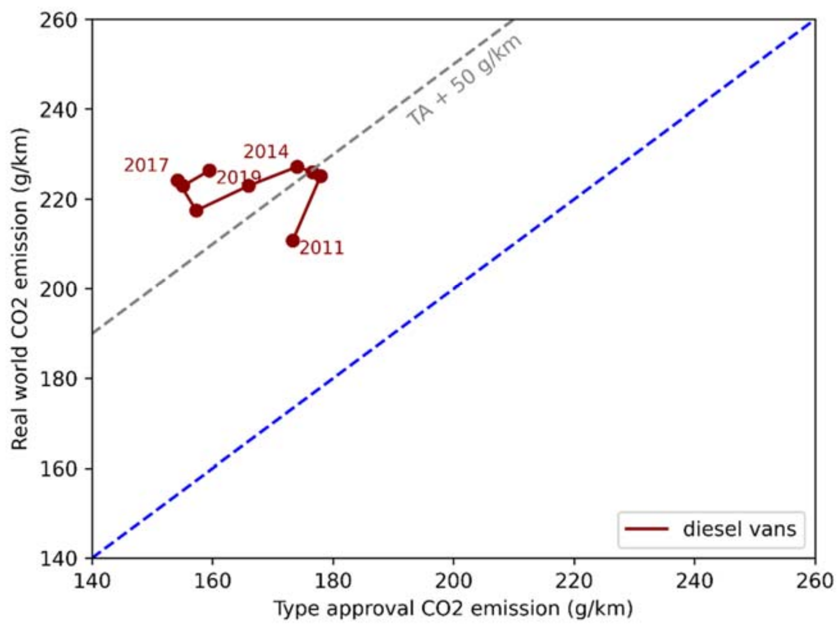

Figure 6-5: Average real-world CO_2 emissions versus the average type approval values of new diesel vans, differentiated by the year of registration.

7 Relation between WLTP type approval fuel consumption and real-world fuel consumption for passenger cars

Since September 2017 (new vehicle models) and September 2018 (all new cars) type approval fuel consumption and CO_2 emission values of new passenger cars have to be determined using the Worldwide Harmonised Light Vehicle Test Procedure (WLTP). One of the goals for developing the WLTP was to reduce the gap between the real-world fuel consumption and the type-approval declared value. Based on a comparison of test conditions an earlier study estimated the average difference between the NEDC and the WLTP declared values of the same car, to be in the order of a 15 g/km + 10% increase[8] This is an average over the effects for petrol (+14.5 g/km + 8%) and diesel (+15.6 g/km + 12%). From these formulas it can already be deduced that the WLTP values will, for now, be closer to the real-world fuel consumption, even if nothing else changes. The changes in declared values were extensively researched, as they have a significant effect on the Dutch vehicle tax (see, for example, TNO reports 2019 R11310, 2019 R10952, 2018 R11145, and 2018 R10732). These studies show a small increase in average weight and engine power with the transition from the NEDC to the WLTP, linked to the increase in type-approval CO_2 emissions.

The real question is whether the WLTP reduces the gap between real-world and type approval beyond the observed difference between NEDC and WLTP values on the same vehicle. If this is the case, this would mean that vehicles, type-approved under the WLTP, are better optimized for real-world fuel consumption and lower CO_2 emissions. Current data is insufficient in terms of model coverage and time span to draw a definite conclusion, but does provide promising first insights.

[8] I.e.: WLTP value [g/km] = NEDC value + 15 + 0.10 x NEDC value [g/km]

