Real-world fuel consumption and electricity consumption of passenger cars and light commercial vehicles - 2023

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Summary

Since 2009, with the Dutch policy on CO_2 emissions of passenger cars, the effects are evaluated on the basis of real-world fuel consumption. This report is one in a series that analyses real-world fuelling data. This effect on the climate of vehicles with internal combustion engines will last until after 2040, since many newly registered vehicles are with a combustion engine, and they will last twenty years. With this report, for the first time, the fleet prognoses of PBL are translated into average CO_2 emission factors for different road types and years. There has been a demand for more detailed information about the climate impact of mobility, that can be used with the changes in mobility demand and vehicle usage. These numbers are more realistic that the type-approval CO_2 values. Only half of the change in type-approval CO_2 values are observed in real world.

The change to the new test procedure, the WLTP, from the old NEDC, from 2019 to 2021, has decreased the absolute gap between type-approval and real world CO_2 from 50% to about 15%. At the same time, the WLTP CO_2 value is less a predictor for individual vehicles of the real world CO_2 value, than the old NEDC value was. Vehicles with a lower WLTP value do not automatically have lower real world fuel consumption. Therefore, in order to scale the findings of this study to the national level, the type-approval CO_2 is no longer used as intermediate. Instead physical parameters, like vehicle weight, are better predictors of real world CO_2. Only for PHEVs the correlation remains and a growing gap is observed, up to 300%, likely because of the already large gap between type-approval and real-world CO_2 of PHEVs, due to the limited fraction of electric driving. In all cases the dependence on vehicle weight explains the observed trends ansd differences.

Since 2016 there is no discernible decrease in real-worl CO_2 emissions. The increased engine efficiency is completely negated by the increasing weight. Likewise, reductions in WLTP CO_2 emissions do not materialize because of the increase in vehicle weight. Hence, vehicle weight is an essential part to understand observed trends.

With the increase in the number of electric vehicles, the electric net capacity and congestion, the energy use of electric vehicles is of increasing concern. Many factors play a role in the real-world energy consumption, of which the type-approval energy consumption is just one and not dominant. Vehicle size and weight, but also differences between vehicle manufacturers all play a role in the real-world energy consumption, which is substantially higher that the type-approval value.

By following a distinct group of vehicles over time, the effects of changing circumstances can be observed.

The effects of the introduction of E10 or the lowering of the speed limits on the motorway can be quantified in this way. In the period around 2020 there has been a reduction of CO_2 emissions in a fixed group of vehicles, likely relaed to the lowering of the speed limit.

Since 2019 the gap between the type-approval and real world fuel consumption, as is the topic of this study, also has the attention of the European Commission. Modern vehicles need to have fuel monitoring system, OBFCM, to quantify and follow the gap. The preliminary results of these vehicles are well in line with this, and previous, studies of TNO.

Samenvatting

Sinds 2009, met het “schoon en zuinig” beleid wordt in Nederland de effectiviteit van CO_2 beleidsmaatregelen voor personenauto’s beoordeeld op basis van praktijkcijfers van brandstofverbruik. Dit rapport past in die lange reeks onderliggende studies naar het brandstofverbruik in Nederland in normaal gebruik. Met de levensduur van auto’s van twintig jaar, en de meerderheid van nieuw geregistreerde personenauto’s nog met een verbrandingsmotor, zal de klimaatimpact van benzine- en dieselauto’s tot voorbij 2040 nog groot zijn, ondanks het snelgroeiende aandeel elektrische voertuigen. Deze studie onderbouwt de impact met behulp van CO_2 uitstoot per gereden kilometer, die gekoppeld kan worden aan de mobiliteitsvraag. Met een groeiende vraag naar de cijfers voor de beoordeling van klimaatbeleid, worden vanaf 2024 ook de gemiddelde CO_2 emissiefactoren van wegverkeer, op de verschillende wegen, voor toekomstige jaren gepubliceerd en met deze studie beschikbaar gemaakt. Deze getallen vertalen de wagenparkprognoses van PBL in de Klimaat- en Energieverkenning naar de situaties op de weg in toekomstige jaren. Beleidsmatig sturen op lagere CO_2 fabrieksopgave heeft een beperkt effect in de praktijk. Ongeveer de helft van de reductie van opgegeven CO_2 emissies wordt in de praktijk ook gehaald.

De overgang van de oude testmethode voor het bepalen van de officiële CO_2 cijfers per voertuig: de NEDC, naar de nieuwe testmethode: de WLTP, van 2019 tot 2021, heeft het groeiende verschil tussen de normwaarden en de praktijkwaarden weer verkleind van 50% naar 15%. Daarentegen is de correlatie tussen de individuele WLTP CO_2 waarde en het praktijkverbruik zwakker geworden. De rangschikking van WLTP waarden is minder een maat voor het daadwerkelijk zuiniger zijn van het voertuig. Daarom is voor de bepaling van de praktijkuitstoot van het Nederlandse wagenpark, vanuit de beschikbare data, overgestapt op de fysieke kenmerken van het voertuig, in het bijzonder het voertuiggewicht. Alleen voor de plug-in voertuigen, mede door het grote verschil tussen norm en praktijk, omdat plug-in auto’s in Nederland beperkt elektrisch rijden, is er duidelijk een groeiend gat te zien tussen normverbruik en praktijkverbruik, tot 300%. In alle gevallen lijkt de gewichtstoename van voertuigen de verklarende variabele voor het praktijkverbruik, terwijl normverbruik beperkt correleert met het gewicht.

Sinds 2016 is er geen daling meer in het praktijkverbruik van personenauto’s, diesel en benzine. De gewichtstoename lijkt de verbeterde efficiëntie, ofwel het zuiniger worden van de voertuigen, volledig te compenseren. Het gevonden verband tussen brandstofverbruik en voertuiggewicht verklaart deze trend.

Met een groeiend aandeel van elektrische voertuigen, en zorgen omtrent de netcapaciteit, is het energieverbruik van elektrische voertuigen in de praktijk een relevant gegeven. Het gewicht, de grootte, de fabrieksopgave, etc. spelen allemaal een rol in het elektriciteitsverbruik. De fabrieksopgave verklaart voor minder dan de helft het praktijkverbruik van elektrische energie, de kWhs. Ook zijn er tussen de fabrikanten verschillen die niet door verschillen in technische eigenschappen verklaard worden.

Effecten van de verlaging van de snelheidslimiet op de snelweg, de introductie van E10 brandstof, etc., indien aanwezig, zouden zichtbaar moeten zijn in het veranderende brandstofverbruik in de loop van de tijd van een vaste groep voertuigen.

Uit dit onderzoek is een beperkte daling van een paar procent rond 2020 te zien, die waarschijnlijk verklaard wordt door de snelheidslimietverlaging.

De Europese Commissie heeft sinds 2019 aandacht voor controle op het verschil tussen de norm en praktijk. Een monitoringssysteem, de OBFCM (On-Board Fuel Consumption Meter) is sinds enige jaren verplicht op nieuwe personenauto’s. De eerste data uit deze voertuigen laten een goede overeenkomst zien met de structurele verschillen tussen norm en praktijk zoals deze al jaren door TNO gerapporteerd worden.

Contents

1 Introduction

Although the share of electric vehicles is growing in the new vehicle registrations, the impact of the internal combustion engine in passenger cars will be felt until after 2040, given the typical lifetime of vehicles of twenty years. Moreover, the growing demand for sustainable energy, the combustion engines and the energy efficiency of electric vehicles will remain a topic of the climate goals beyond 2040. The current attention for details and dedicated measures will affect the climate impact of mobility for the coming twenty years. Road transport hardly had any overall reduction of CO_2 emissions, partly due to the growing fleet and mileages. However, vehicles also do not perform as well in real world as in the laboratory, and the declared CO_2 emissions overestimate reductions. Still, all legislation has to refer to these official numbers. The current study, part of a long series of studies[1] since 2009 when vehicle CO_2 policies first were introduced, provides new information, on the new vehicles entering the market but also on the effect of the new test procedure, the WLTP. This procedure was intended to close the gap and create a more realistic fuel consumption standard. However, in the last years it has become clear that this has not fully materialised. In the meantime average vehicle size, weight and power have increased considerably, which correlates with the increases the real-world fuel consumption.

At the same time, in the lease market, where vehicle costs seem less of an issue, there has been an influx of electric cars. With the climate goals relying heavily on the availability of sustainable energy sources, like wind and solar, the energy efficiency is a key issue to make proper use of these energy sources. The overall energy efficiency of electric cars should be a major issue, as energy consumption can vary easily 100% between different electric cars. Moreover, the energy consumption displayed in a car is not necessarily a good indicator of the overall energy use, because it does not include charging losses and continuous power consumption while the vehicle remains plugged in. Current study takes these aspects into account when determining the energy efficiency.

Since 2009, TNO has developed and improved the fuel pass transaction data analyses of a group of vehicle users. This group consists currently of about 630,000 vehicles covered with plausible data over longer periods as a basis of the analyses. Current study contains the progress in data after last report[2] of 2022 regarding fuelling data from 2004 to 2021, with new fuelling data up to summer of 2023.

In this report tank and charge event data from Travelcard is used to determine the total real-world energy use of vehicles. The groups of vehicles with petrol, diesel, plug-in, and electric drivetrains are analysed separately, given their own aspects. Moreover, in the last years the category of light commercial vehicles, or vans, which is a growing category on the road, is included. Finally, legislation and circumstances have changed, like the speed limits on the motorway. This context is given and quantified.

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[1] CO_2 uitstoot van personenwagens in norm en praktijk: analyse van gegevens van zakelijke rijders, TNO report 2010 MON-RPT-2010-00114.

[2] Real-world fuel consumption and electricity consumption of passenger cars and light commercia vehicles – 2021, TNO report 2022 R10409.

2 The role of the internal combustion engine in CO_2 emissions in past years

The overall CO_2 emissions of road transport are 27 megaton and increasing rather than decreasing since 1990. Vehicles have become more fuel efficient, but the size, the number, and the mileages increased so much that the net effect has been an increased fuel consumption over the last decennium. For the next twenty years the CO_2 emission of combustion engines of light-duty vehicles will remain a source of greenhouse gas emissions. At the same time, energy efficiency of electric cars, and benefits of zero emission use of plug-in hybrids (PHEVs) will play a growing role in the electricity use. The analyses by TNO are at the basis of the energy use reporting of mobility by CBS and the Klimaat- en Energieverkenningen (KEV) of PBL. This report, in a long series started back in 2009, serves two main goals: updating and extending the existing figures and prognoses of energy use and CO_2 emissions of light-duty vehicles, and signalling new trends and aspects that affect the real-world fuel consumption. This chapter links the analyses in the report to the recent changes in Europe and the Netherlands on this topic.