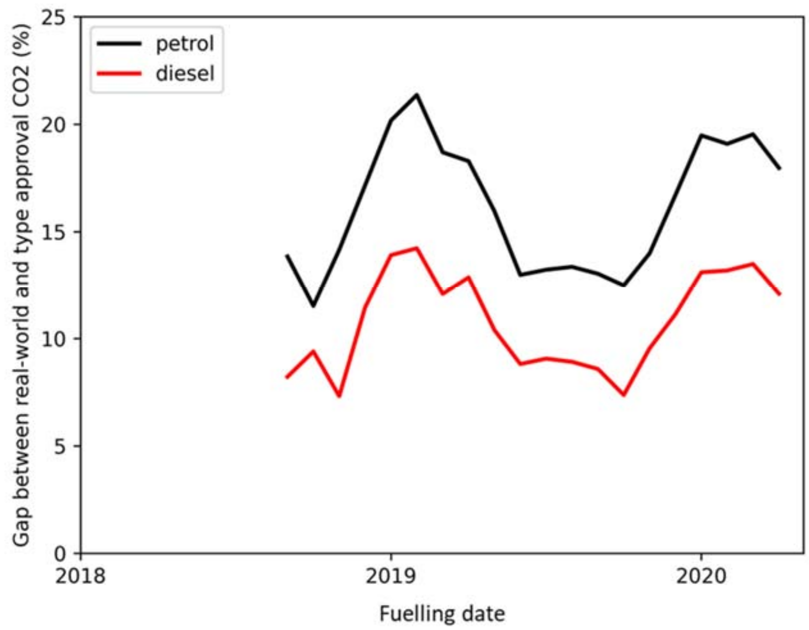

Figure 7-1: Gap between real-world CO_2 emission and WLTP CO_2 values for petrol and diesel passenger cars (graph starts when >100 vehicles in the Travelcard fleet were admitted under WLTP regulations)

On average, for petrol cars the real-world fuel consumption is 16% higher than the declared WLTP values. If this gap is combined with the abovementioned NEDC-to-WLTP conversion formula of 14.5 g/km + 8% for petrol cars, it would yield 14.5 g/km + 24% gap between the NEDC and the real-world value of WLTP vehicles. Subtracting the difference between NEDC and WLTP from the gap between real-world and NEDC, leaves the smaller gap. The size of this gap is roughly confirmed by the new fuel consumption data of WLTP approved vehicles. This is close to, but slightly lower than the gap observed for the latest NEDC petrol vehicles.

For diesel vehicles the real-world to WLTP gap is 10%, according to Figure 7-1. Combined with the 15.6 g/km + 12% gap between NEDC and WLTP for diesel cars, the total gap between NEDC and real-world is 15.6 g/km + 22%. Also this result suggests a reduction of the gap, and an improvement of real-world fuel consumption for WLTP vehicles.

These results are very preliminary, considering the limited amount of data, and the possible bias from WLTP-approved vehicle models that were early on the market. Moreover, the estimated effects are minor, in the order of 5% change in real-world fuel efficiency on a total of close to 50% gap, for the lowest CO_2 value vehicles around 100 g/km, between NEDC and the real-world fuel consumption.

8 Summary of SEMS monitoring of three plug-in hybrid vehicles in Flanders

For the Flemish government VUB, TNO and Emisia have monitored three plug-in hybrid vehicles in normal use. Results were used in an impact assessment in support of policy development. Here a summary of the findings is included to provide some more insight in the reasons for the low share of electric driving of plug-in hybrids reported in chapter 5. The full research is reported in Hooftman, N. et al., 2020, Emissiereductiepotentieel voor hybride voertuigen bestemd voor de weg (*Emission reduction potential for hybrid road vehicles*).

With the second-by-second data collected in the study, including charging data and location, detailed information on the vehicle use and underlying factors of electric driving could be determined. With the detailed data this information the share of electrically driven kilometres can be differentiated for different road types.

Using TNO's *Smart Emissions Measurement System* (SEMS), the use and emissions of three plug-in hybrid passenger cars in Flanders, Belgium, have been monitored. This test contained two vehicles with petrol engines, the Mitsubishi Outlander and the Volvo XC90 T8, and one diesel engine driven vehicle, the Volvo V60 Twin Engine, which were selected based on their popularity in Flanders. Fuel consumption has been monitored for all three vehicles, as well as electricity consumption for the two Volvos.

Plug-in hybrids operate in two different modes, as described in chapter 5: EV mode and hybrid mode. To determine the electricity consumption in EV mode, the battery state of charge (SoC) was monitored. The net depletion of the battery (and subsequent top-up) is an indication of the amount of electricity added by charging. Brake energy recovery and the subsequent use of this energy do not affect the amount of charged kilowatthours, and were therefore disregarded.

By coupling the SEMS GPS signal to road maps of *Open Street Map* (OSM, www.openstreetmap.org), the data has been divided into three categories based on the road type. A distinction has been made between city roads, rural roads and motorways. Measurements for which the GPS coordinates could not be matched with a road type in OSM have been omitted from the final sample. For each vehicle about 70% of the raw data has been included in the analysis, which corresponds with a total driven distance of about 3,200, 5,500 and 4,200 kilometres for the Volvo V60, Volvo XC90 and the Mitsubishi Outlander respectively, over a period of two months. More details of these tests are summarized in Table 8-1.

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Table 8-1: Overview of tests with three plug-in hybrids.

	Mitsubishi Outlander (petrol)	**Volvo V60 (diesel)**	**Volvo XC90 (petrol)**
Test duration (ignition switch on, SEMS on) [hours]	108.8	78.5	145.3
Duration vehicle in motion [hours]	97.3	69.9	116.0
Distance driven [km]	6,002	4,270	7,056
Time in hybrid mode [hours]	58.6	42.7	66.7
Distance in hybrid mode [km]	4,487	3,119	5,377
Time EV mode [hours]	38.7	27.2	44.9
Distance EV mode [km]	1,515	1,151	1,679
Average speed [km/hour]	55.2	54.4	48.6

Figure 8-1 shows the share of EV mode driving and hybrid mode driving for each road type separately. For all three vehicles half the urban distance is driven in EV mode, plus 30-50% of the rural distance and 10-20% of the highway distance.

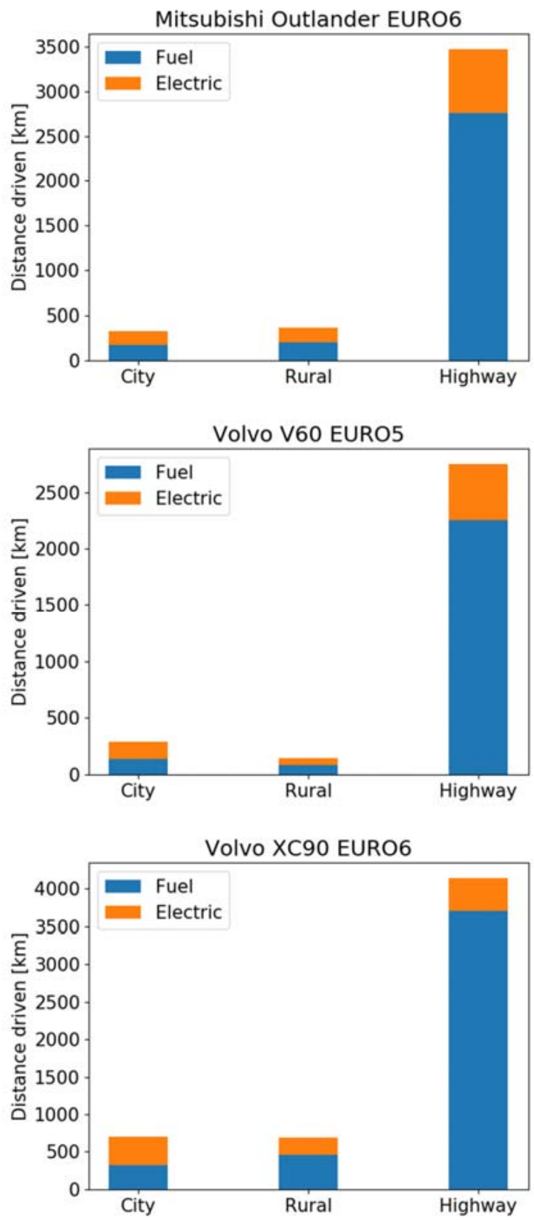

Figure 8-1: The distance in kilometres that each vehicle has driven in hybrid mode (blue) and EV mode (orange), per road type. For all three vehicles approximately half of the urban kilometres were driven in EV mode.

Weighted by the shares of the different road types in the travelled distances, the share of electric driving was 25%, 27% and 24% for the Outlander, V60 and XC90. These numbers are higher than the averages estimated for these models in the Travelcard database in chapter 5.