2.1 European control of factory values

The systematic gaps between the CO_2 results reported by the manufacturer, on both the NEDC and the WLTP, and the results of independent tests by institutes like TNO, raised the concerns that a better laboratory test will not reduce the flexibility in testing available to the manufacturer. Consequently, the declared CO_2 values may deviate for two reasons: First, the representativeness of the test for the real-world usage. Second, the manipulation of the test to achieve the desired outcome. The latter problem is addressed by the European Commission by two mechanisms: the OBFCM, i.e., accurate on-board fuel consumption monitoring, showing the typical deviations due to limited representativeness of the test, and the ISV, i.e., in-service verification, or independent control of the CO_2 values by repeating the tests by type-approval authorities on registered vehicles. Only recently, OBFCM data is available, and in this report a first analysis is performed, confirming the findings of TNO over the last couple of years. The purpose of OBFCM is also to find and select vehicles with dubious declared CO_2 values. In this report an alternative analysis, over all models and brands, is made to identify the outliers from amongst the normal deviations that are occurring due to the limited representativeness of the tests.

In the last couple of years the COP, i.e., Conformity of Production, testing at the factory as part of quality control, was the only check of the declared CO_2 value, but it seemed to be used by the manufacturers to strategically under- and overreport CO_2 values during the transition from NEDC-based to WLTP-based manufacturer targets for new registrations.

Finally, the European Commission also ensured more transparency around this process by making more details like rolling resistance and air-drag information available.

So for the first time it has been possible to investigate the physical soundness of the declared CO_2 values given the technical characteristics of the vehicles. This was investigated.

2.2 Behavioural changes

Fuel consumption data incorporates all aspects that influence the real-world use. This includes lockdowns, adaptation to new speed limits, responses to changing prices, etc. Since there have been a number of large changes and dramatic events in the last couple of years, the question is if these are visible in the trends in fuel consumption data. In particular, lowering the speed limits in March of 2020, should give a good indication if extension of such measures would be effective as climate policies. These effects are analysed but there are three complicating factors: Firstly, the speed limit measure coincided with the first pandemic lockdown, secondly, less traffic, e.g., in the lockdown, on the road leads to less congestion but also to a higher free-flow velocity, thus generating results in opposite directions, given the specific situations, and, thirdly, fuel-pass owners generally care less about the cost of fuel and may react very little to large increases in fuel prices. The analyses show some effects but not large.

2.3 Electrification versus cleaner fuel-based vehicles

Manufacturers are bringing an increasing number of electric vehicle models to the market. The CO_2 targets for European light-duty vehicle manufacturers are as such that a limited fraction of electric and plug-in vehicles are needed to meet them. This has been observed for the years 2019-2021 when the most recent targets applied. The next target is for 2025. Likely the strategies to meet those targets will be clear only in 2027. At the moment the post-2020 trend becomes clear in the data, with increasing WLTP values, and even larger increases in real-world fuel consumption from some vehicles.

The Dutch stimulation of plug-in and electric vehicles means that some business lease drivers are already at their third electric or plug-in vehicle, and most plug-in vehicles were and are business cars.,.. Their use is different from the average Dutch vehicle use. The higher mileages are associated with more motorway shares, over 50%, and longer trips.. The effect of average vehicle use for the WLTP is expressed in the Utility Factor, used to determine the CO_2 emission standard for plug-in vehicles, based on a collection of representative trips. The problem with these trips are the typical older and smaller vehicles, and not the typical Dutch plug-in user, doing the shorter trips, which are not the common electric and plug-ins.

The largest lasting effect for the Netherlands is the current influx of vehicles with a combustion engine, new registrations and import, which will affect the CO_2 emissions till 2040. The changes in the fleet, like increasing weight, and their relation to the real-world CO_2 emissions are important aspects to take into account. ,They can be determined based on the analyses in this report, and serve as a basis for a method to forecast the effects of recent trends.

3 Trends in real-world fuel consumption with regards to WLTP specifications

3.1 Introduction

In this chapter the real-world fuel consumption of internal combustion engine vehicles in the Travelcard fleet is evaluated. Most analyses in this chapter refer to fuel consumption of passenger cars, although some graphs referring to light commercial diesel vans are included as well.

Most graphs are displayed by fuelling date meaning that monthly averages of all passenger car data (respectively, light commercial vehicle data) in the given month are taken and the average values for that month are displayed. Therefore, both changes in fuel consumption and changes in fleet composition will be visible in these graphs. To separate changes in fuel consumption from changes in fleet composition, later in the chapter the effect of average vehicle mass on emissions is further examined.

All graphs are displayed in terms of CO_2-emissions in g/km. These values are directly calculated from fuel consumption by the following multiplication factors: for petrol CO_2 [g/km] = 2370 * FC [l/km] and for diesel CO_2 [g/km] = 2650 * FC [l/km] . These conversion factors allow for direct translation of the CO_2-graphs in this chapter into fuel consumption graphs.

The full dataset contains about 300 000 petrol passenger cars and 280 000 diesel passenger cars. Filtering out data points covered by previous reports, there are about 80 000 petrol registrations and 22 000 diesel registrations available in the Travelcard dataset with a fuelling event after the 31st of June 2021. Similarly, there are about 70 000 diesel vans in the dataset and about 35 500 registrations with a fuelling event after the 31st of June 2021.

Plug-in hybrid electric passenger cars have been excluded from the analyses in this chapter since these will be covered in the next chapter.

3.2 Trends in real-world CO_2-emissions with respect to type-approval numbers

The following graphs show the evolution of real-world CO_2-emissions over time with respect to NEDC and WLTP type-approval values.

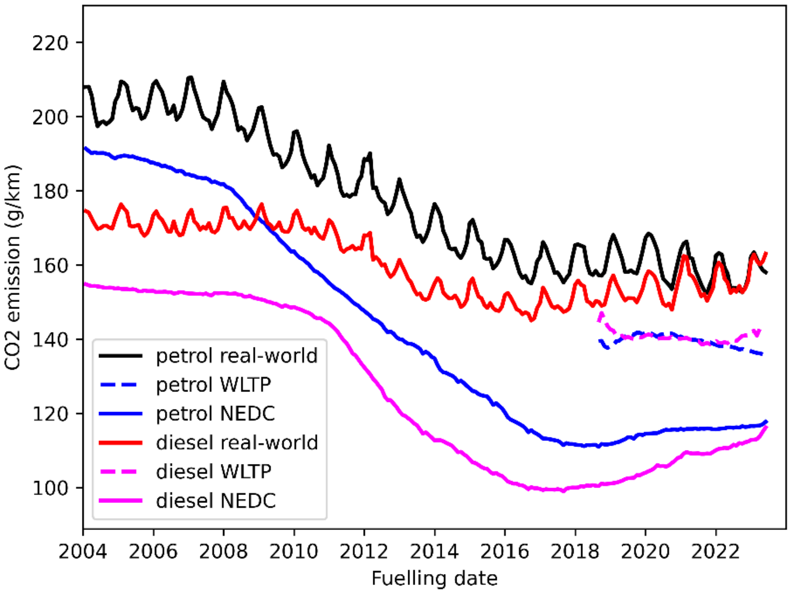

Figure 3-1: Monthly fleet averages of real-world CO_2-emissions and type-approval CO_2-values for petrol and diesel passenger cars.

As was expected, after the reference period for the 2025 and 2030 targets for the manufacturer, the WLTP values of petrol cars are decreasing. The real-world CO_2 emissions follow a different trend. With a real-world fuel consumption of 160 g/km and a WLTP type-approval of 140 g/km, the difference is around 15% with no clear trend.

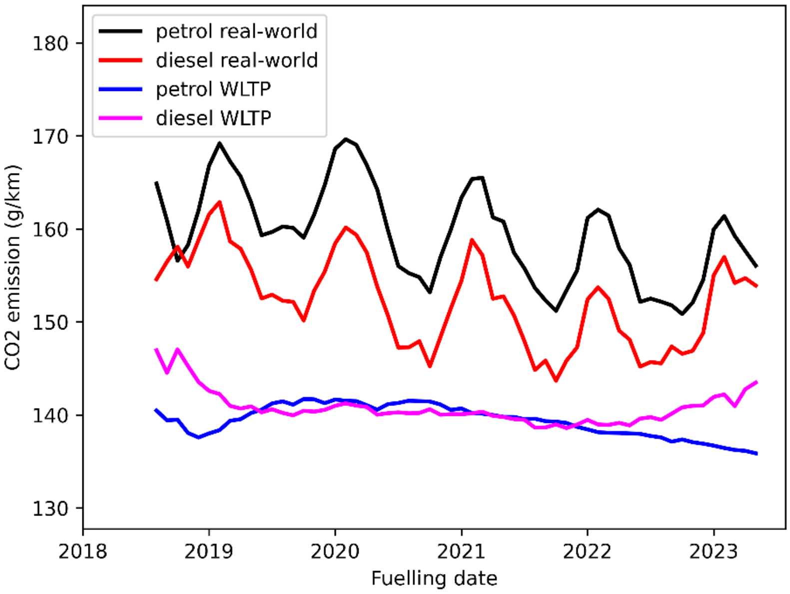

Figure 3-2: Monthly fleet averages of real-world CO_2-emissions and WLTP CO_2-values since the start of WLTP.

These graphs show a downward trend in real-world emissions since the start of WLTP.

For petrol passenger cars the downward trend in real-world emissions is comparable to the trend in average WLTP values. For diesel passenger cars we see an upward trend in real-world and average WLTP values. This is explained by an increased average weight.

3.2.1 The effect of vehicle mass on emissions

The recent increase of WLTP and real-world CO_2-emissions is largely explained by higher average vehicle masses for diesel passenger cars since the start of 2022 as can be seen in the following figure.