For each vehicle the average fuel consumption and average tailpipe CO_2 emission was calculated for driving in hybrid mode (combustion engine running).

For the two Volvos also the electricity consumption in kWh/km has been calculated from the battery state-of-charge data. The numbers are in-vehicle results excluding charging losses. A summary is presented in Table 8-2.

Despite the hybrid drivetrain, fuel consumption numbers in hybrid mode are in line with non-hybrids of the same vehicle class.

Table 8-2: CO_2 emission, fuel and electricity consumption. For the Mitsubishi Outlander the battery details could not be monitored.

	Mitsubishi Outlander (petrol)	**Volvo V60 (diesel)**	**Volvo XC90 (petrol)**
Tailpipe CO_2 emission, average including electric kilometres [g/km]	202	163	241
Tailpipe CO_2 emission in hybrid mode [g/km]	270	217	307
Fuel consumption in hybrid mode [g/km]	85	68	97
Fuel consumption in hybrid mode [ℓ/100 km]	11.4	8.2	13.0
Battery capacity [kWh]	12.0	11.2	11.6
Usable battery capacity [kWh] (estimated)	9.0	9.9	9.9
Energy consumption, average including fuelled kilometres [kWh/100 km]	Could not be determined	3.5	6.1
Energy consumption in EV mode [kWh/100 km]	Could not be determined	13.0	22.7

The battery charging behaviour of the two Volvos has been studied. An overview of the results is shown in Figure 8-2 and Figure 8-3. The line in the left panels of these figures shows the average State of Charge (SoC, charging percentage of battery) after the battery has been charged with at least 50% extra energy. After about 50 kilometres the SoC of both vehicles is back to 20%, after which the vehicles are powered by fuel only. The histograms in the leftside panels of Figure 8-2 and Figure 8-3 show when the battery is recharged, in terms of after how much driven distance. The Volvo XC90 was charged on average after about 100 kilometres, whereas the Volvo V60 was charged on average every 200 kilometres, with outliers between 400 and 500 kilometres. This means that in general the battery of the Volvo XC90 has been charged more often.

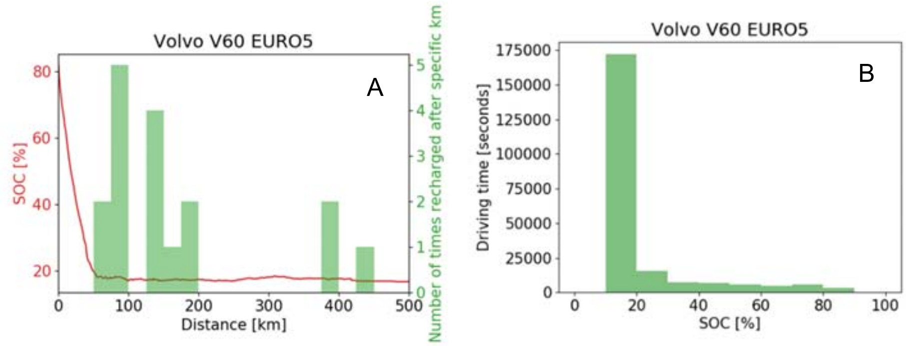

Figure 8-2: Charging behaviour for the Volvo V60. A) The average state of charge as a function of the distance driven after a recharge of at least 50% (red line). Green histogram: the frequency of battery charging after a specific driven distance. B) Histogram of state of charge. The peak at 20% shows driving in charge sustaining mode.