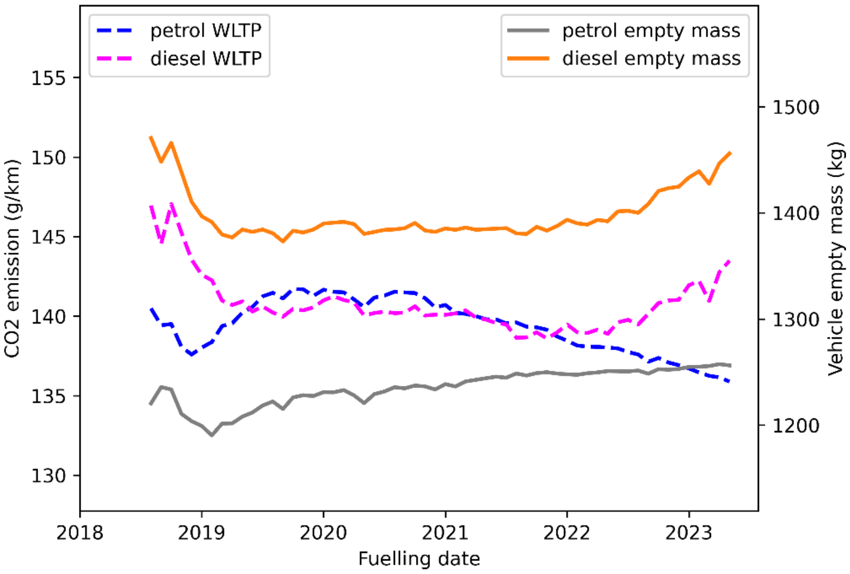

Figure 3-3: Monthly averages of WLTP CO2-values and vehicle empty mass for petrol and diesel passenger cars.

The increase in average WLTP-values perfectly follows the trend in average vehicle empty mass for diesel passenger cars. An analysis of the underlying data shows that most of the diesel passenger cars with high empty masses are SUVs and (van-based) MPVs. Note that these MPVs are classified as passenger cars if they are used for the carriage of passengers and have no more than 9 seats in total. It is possible that due to the general decrease of the diesel fleet size, these types of vehicles make up a larger percentage of the fleet in recent years.

For petrol passenger cars the average WLTP CO_2-values of the fleet are decreasing since mid-2020 whilst the average weight of the fleet has been slightly increasing in the same period. This opposite effect may be explained by manufacturers declaring higher WLTP CO_2-values during the years used as the norm years for 2025 and beyond, as explained below.

3.3 Evolution of the gap between real-world and WLTP CO_2-emissions

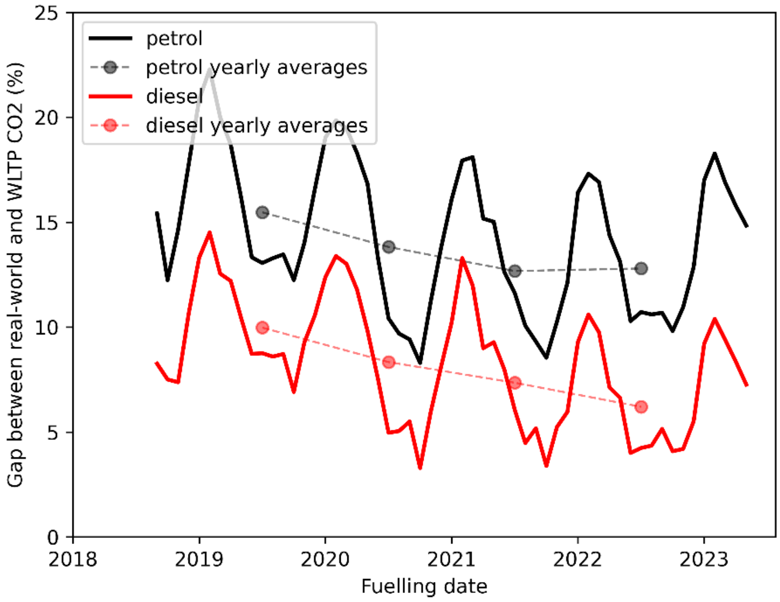

Figure 3-4: Monthly average percentual gap between real-world CO_2-emissions and declared WLTP CO_2 -values.

Plotting the percentual gap between real-world CO_2 and WLTP CO_2, it becomes clear that the gap is on average decreasing since the start of the WLTP. Since 2021, emission targets for manufacturers are based on the WLTP. For the period starting in 2025, the EU fleet-wide CO_2 emission targets are defined as a percentage reduction from a 2021 starting point. For passenger cars the targets are a 15% reduction from 2025 to 2029 and a 55% reduction from 2030 to 2034.[3] By this legislation manufacturers were incentivised to declare relatively high WLTP values compared to real-world CO_2-emissions until 2021. Since this incentive has now disappeared, it is likely that the downward trend will not continue and the gap will possibly start increasing again. Based on the currently available data it is still too early to confirm or falsify these expectations.

3.3.1 Real-world CO_2-emissions and WLTP-values for vans

For diesel light commercial vehicles (i.e. 'vans') we see rather constant real-world and WLTP CO_2-values since mid 2020. Since there were too little WLTP-values for diesel vans available from before 2020, we have not included those months in our analysis.

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[3] 'CO_2 Emission Performance Standards for Cars and Vans', https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en.

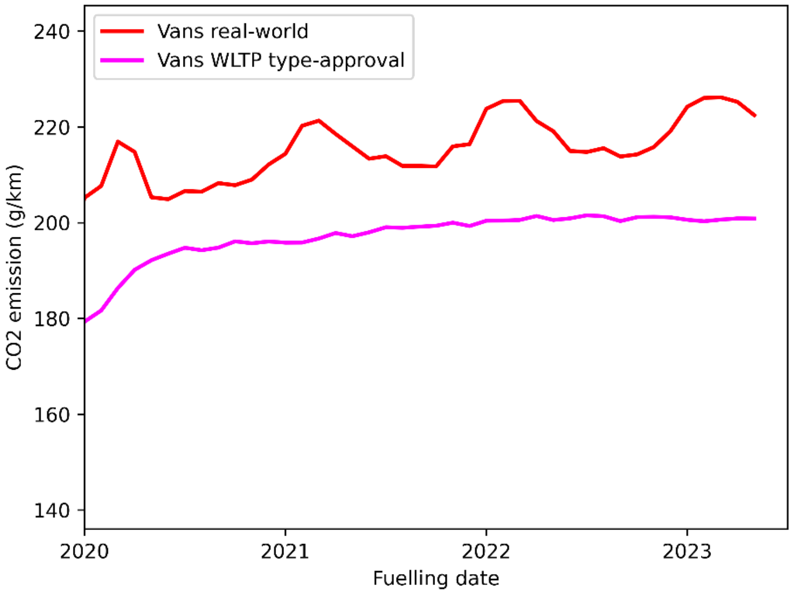

Figure 3-5: Monthly fleet averages of real-world CO_2-emissions and WLTP CO_2-values for diesel vans.

3.3.2 Trends in real-world and WLTP CO_2 per year of manufacture

The absolute gap between type-approval and real-world CO_2 can best be visualised, as the distance to the one-to-one relation. This may rely on the actual values of both, especially in the trends towards lower values. Considering fleet averages for real-world CO_2-emissions and WLTP declared CO_2-values per year of manufacture, the evolution of WLTP CO_2-values versus real-world CO_2-emissions over multiple manufacturing years may be visualised.
In the figures below a greater distance to the blue 'y=x'-line means a greater absolute deviation from the absolute type-approval CO_2-values.

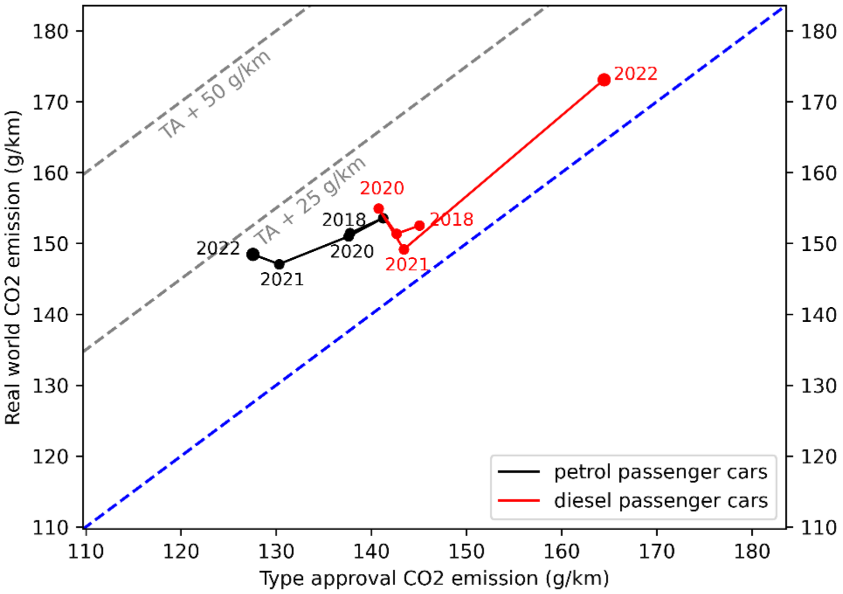

Figure 3-6: WLTP CO_2-values versus real-world CO_2-emissions per year of manufacture for petrol and diesel passenger cars.

For all passenger cars, vehicles with a year of manufacture in the early years of the WLTP, the type-approval values and real-world CO_2-emissions are more or less in the same region: WLTP-values around 140 g/km and real-world CO_2 around 150 g/km. For petrol passenger cars, a strong trend for manufacturing year 2021 and 2022 is observed in which WLTP CO_2-values are quickly decreasing while real-world CO_2-emissions are not changing significantly. This trend is likely caused by manufacturers declaring higher CO_2 WLTP-values during the norm years on which the reduction targets from 2025 onwards are based, as explained above. This was extensively discussed in the UNECE as part of the Conformity of Production requirements, that showed that different manufacturers declared WLTP CO_2 values substantially above the measurements of new vehicles.[4] For diesel passenger cars such a trend is not visible in this figure, but the rise in average vehicle mass and correspondingly in WLTP CO_2-values is clearly seen for manufacturing year 2022.

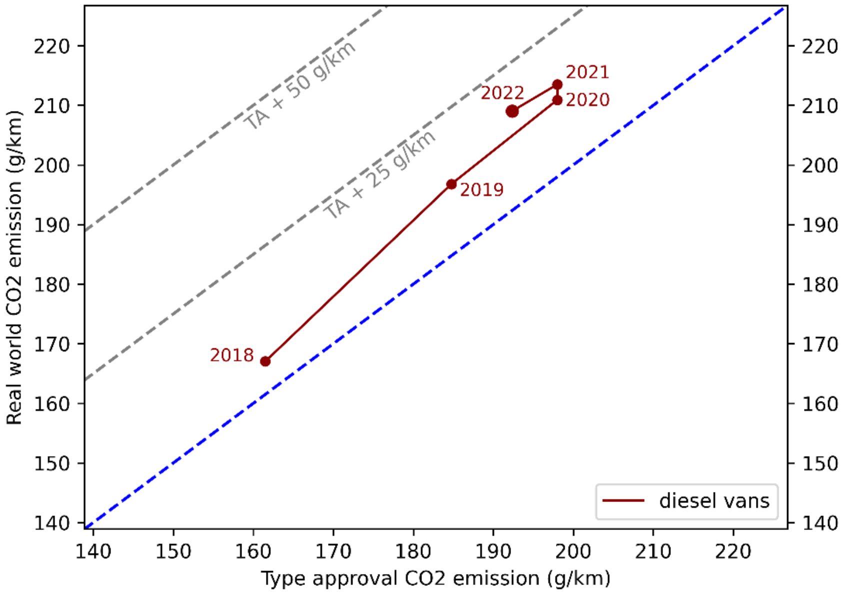

Figure 3-7: WLTP CO_2-values versus real-world CO_2-emissions per year of manufacture for diesel vans.

For diesel vans, we see that both average WLTP CO_2-values and real-world CO_2-emissions are increasing from year of manufacture 2018 until 2020. This increase may largely be accounted for by an average weight increase for these years. More data is needed to identify the lower WLTP and real-world CO_2-emissions for year of manufacture 2022 as a trend.

3.4 Outliers

It is possible to analyse whether certain passenger car models have higher real-world CO_2-emissions than we expect from the average gap between real-world and WLTP CO_2. The following figure shows the top 5 models for both petrol and diesel passenger cars that have the highest percentual gap between their real-world and WLTP CO_2-emissions. Before doing this analysis, the data was filtered such that only brand-model combinations with at least 25 vehicles in the dataset were remaining. The averaged results in the graph below were weighted by driven kilometres.

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[4] UNECE, WLTP Task Force on Conformity of Production

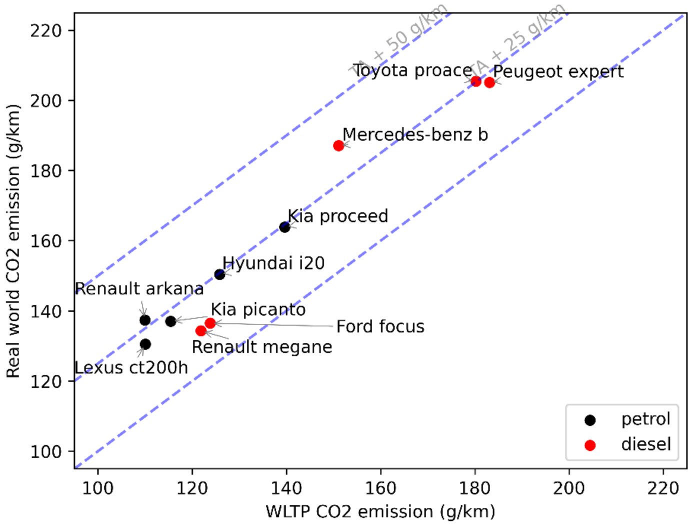

Figure 3-8: Models of passenger cars with at least 25 vehicles in dataset and the highest percentual gap between real-world and WLTP CO_2 weighted by distance driven.

3.5 Differences between petrol and diesel

For petrol and diesel the average real-world CO_2 as well as average empty mass and power is considered. After normalising for weight and power (by dividing by weight and power), the percentual gap between diesel and petrol CO_2-emissions may be calculated for different manufacturing years.

Table 3.1: Average real-world CO_2, empty mass and power for petrol passenger cars by year of manufacture.

Year of manufacture	Fuelling count	Mean RW CO_2 (g.km)	Mean empty mass (kg)	Mean power (kW)
2005	1245263	203.76	1280.11	89.4
2006	1260691	199.43	1263.84	86.92
2007	898331	198.13	1270.02	86.67
2008	1328399	184.52	1244.36	71.57
2009	1220877	179.55	1252.34	71.45
2010	1117876	176.6	1258.33	76.91
2011	1451542	176.9	1253.28	83.61
2012	1388747	169.53	1234.37	81.36
2013	976412	162.09	1182.78	75.33
2014	804903	159.35	1127.8	75.15
2015	897328	158	1109.53	72.82
2016	963070	157.21	1100.75	77.21
2017	1378313	162.92	1150.91	85.27
2018	1459107	160.67	1158.38	86.88
2019	1304891	162.47	1220.21	93.55
2020	673525	160.04	1230.39	94.13
2021	340250	156.6	1215.59	90.32
2022	113927	156.2	1197.61	87.51

Table 3.2: Average real-world CO_2, empty mass and power for diesel passenger cars by year of manufacture.

Year of manufacture	Licence count	Mean RW CO_2	Mean empty mass	Mean power
2005	1924664	170.87	1368.84	79.66
2006	1796260	171.92	1386.42	82.98
2007	1242297	174.67	1415.18	85.93
2008	1445848	172.17	1407.38	88.46
2009	1079411	167.47	1406.87	88.23
2010	968351	160.81	1374.23	86.89
2011	1818798	153.9	1314.64	79.18
2012	2140086	150.84	1318.62	78.86
2013	1884744	150.71	1330.72	78.99
2014	1758303	148.83	1299.58	81.85
2015	2313592	145.31	1286.82	56.96
2016	1070603	151.46	1341.87	52.86
2017	1108964	153.84	1364.13	92.37
2018	830007	152.53	1360.52	92.22
2019	330052	156.62	1428.52	96.81
2020	92272	155.79	1441.37	95.28
2021	18269	157.84	1515.9	99.58
2022	4230	214.91	2030.24	107.16

From these two tables, it is possible to calculate the average difference in real-world CO_2 between diesel and petrol. For a fair comparison, the CO_2-emissions are normalised for weight and power. In the years 2014 and 2015, employee benefits ("14% bijtelling") let to an influx of vehicles below 83-89 g/km CO_2. These were lighter vehicles with smaller engines, causing a dip in physical characteristics.

Table 3.3: Ratio of diesel real-world CO_2 over petrol real-world CO_2 after normalising for weight and power.

Year of manufacture	Petrol / diesel ratio for normalised real-world CO_2
2005	95%
2006	101%
2007	105%
2008	125%
2009	124%
2010	113%
2011	95%
2012	97%
2013	106%
2014	112%

2015	82%
2016	72%
2017	114%
2018	110%
2019	105%
2020	102%
2021	114%
2022	126%

So far, for the same user demands, reflected in weight and power, the diesel has on average a 6% lower CO_2 emission. However, the large fluctuations indicate that other aspects, like, e.g., level of hybridization, play a similarly large role in the fuel efficiency of cars. The special incentives for fuel efficient vehicles in the past

4 Trends for PHEVs

4.1 Introduction

In this chapter trends for plug-in hybrid electric vehicles are evaluated. In the Travelcard dataset there is data of about 16 000 petrol plug-in hybrid registrations and about 2000 diesel plug-in hybrid registrations. Out of these registrations, about 5800 petrol registrations and 200 diesel registrations have had a fuelling event after the 31st of June 2021, therefore supplying datapoints not included in the previous report.

4.2 Percentage of electric driving per model

First, the percentage of electric driving will be analysed on a model-by-model basis. For this type of model by model analysis, only models are analysed with more than 1500 fuelling events in the Travelcard dataset.

Simply speaking, plug-in hybrid vehicles have a few modes of operation: full EV mode, charge depleting hybrid mode and charge sustaining hybrid mode. In full EV mode, the vehicle is propelled only by the electric motor and all consumed energy comes from the battery. In charge sustaining hybrid mode, energy from regenerative braking and power from the engine is used to keep the battery at a constant state of charge. At the same time, the electric motor supports the internal combustion engine allowing for more efficient driving than a traditional engine. This mode is similar to the operation of a hybrid vehicle without a plug. The charge depleting hybrid mode, is similar to charge sustaining hybrid mode except that the vehicle control strategy allows for a gradual depletion of the battery, using the energy where fuel consumption can be effectively reduced..

It is possible to plot a frequency distribution of all fuelling events of a vehicle, with its fuel efficiency in kilometres per litre on the x-axis. Similarly to a histogram, such a graph displays the relative frequency of a certain number of kilometres per litre being observed for that model PHEV over all available fuelling events. For example, if the Toyota Prius Plug-in Hybrid has a value of 10% at 20 km/l, this means that 10% of the observed fuelling events for all Toyota Prius registrations had a fuel efficiency of 20 km/l.

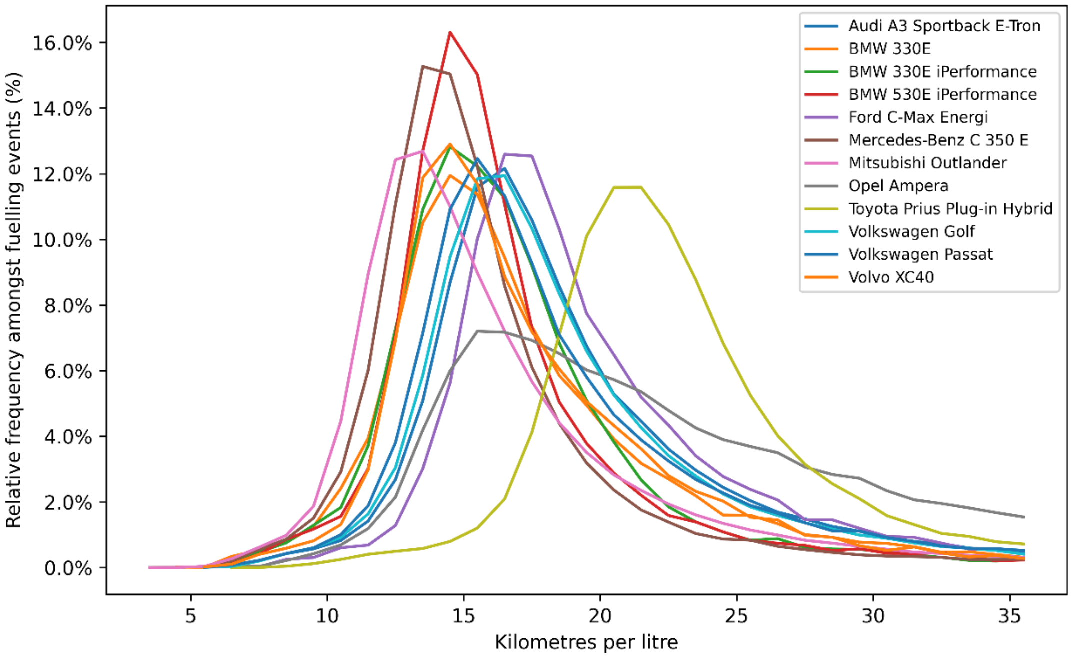

Figure 4-1: Relative frequencies of fuel consumption for PHEVs amongst all fuelling events by model. Only models with more than 10 000 fuelling events have been displayed.