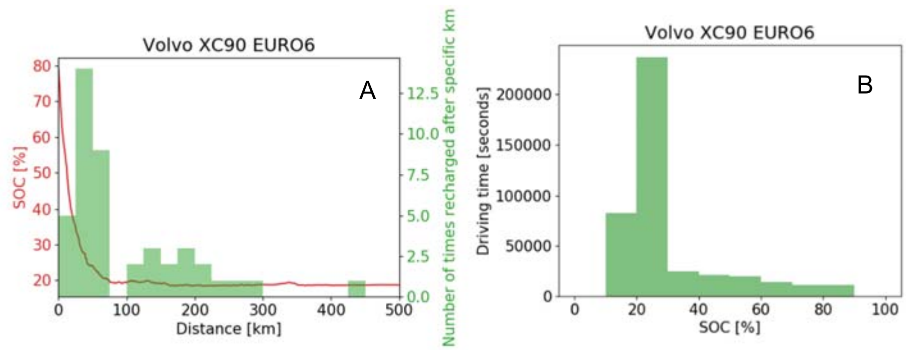

Figure 8-3: Charging behaviour for the Volvo XC90. A) The average state of charge as a function of the distance driven (red line). Green histogram: the frequency of battery charging after a specific driven distance. B) Histogram of state of charge. The peak at 20-30% shows driving in charge sustaining mode.

In conclusion, this study shows that the three tested plug-in hybrids drove about half of the distance in the city in EV mode and 10-20% of the distance on the motorway. The remaining distance is driven in hybrid mode. The average CO_2 emission ranged from 163 g/km (Volvo V60) to 241 g/km (Volvo XC90) and the fuel consumption between 8.2 l/100 km (Volvo V60) to 13.0 l/100 km (Volvo XC90). Compared with the average fuel consumption of these PHEV models in the Travelcard fleet (see Table 5-2, “km/liter combustion engine”) these results are about 20% higher.

The electricity consumption is around 13 and 23 kWh/100 km respectively for the Volvo V60 and the Volvo XC90. These values cannot be compared to full EVs, because the plug-ins, when driving in EV mode, mostly drove in the city (see Figure 8-1). However, despite the low average speed in EV mode (36 km/h when in motion), the electricity consumption of the XC90 is not much lower than that of similarly sized full EVs such as the Audi E-tron and the Jaguar I-Pace (see chapter 4).

9 Effect of transition to E10 petrol on real-world fuel consumption

The small effect that E10 is expected to have on the fuel consumption of vehicles (expressed in liters) is difficult to isolate from all other effects that affect the fuel consumption of vehicles. Large seasonal variations in the data, as visible in e.g. Figure 3-1, make it difficult to observe small systematic changes in the data. However, with the recent introduction of E10 petrol fuel, compulsory from October 2019, concern was raised on the effect on fuel efficiency, i.e., whether the lower energy content per liter for ethanol would lead to less distance driven on the same amount of fuel.

The following method has been developed for investigating the relative effect of changes in the composition of petrol in the presence of large seasonal variations.

It is based on the following assumptions:

- To isolate fuel composition changes, it is necessary to compensate for seasonal variation.
- The composition and energy content of diesel fuel did not change (significantly) around October 2019.
- Diesel can therefore serve as a reference point, however diesel has a different amplitude of seasonal variation.
- Seasonal variation of fuel consumption of both petrol and diesel powered vehicles is related to a combination of changes in fuel composition, traffic conditions and changes in ambient temperature. These are (close to) equal for all vehicles that tanked the same fuel at a given day. The factors causing the seasonal variations are also (close to) equal for vehicles running on petrol and diesel, albeit with a different impact on fuel consumption, resulting in different amplitides of the seasonal variations for petrol and diesel.
- The long term average ratio of the amplitudes of the seasonal variations for petrol and diesel vehicles can be derived from the complete set of data in the database.
- This ratio of the amplitudes of the seasonal variations for petrol and diesel vehicles can then be used to predict the seasonal variations in petrol vehicles on the basis of observed seasonal variation in diesel cars.
- The seasonal effect for petrol cars can be cancelled out by dividing the actually observed (seasonal) variation in the data for petrol vehicles by the predicted seasonal variation.
- Relatively small impacts of an increased share of ethanol in petrol on the real fuel consumption of petrol cars after October 2019 could become visible in the residual data.

For each individual vehicle, a long-term average fuel consumption was calculated. Next, for each tank filling event the deviation from this average was calculated, for each vehicle. Now going through these results, for each calendar week the average deviation could be calculated for petrol cars and for diesel cars, by averaging the deviation of all cars that tanked petrol that week, and of all cars that tanked diesel that week. These average deviation values were plotted as a time series in Figure 9-1.

Each dot represents a calendar week, with the average deviation of diesel cars tanked in that week on the y-axis and the average deviation of petrol cars tanked in that week on the x-axis.