When the vehicle is only driving in charge sustaining hybrid mode, the frequency graph is completely symmetrical on either side of its peak. The more asymmetrical the graph is, the more full EV or charge depleting hybrid mode driving has taken place. Therefore, it is possible to infer the average fuel consumption for both charge sustaining hybrid mode and overall fuel consumption from the frequency graph. This is used to calculate the percentage of electrically driven kilometres per model.

In the table below fuel efficiency (in km/l) per vehicle make and model for PHEVs is displayed both for driving on the internal combustion engine as for overall driving. The percentage electrically driven kilometres is then calculated as the difference between these two as a percentage of overall fuel efficiency. Only make and models have been selected with at least 1500 fuelling events in the Travelcard database.

Table 4.1: PHEV make and models and their corresponding calculated percentage electrically driven kilometres.

Model	Fuel	Number of fuelling events	Fuel efficiency on internal combustion engine [km/l]	Fuel efficiency overall [km/l]	Percentage electrically driven kms
AUDI A3	Petrol	102219	14.77	18.42	19.8%
BMW 225XE	Petrol	18738	13.07	16.32	19.9%
BMW 320E	Petrol	3605	13.48	17.13	21.3%
BMW 330E	Petrol	38154	13.25	16.26	18.5%
BMW 530E	Petrol	17768	13.34	15.91	16.2%
BMW 740E	Petrol	2083	11.81	14.24	17%
BMW 740LE	Petrol	1765	12.29	14.15	13.1%

BMW 745E	Petrol	2607	12.58	14.5	13.2%
BMW X3	Petrol	3118	11.64	15.22	23.5%
BMW X5	Petrol	4551	8.74	12.64	30.8%
CHEVROLET VOLT	Petrol	4943	15.49	22.31	30.6%
CITROEN C5	Petrol	2987	12.65	17.48	27.6%
FORD C-MAX	Petrol	11817	15.68	19.26	18.6%
FORD KUGA	Petrol	7757	15.76	19.91	20.8%
HYUNDAI TUCSON	Petrol	3230	13.28	16.7	20.5%
KIA CEED	Petrol	3839	17.23	20.33	15.3%
KIA NIRO	Petrol	5482	18.59	20.86	10.9%
LYNK&CO 01	Petrol	3239	12.18	16.58	26.6%
MERCEDES-BENZ A250	Petrol	5496	14.86	19.44	23.6%
MERCEDES-BENZ C300	Petrol	2071	12.87	17.08	24.6%
MERCEDES-BENZ C350	Petrol	87383	12.46	15.09	17.4%
MERCEDES-BENZ CLA250	Petrol	4675	14.89	19.75	24.6%
MERCEDES-BENZ E350	Petrol	7939	12.54	14.14	11.3%
MERCEDES-BENZ GLC300	Petrol	2868	10.93	14.05	22.2%
MINI COUNTRYMAN	Petrol	2412	13.74	16.53	16.9%
MITSUBISHI OUTLANDER	Petrol	478202	11.63	15.49	24.9%
OPEL AMPERA	Petrol	35695	14.43	22.65	36.3%
PEUGEOT 3008	Petrol	2875	13.18	16.99	22.4%
PORSCHE CAYENNE	Petrol	2292	8.14	10.99	25.9%
RENAULT MEGANE	Petrol	2218	15.91	18.59	14.4%
SEAT LEON	Petrol	2435	14.4	17.77	19%
SKODA OCTAVIA	Petrol	3996	16.11	19.34	16.7%
SKODA SUPERB	Petrol	2414	14.34	18.33	21.8%
TOYOTA PRIUS	Petrol	44941	19.55	22.51	13.1%
VOLKSWAGEN GOLF GTE	Petrol	179176	14.53	18.12	19.8%
VOLKSWAGEN PASSAT GTE	Petrol	93315	14.08	18.04	22%
VOLVO V60	Petrol	10891	12.85	16.76	23.3%

VOLVO V90	Petrol	1561	12.74	16.88	24.5%
VOLVO XC40	Petrol	19860	13	17.01	23.6%
VOLVO XC60	Petrol	7753	11.84	15.03	21.3%
VOLVO XC90	Petrol	49126	10.16	13.02	22%
AUDI Q7	Diesel	4630	10.95	14.83	26.1%
VOLVO V60	Diesel	177749	15.18	18.75	19.1%

4.3 Comparison with WLTP values

It has long been known that plug-in hybrid electric vehicles have much higher real-world CO_2-emissions than their type-approval values would suggest. Based on the currently available Travelcard data, an analysis is made of the real-world CO_2-emissions and WLTP declared CO_2-values for PHEVs registrations for which the WLTP values are known.

In the available data there are about 15 500 petrol and 2000 diesel registrations of PHEVs for which also WLTP CO_2-values are known. Out of these registrations, about 6000 petrol registrations and 200 diesel registrations have had a fuelling event after the 31st of June 2021, therefore contributing to new data since the last available report. The numbers of diesel PHEV registrations were deemed too low for a reliable analysis and diesel PHEVs have therefore been excluded below. The figures below were again displayed over fuelling date by calculating the monthly average for all PHEV fuelling events in the available data.

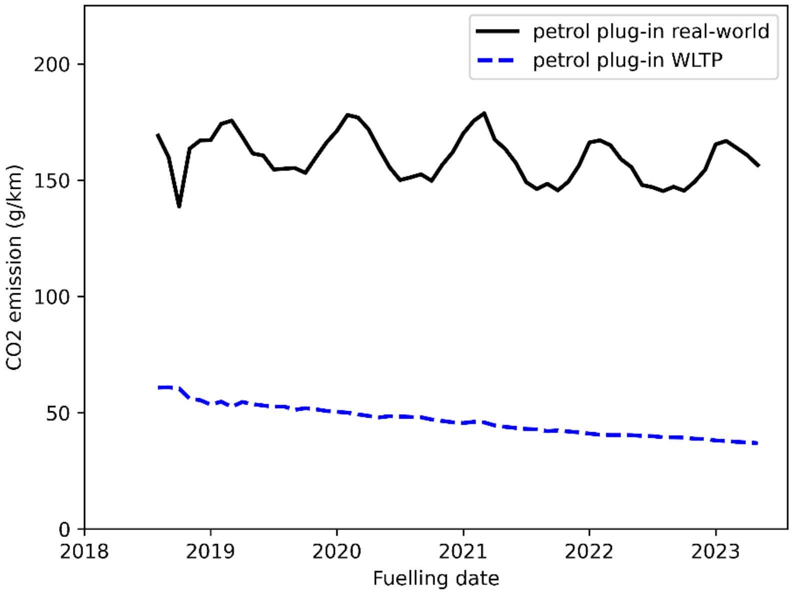

Figure 4-2: Real-world CO_2-emissions and WLTP CO_2-values for petrol plug-in hybrid vehicles.

From this figure it is clear that although PHEVs have similar real-world CO_2-emissions to non-plugin petrol passenger cars of around 160 g/km, the declared WLTP CO_2-values for PHEVs are substantially lower than for their non-plug-in petrol passenger car counterparts. For petrol PHEV vehicles the average WLTP CO_2-values are around 45 g/km, whereas for non-plugin petrol passenger cars these values are about 140 g/km.

Moreover, it is observed that the average real-world CO_2-emissions are virtually constant since the start of the WLTP, whereas the WLTP CO_2-values have been decreasing (similarly to non-plug-in petrol passenger cars).

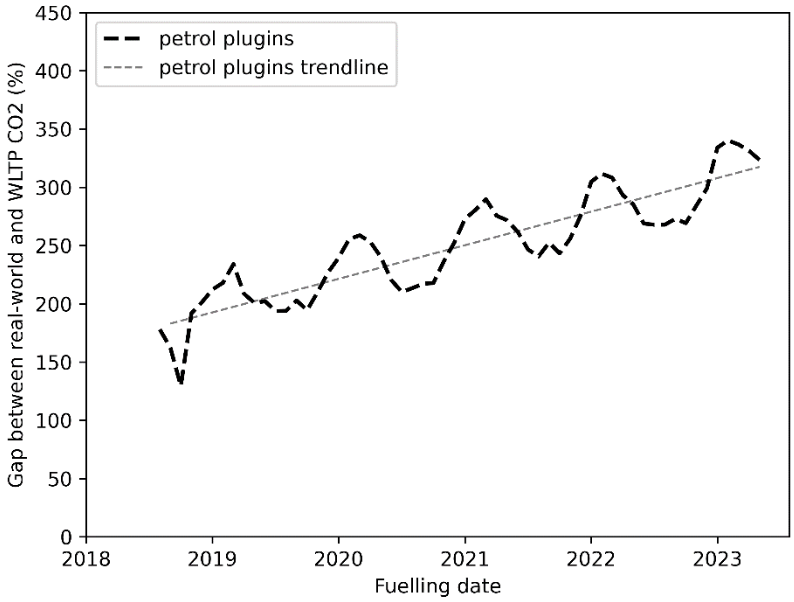

Figure 4-3: The percentual gap for petrol plug-in hybrid vehicles since the start of the WLTP.

A direct consequence of real-world CO_2-emissions remaining virtually unchanged and WLTP CO_2-values decreasing is that the percentual gap between real-world and WLTP CO_2 is growing since the start of the WLTP. In 2022 the gap has grown to real-world CO_2 being nearly 300% of the declared WLTP CO_2-value for petrol plug-in hybrids in the Travelcard dataset.

4.4 Accounting for the use of electricity by PHEVs

In the preceding paragraphs, calculations were based only on the real-world fuel consumption by PHEVs in the Travelcard dataset. For a fair comparison with other types of vehicles, not only tailpipe emissions should be considered but also CO_2-emissions from the use of electricity by the car. Such an combination could be used when comparing vehicles' emissions through energy labels.

To account for CO_2-emissions of electricity use of the vehicle, a value of 400 g CO_2 per kWh is used. To the total number of driven kilometres, the utility factor[5] of the vehicle is applied to calculate the number of charge depleting kilometres driven.

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[5] See Sub-Annex 8, Appendix 5 of COMMISSION REGULATION (EU) 2017/1151.

The formula described in the EU regulation[Fout! Bladwijzer niet gedefinieerd.] legislation was used to c alculate the utility factors, i.e.

$$UF_{vehicle}(R_{elec}) = 1 - \exp\left[-\sum_{i=1}^{10} c_i \left(\frac{R_{elec}}{800}\right)^i\right],$$

where R_{elec} denotes the WLTP all electric range of the vehicle and the numerical constants c_i are given by c_1 = 26.25, c_2 = -38.94, c_3 = -631.05, c_4 = 5964.83, c_5 = -25094.60, c_6 = 60380.21, c_7 = -87517.16, c_8 = 75513.77, c_9 = -35748.77, c_{10} = 7154.94.

This complex equation represents a simple relation between the distance a PHEV can drive on a full battery, i.e., in charge depleting mode, and the weighing of the share of electric driving in the type-approval results. See Figure 4-4.

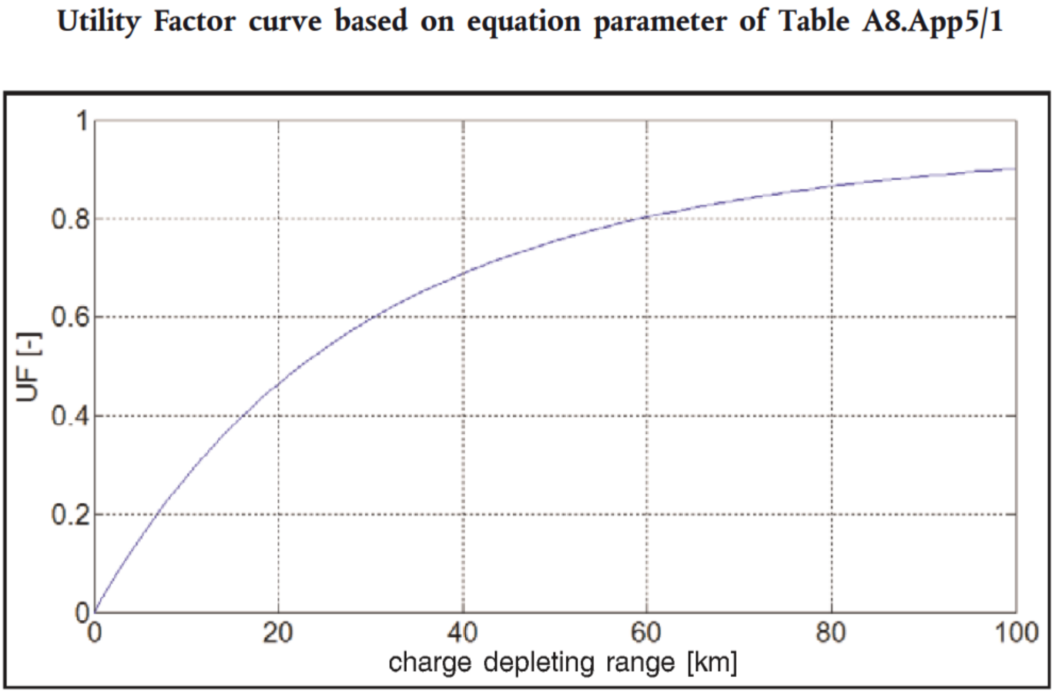

Figure 4-4: The relation between the share of electric driving (UF[-]) in the CO_2 type-approval value, and the electric range, from EU 2017/1151.

The WLTP energy consumption value is used to calculate the energy use for these electric kilometres. In summary, on top of the WLTP tailpipe CO_2-emissions, total CO_2-emissions including emissions due to the use of electricity are calculated as

$$WLTP_{total\ CO_2}\left[\frac{g}{km}\right] = WLTP_{CO_2}\left[\frac{g}{km}\right] + UtilityFactor\,[\%] * WLTP_{EC}\left[\frac{kWh}{km}\right] * 400\left[\frac{g}{kWh}\right].$$

The real-world CO_2-emissions from fuel consumption and WLTP (tailpipe) CO_2-values are included in the graph below for reference. In the travelcard dataset, there are 3748 petrol and 20 diesel PHEV registrations available for which sufficient WLTP values are known to do the above calculation.

Diesel PHEV registrations were therefore excluded below, since the numbers are too low for robust results. For petrol PHEVs the results were aggregated by manufacturing year instead of fuelling date.

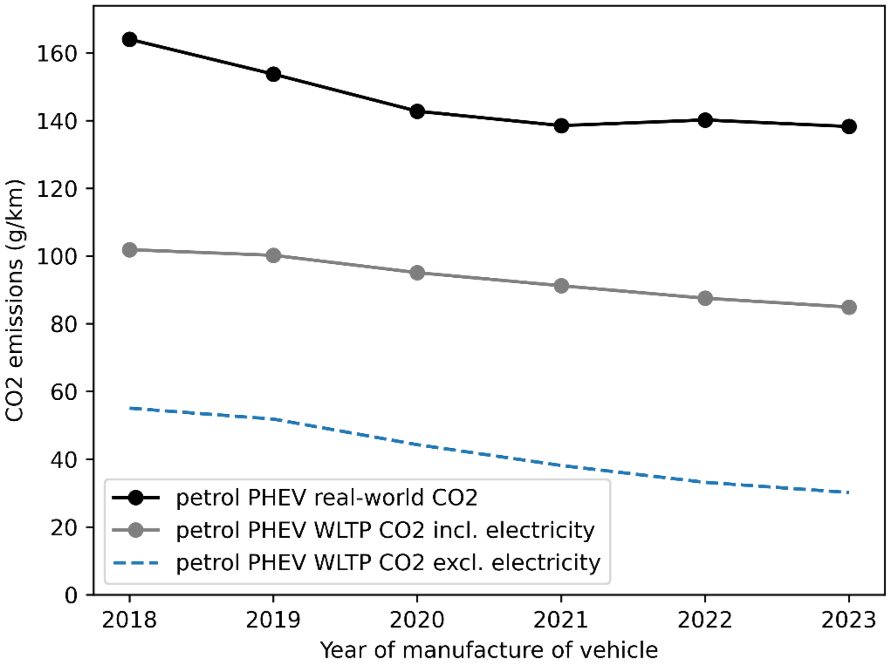

Figure 4-5: CO_2-emissions due to real-world fuel consumption and estimated electricity consumption for petrol PHEVs by year of manufacture. The real-world value, with the CO_2 from electricity, if of course, even higher than current real-world results, but the effect is much less than for the type-approval results.

5 Real-world energy consumption of BEVs

5.1 Introduction and methodology

In the current chapter we will look at real-world energy consumption of battery electric vehicles (BEVs). For electric vehicles in the Travelcard dataset, there are no odometer readings available on a charge-to-charge basis. To mitigate the missing odometer readings, the Travelcard BEV registrations are linked to odometer data from the RDW NAP database. However, often odometer readings and charge data are not available for matching dates. It is also possible that charging data is missing (even though driving has taken place) due to holidays, service, the temporary use of a different card or the use of unmetered charging points. Therefore, it is important to develop a careful filtering and validating methodology to overcome these difficulties in the data.

5.1.1 Matching charging and odometer data

After removing any negative charges found, the charging data is dived up into charging sequences of uninterrupted charging data.

A series of subsequent charges is considered a valid charging sequence if:

1) no subsequent pair of charges exceeds a maximum timespan determined based on the average time between two charges and the total number of available charges for the given vehicle;
2) the sequence contains at least 10 charging events;
3) the sequence spans a period of at least 14 days.

For any valid sequence of charging data, matching odometers records are found. Odometer readings are matched to the sequence if they lie between the start and end date of the sequence or at most 45% outside of these dates in either direction. If at least two odometer readings, at least one of which is within ±45% of the sequence start date and at least one is within ±45% of the sequence end date, then the sequence and odometer readings are considered a valid match. The energy consumption for this charging sequence is then calculated by linearly fitting the matched odometer readings and inter- or extrapolating to the start and end date of the charging sequence.

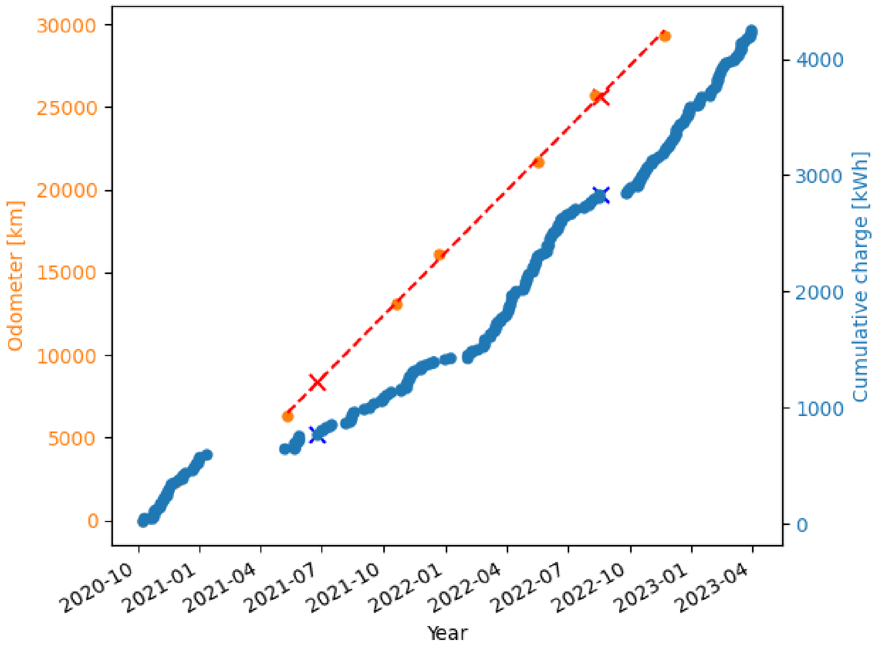

Figure 5-1: A figure from charging and odometer data from a vehicle in the Travelcard BEV fleet. The blue crosses represent the beginning and end of the (only) valid charging sequence. The dotted red line is the linearly fitted line of the matching odometer readings. The red crosses represent the calculated odometer standings at the beginning and end of the valid charging sequence.

If this approach is unsuccessful for any of the valid charging sequences of a particular vehicle, a different approach is attempted for the vehicle as long as the vehicle has more than 3000 kilometres between the lowest and highest odometer reading and it has at least 25 charging events.

We consider the largest sequence of charging events such that:

1) no subsequent pair of points exceeds the maximum allowed timespan;
2) the sequence contains at least 10 charging events.