From the cloud of dots, a trend can be observed. As expected, a large seasonal effect on petrol cars coincides with a large seasonal effect on diesel cars, generally speaking. Only diesel cars are less affected: the correlation coefficient is 0.59, which means that the effect on diesel cars is on average 59% of that on petrol cars.

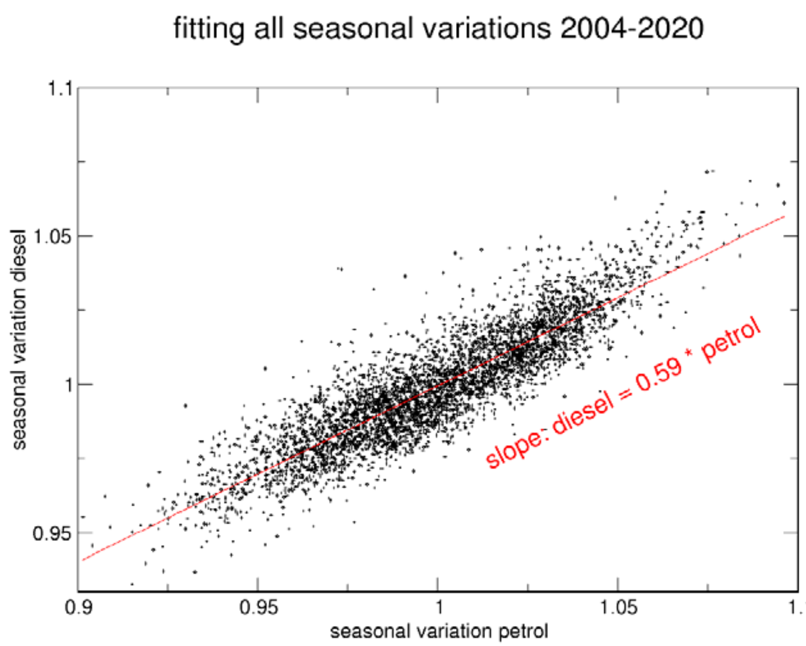

Figure 9-1: The variation of the relative deviation of actual fuel consumption averaged over the from the individual averages per vehicle, averaged over all petrol vehicle and all diesel vehicles, over time for petrol and diesel plotted, show a clear correlation between the seasonal variations of both fuels. The size of the variations is larger for petrol.

Using the generic correlation of seasonal effects for petrol and diesel, the variations in fuel consumption of petrol vehicles can be predicted from the seasonal variation for diesel vehicles. It can be expected that the sudden change in petrol composition, with possibly a sudden change in fuel economy, would lead to a clear deviation between the actual fuel consumption and the predicted fuel consumption. Figure 9-2 shows the ratio between the real deviation in fuel consumption for petrol cars and the predicted deviation in fuel consumption for petrol cars.

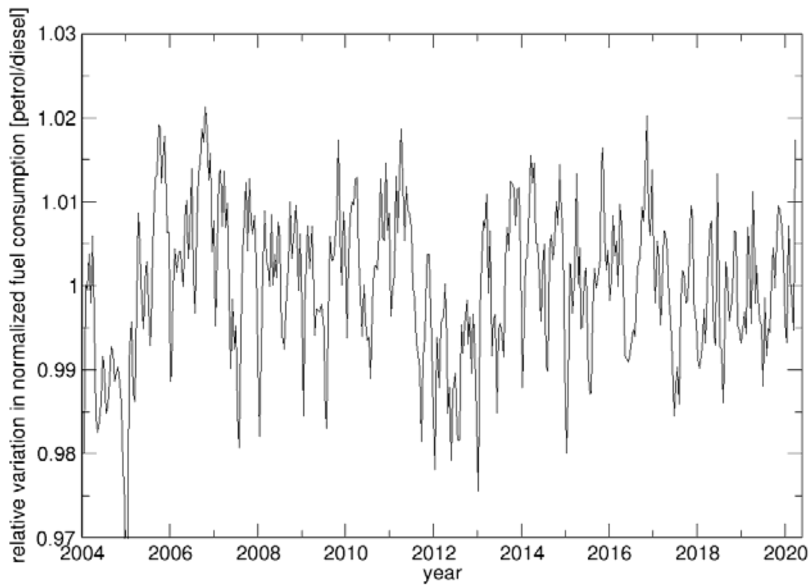

Figure 9-2: Residue of variation in petrol fuel consumption after correcting for seasonal variations estimated on the basis of a constant ratio with the seasonal variations in the diesel fuel consumption. Observed remaining variations are less than 2%.