This largest uninterrupted charging sequence is then used to calculate the average annual cumulative charge per year for the given vehicle through a linear regression. If the regression has an R-squared value of less than 0.9, the vehicle is rejected. Similarly, we use the odometer readings (up to at most one reading after the end of the largest sequence) to calculate the average driven kilometres per year for the vehicle through a linear regression, again rejecting with an R-squared below 0.9.

Then we calculate the average energy consumption of the vehicle by:

$$EC\left[\frac{kWh}{100km}\right] = \left(\frac{cumulative\ charge}{year}\left[\frac{kWh}{y}\right]\right) \Big/ \left(\frac{distance}{year}\left[\frac{100km}{y}\right]\right).$$

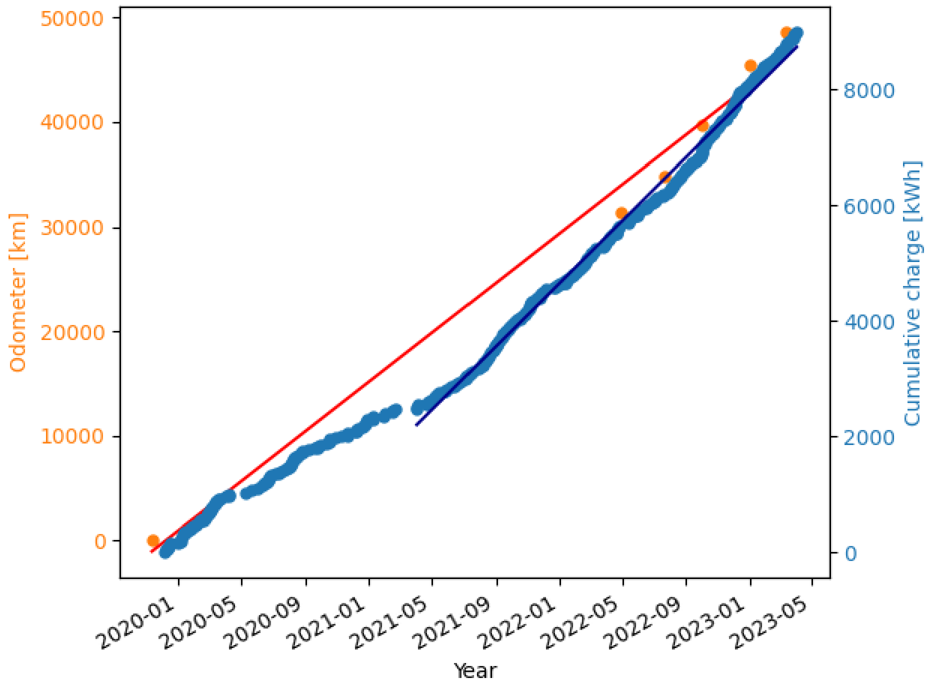

Figure 5-2: A figure of charging and odometer data for a BEV vehicle from the Travelcard fleet. The blue line represents the largest continuous charging sequence used to determine the average cumulative charger per year. The red line represents the fitted linear line to determine the average driven distance per year for this vehicle.

5.1.2 Filtering

After the process described above, we are left with (calculated) energy consumption values for about 45 000 registrations. For about 30 000 of these registrations we also have WLTP energy consumption values through the RDW database, the remainder are older vehicles under NEDC. For extra validation, further filtering of the energy consumption data takes place. Any values below 70% or above 250% of the WLTP energy consumption values are removed. We delete make/model combinations with less than 10 corresponding registrations. For each make/model, we delete datapoints that exceed two standard deviations for that make/model. By the end of this process we have about 26 500 datapoints left for about 22 000 distinct BEV registrations.

5.2 A formula to determine real-world energy consumption for specific models

In previous reports the real-world energy consumption was analysed for a list of common make/models of BEVs. However, currently most models come in many different versions, for example with different battery capacities, 2WD, 4WD or AWD and performance versions. These variations are expected to have significant impact on the real-world energy consumption of the vehicle, but were unaccounted for in the previous approach.

Therefore, in this report the following formula is presented taking into account many more aspects than only the make and model of the vehicle:

$$\boldsymbol{RWEC}\left[\frac{kWh}{100km}\right] = \mathrm{a} * \mathbf{m}\,[\mathrm{kg}] + b * \boldsymbol{A}\,[m^2] + c * \boldsymbol{EC_{WLTP}}\left[\frac{Wh}{km}\right] + d * \boldsymbol{P}\,[kW] + \boldsymbol{M} + f,$$

where

- **RWEC** stands for real-world energy consumption including charging losses;
- **m** is the vehicle empty mass;
- **A** is the width * height of the vehicle;
- **EC_{WLTP}** is the energy consumption according to the WLTP test;
- **P** is power;
- **M** is a make/model specific factor,

and the coefficients of the formula are given by the following table.

Table 5.1: Coefficients for real-world energy consumption formula for electric vehicles.

A	0.00412059
b	0.775381855
c	0.04188555
d	0.01095102
f	4.893820606

All variables in the formula are available in the RDW open data portal[6] except the model specific factor **M**. The factor **M** mostly compensates for specific make/models being more or less aerodynamic than expected or having a more or less efficient powertrains. Note that **A** is literally the width * height of the vehicle so nowhere except for in **M** we account for the streamlining of the vehicle.

Table 5.2: Value of the correction factor **M** for different make/models.

Make/model	M
AIWAYS U5	0.903
AUDI E-TRON	-0.832
AUDI Q4	-1.440
BMW I3	-1.065
BMW I3S	-1.263
BMW I4	-2.764
BMW IX	0.564
BMW IX3	-2.037
CITROEN E-C4	0.173
CUPRA BORN	-0.539
DS 3	0.932
FIAT 500	0.370319444
FORD MUSTANG	-0.87512204
HYUNDAI IONIQ	-3.10414409
HYUNDAI IONIQ5	-2.4847517

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[6] More specifically under the column names ‘massa_ledig_voertuig’, ‘breedte’, ‘hoogte_voertuig’, ‘elektrisch_verbruik_enkel_elektrisch_wltp’, ‘nominaal_continu_maximumvermogen’, respectively.

Make/model	M
HYUNDAI KONA	-2.86033025
JAGUAR I-PACE	1.222355836
KIA EV6	-2.44824178
KIA NIRO	-2.99953951
KIA SOUL	-0.98512793
LEXUS UX300E	0.234737502
MAZDA MX-30	-0.57434485
MERCEDES-BENZ EQA	-1.42463453
MERCEDES-BENZ EQB	-1.92173876
MERCEDES-BENZ EQC	-0.62141273
MERCEDES-BENZ EQS	3.489838982
MERCEDES-BENZ EVITO	9.414740159
MG ZS	-1.05966243
MINI COOPER	-1.35309791
NISSAN E-NV200	0.153830413
NISSAN LEAF	-1.22457977
OPEL AMPERA-E	-1.00809929
OPEL CORSA	1.522936709
OPEL MOKKA	0.287289706
OPEL VIVARO	9.265322221
OTHER BRAND/MODEL	0
PEUGEOT 2008	-0.53977025
PEUGEOT 208	1.148428904
PEUGEOT EXPERT	6.082256848
POLESTAR 2	0.430176687
PORSCHE TAYCAN	1.026140572
RENAULT KANGOO	3.234182579
RENAULT MEGANE	-0.25207146
RENAULT ZOE	0.769503195
SEAT MII	1.107710509
SKODA CITIGO	1.020164714
SKODA ENYAQ	-2.31912829
SMART EQ	1.515146322
TESLA MODEL3	-2.29154242
TESLA MODELS	-2.21970429
TESLA MODELX	-2.46663884

Make/model	M
TESLA MODELY	-2.22332299
TOYOTA PROACE	9.305008597
VOLKSWAGEN GOLF	-3.47506941
VOLKSWAGEN ID.3	-0.82337601
VOLKSWAGEN ID.4	-2.1277988
VOLKSWAGEN UP!	-1.13152054
VOLVO C40	0.781842068
VOLVO XC40	-0.19808887

Lastly, it is noted that there is much more variation in the data than is captured by this formula. Therefore, the formula should be used to predict an average over a group of vehicles, but for individual vehicles other variables such as driving style are expected to have a large influence on real-world energy consumption which is not captured by the formula.

5.3 Comparing real-world and WLTP energy consumption

Similarly to the previous chapters, energy consumption over time is evaluated for the BEVs. For BEVs, no fuelling date with matched odometer readings is available. Instead, every vehicle has a (number of) valid charging sequences. In the figures below the midpoint of each charging sequence is taken as a replacement for the fuelling date. For a small number of sequences or vehicles, this is would lead to very uneven data. For the whole fleet, however, it is reasonable to use the midpoint of each sequence in trend analyse

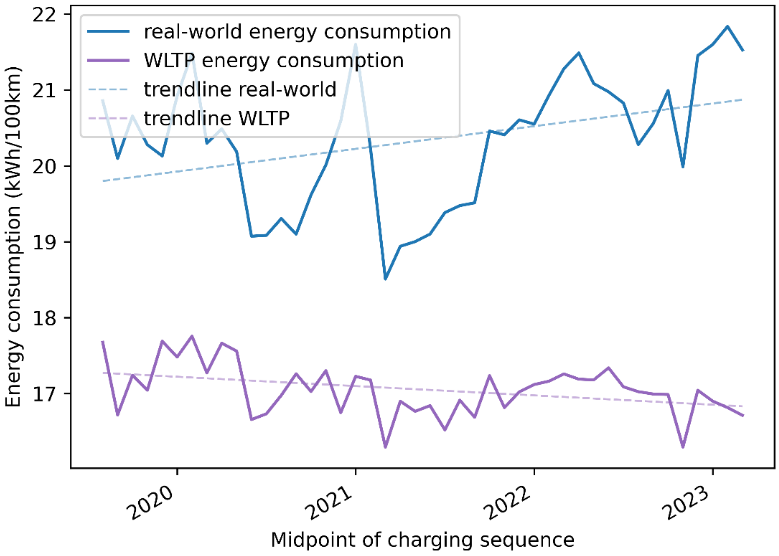

Figure 5-3: Monthly averages of real-world energy consumption and WLTP energy consumption for all BEVs in the Travelcard fleet (after filtering and validation checks).

It becomes immediately clear that although WLTP energy consumption is roughly constant over the given period, real-world energy consumption is trending upwards. The following figure shows that the percentual gap between real-world and WLTP energy consumption has been trending upwards for a number of years from about 15% at the beginning of 2020 to roughly 25% at the beginning of 2023.