Overall the remaining variations, which may be attributable to changes in fuel specifications, are estimated to be smaller than 1%. The introduction of E10 is not noticeable in the autumn of 2019, while the data continues till first quarter 2020.

It is possible, however, that the actual ethanol content did not change sharply around October 2019. In the Netherlands the ‘E10’ label indicates a maximum ethanol content of 10%, no minimum content is set. It is possible that the actual ethanol content gradually increases over a longer period of time, even after the first quarter of 2020. The actual average content can be calculated on an annual basis from the monitoring data from the Netherlands Emission Authority (NEA). Combining the most recent record, 354 million liters of admixed biopetrol in 2018, with the total petrol sales of 5,648 million liters in 2018 (CBS), results in an average ethanol content of 6.3 vol%. Information for 2019 is not available yet.

10 Aging effects

In the past, as input for discussions on run-in effects for Conformity of Production testing according to the WLTP, the change of fuel consumption at low mileage has been investigated (see Report TNO 2015 R11766). The effects are small: the reduction in fuel consumption over the first thousands of kilometres is in the order of 1 - 2%. On the other hand vehicle aging over longer periods may affect the fuel consumption as well. This was analysed on vehicles with 4 years or more of fuelling data in the Travelcard database. Typically vehicles enter the data set at a low mileage.

Figure 10-1 compares the average fuel consumption of a car, over the entire milieage for which data are available, with the fuel consumption of that car at a particular mileage. From this graph a small but clear trend can be observed.

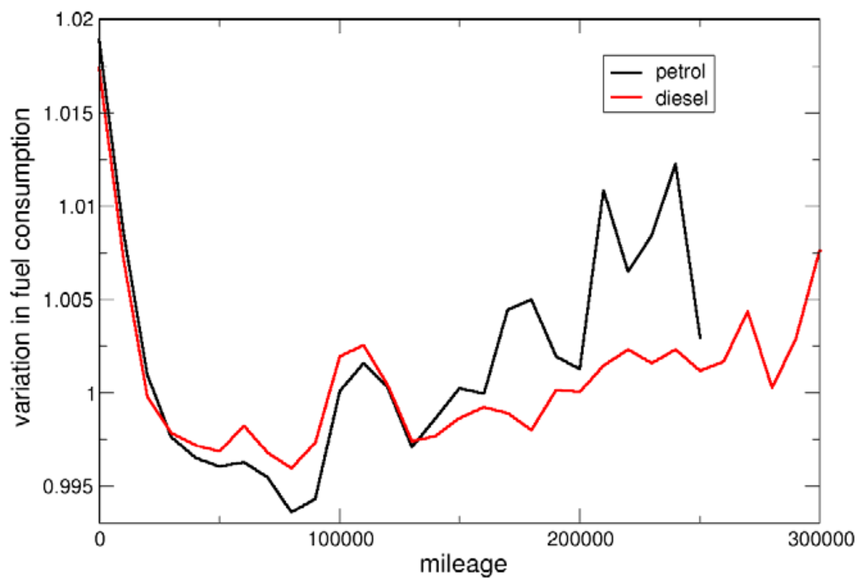

Figure 10-1: The variation in fuel consumption over the distance driven, relative to the average over the total mileage, shows a minimum at about 50,000 to 100,000 kilometres, with a small increase over distance to about 1% higher fuel consumption for petrol at the end of life around 250,000 km, and a 0.5% increase in fuel consumption for diesel vehicles at 300,000 kilometres.

The lowest fuel consumption occurs at 50,000 - 100,000 km. The effects of aging on fuel consumption are +1.0% at 250,000 km for petrol vehicles and +0.5% at 300,000 km for diesel vehicles.These effects are only minor, but given the limited spread in the data, one could conclude the effect is significant.

11 Conclusions

The real-world CO_2 emission and energy consumption of passenger cars and light commercial vehicles was studied from different angles. Data was obtained from Travelcard B.V., RDW and other studies performed by TNO (monitoring of PHEVs in Flanders, KEV, NEDC-WLTP transition analyses).

Petrol and diesel passenger cars
In the Dutch new vehicle registrations the average type approval CO_2 emission has increased again since 2016, after a downward trend over the ten years before that. The same upward trend can be observed in both the type approval and the real-world CO_2 emissions for the Travelcard fleet. The increase is most likely caused by a combination of company car tax regime changes, the waning popularity of diesel cars and increased vehicle mass and/or engine power. As a result of that the Dutch new vehicle average follows the same trend as the EU average The gap between real-world and type approval seems to have decreased slightly. For plug-in hybrids the gap is invariably large, suggesting the type-approval CO_2 values of these vehicles have little relation with the real-world CO_2 emissions.

Now that WLTP approved vehicles have entered the fleet for a few years, the gap between real-world and WLTP-based type approval values can be analysed as well. In general, for now, WLTP values are closer to the real-world CO_2 emissions than the old NEDC values were. Based on limited data since mid 2018 (23,000 vehicles), the gap is 16% for petrol passenger cars and 10% for diesel passenger cars. This may be in part related to the fact that the manufacturer's reference for the 2025 and 2030 reduction targets will be based on current average WLTP CO_2 values, providing an incentive to inflate the declared WLTP type approval values.

Electric passenger cars
For full electric vehicles in the database the charged kilowatthours were analysed by combining odometer data with charging data. Charging losses are included in the numbers. The average consumption varies among the vehicle models from 16 up to 29 kWh/100 km. Considering the EV fleet composition in the Netherlands, the average electricity consumption is 20.2 kWh/100 km. The gap with the WLTP declared value is 18% on average, the real-world number being higher.

The variation in energy consumption from model to model is not notably larger or smaller for EVs than for similar combustion engine vehicles. Note that for each model individually the energy consumption varies considerably from vehicle to vehicle. This is most likely related to differences in the share of highway driving and the use of heating/cooling on short trips. Further research needs to be done to link these variations to the actual use pattern, as well as outside temperature and charging speed.

Plug-in hybrid passenger cars
Also investigated was the real-world fuel consumption of plug-in hybrids. From the histogram of mileage per liter for each fuelling event, the ‘empty battery’ fuel consumption was derived for each plug-in car model. From this information the share of electrically driven kilometres could be estimated. This value varies among the models in the database from 5% to almost 40%.

In Belgium TNO monitored three plug-ins in normal use during two months in 2019, for a total distance of 13,000 km. The share of electric driving was around 25% for each of the three vehicles, varying from 50% in the city to 10-20% on the highway.

Light commercial vehicles
The fuelling data for 54,000 diesel vans was used to analyse the real-world fuel consumption and CO_2 emission of light commercial vehicles. Since 2014, the average real-world CO_2 emissions of this vehicle category have increased slowly, while the type approval CO_2 values (NEDC) decreased at the same time. A step change in both type approval and real-world values in January 2017 is caused by an expansion of the monitored fleet by a large amount of relatively new vehicles. In 2019-2020 the relative gap for vans is similar to that of passenger cars. The absolute gap however is much bigger than for passenger cars, in the order of 70 g/km, or 2.5 liters per 100 km.

E10 fuel
After correcting for seasonal effects, based on the long term average ratio of seasonal variations in the fuel consumption of petrol and diesel vehicles, the remaining variations in the average fuel consumption of petrol cars indicate that the possible effect of the change from E5 to E10 for petrol in the autumn of 2019 on the fuel consumption of petrol cars is smaller than 1%.

Aging
Analysing data for high mileage passenger cars in the Travelcard fleet, a small run-in effect was found: approximately 1-2% at very low odometer readings. The minimum fuel consumption seems to be at odometer readings of 50,000-100,000 km. After that, a fuel consumption increase is observed to around 1% at 250,000 km for petrol vehicles and 0.5% at 300,000 km for diesel vehicles.

12 Signature

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