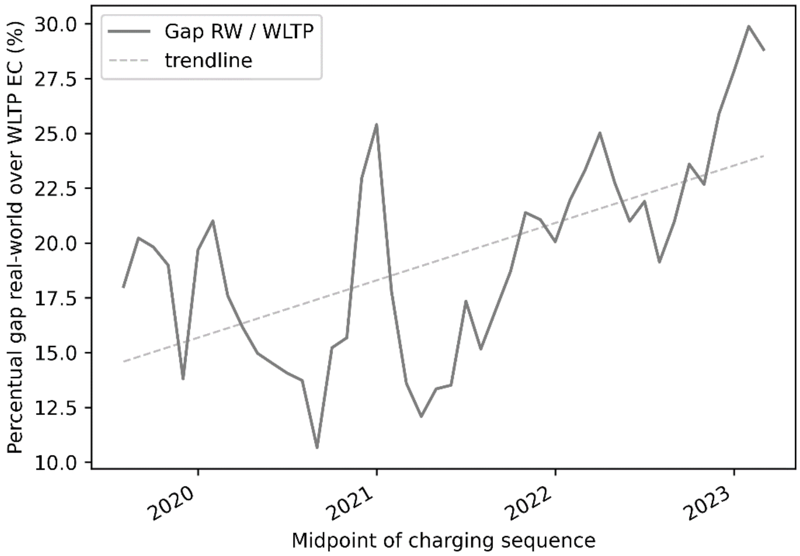

Figure 5-4: Monthly averages of gap between real-world energy consumption and WLTP energy consumption as a percentage of the WLTP value.

5.4 Changes in average weight

The real-world energy consumption trending upwards is strongly correlated with the increased average weight of electric vehicles in the available data. This can be seen in the following figure.

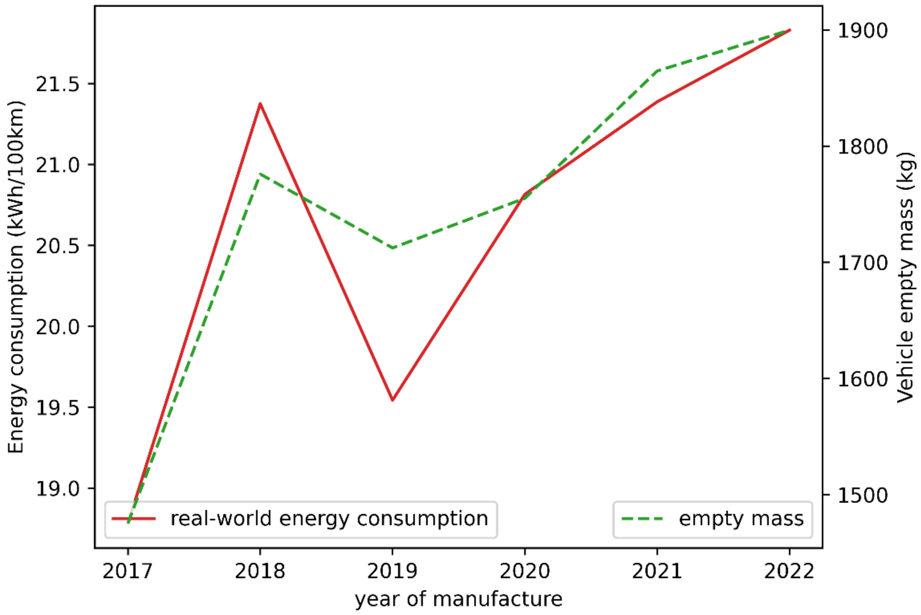

Figure 5-5: Average real-world energy consumption and vehicle empty weight by year of manufacture for BEVs in the Travelcard dataset (after filtering).

It is observed that trends in real-world energy consumption perfectly mimic trends in average weight. Once we normalise for weight, we obtain energy consumption per tonne of vehicle empty mass. Then the (weight-normalised) real-world energy consumption is no longer increasing, but very slightly decreasing. This indicates that there may be small efficiency gains over the past years that have not resulted in lower energy consumption due to a strong rise in increased average weight of electric vehicles.

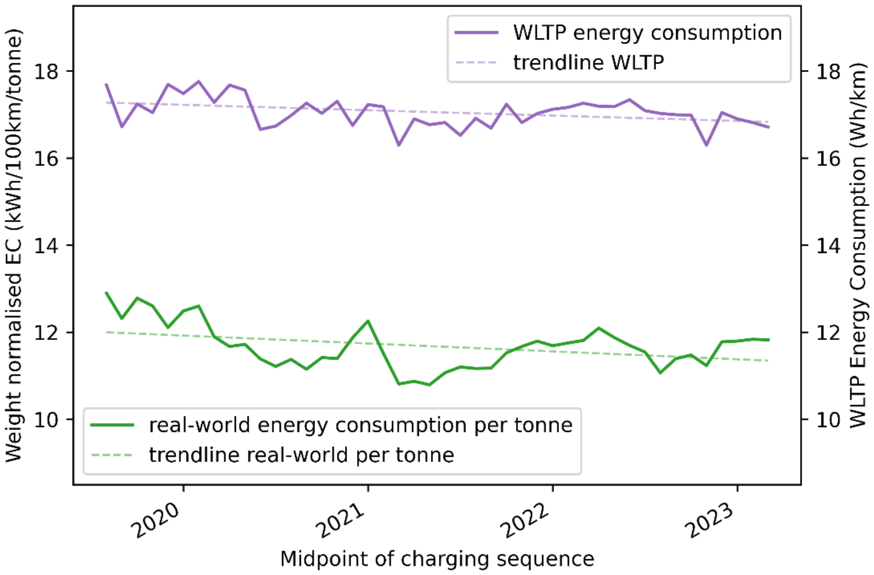

Figure 5-6: Monthly averages of real-world energy consumption per tonne of empty vehicle mass and WLTP energy consumption. The real-world energy increase is linked to the weight increase, as per weight limited effect remains. Note that the real-world energy consumption only appears lower in the graph than the WLTP energy consumption because the units on the axes are different.

5.5 Charging losses and in-vehicle displays

The numbers presented in this chapter may deviate from in-vehicle displays of energy consumption and will generally be higher. This is mainly caused by us using charge pass data, meaning that all our analyses include charging losses. This is a useful metric since this is the electricity that has been lost at the end of charging and should therefore be counted as part of the energy consumption of the vehicle. The in-vehicle display does not account for charging losses. Measurement data of Green NCAP implies that charging losses when charging at a standard public charger of 11 kW AC varies between 11% and 21%. There are indications that charging losses are even higher when charging below 11 or 22 kW. When charging at a DC charger, losses are different and probably lower, unless charging at high speeds.

There are other reasons why in-vehicle displays may display lower energy consumption than the figures presented in this chapter.

The following functionalities are (probably) not included in in-vehicle display energy consumption, but visible in the charging card data.

1) Preheating and cooling before leaving using charging grid or battery energy
2) Periodically balancing battery cells
3) Battery conditioning to prevent freezing (for certain models)
4) On board electronics remaining active when the car is parked (e.g. data communication systems)

6 Emission factors for CO_2 and energy consumption

6.1 Short description of SRM-I and SRM-II and bottom-up

TNO calculates emission factors to be used for the calculation of air quality by Dutch governments and companies. These emission factors are updated yearly and the most recent version is published by the ministry of I&W on March 15th [7]. An elaborated overview of these emission factors and the way that they are calculated can be found in [1] and [2]The emission factors are part of the Standaard Rekenmethoden (SRM) 1 and 2 that are defined in the Regeling beoordeling luchtkwaliteit 2007. SRM-I concerns roads in an urban environment and SRM-II concerns roads outside the urban environment (rural roads and motorways).

The following vehicle categories are distinguished for the SRM-factors:

- Busses (not on motorways)
- Licht-duty vehicles: passenger cars and vans
- Medium-duty vehicles: Trucks < 20 ton GVW [8] and busses (only on motorways)
- Heavy-duty vehicles: Trucks >= 20 ton GVW and tractor-trailer combinations

For the national emission registry (ER) emissions related to road traffic are calculated with a so-called bottom-up approach. This means that each vehicle in the fleet is associated with designated emission factors (in g/km) based on their specific characteristics such as engine type, mass or age. These emission factors are multiplied with the specific mileage (based on odometer readings) of the vehicle in order to calculate the total emissions for each vehicle separately. This approach is described in more detail in the methodology report of the taskforce traffic and transport [3].

Specifically for CO_2-emissions (in g/km) and energy usage (in MJ/km) of light-duty vehicles (vans and passenger cars) vehicle specific values have been calculated based on analyses of the Travelcard data.

6.2 Driving behaviour per road type and the effect on the fuel consumption

Th SRM emission factors are calculated for different road types, maximum speeds and traffic situations that each represent different driving behaviour and thus fuel consumption.

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[7] Latest version: https://www.rijksoverheid.nl/documenten/publicaties/2023/03/15/emissiefactoren-voor-snelwegen-en-niet-snelwegen-2023

[8] Gross Vehicle Weight

The following road types are distinguished:

- Urban roads
    - Free flow
    - Congested
    - Normal
- Rural roads
- Motorways
    - 80 km/h with strict enforcement
    - 80 km/h without strict enforcement
    - 100 km/h with strict enforcement
    - 100 km/h without strict enforcement
    - 120 km/h
    - 130 km/h
    - Congested

Each of the road types represent a different distribution of average speeds and mild and heavy accelerations, each affecting the average emissions. More information on the road types can be found in [4].

6.3 Implied Emission Factors

The vehicle specific CO_2 and MJ (?) factors are used for calculating SRM emission factors for CO_2-emissions and energy usage. A similar approach to calculating the SRM emission factors for air quality is used where the total annual mileages calculated by PBL for the Klimaat en Energieverkenning (KEV) are used for weighing the factors to SRM vehicle categories.

In short the process can be summarized as follows:

1. Calculate average emission factors per vehicle
2. Aggregate factors to VERSIT+ classes (vehicle classes distinguishing vehicle type, fuel and emission regulations).
3. Convert to factors per road type (urban, rural and motorway) based on bottom-up results
4. Convert to SRM road types with scaling factors per vehicle road type
5. Add total kilometres per sight year per VERSIT class per road type
6. Calculate weighted average emission factors per SRM vehicle class.

The resulting SRM factors can be found in a separate excel for 2023. For 2024 and further the CO_2 emission factors will be part of the larger set of emissions factors, which are annually updated with the methodology described here.

7 Changing circumstances

7.1 Speed limits, COVID19 lockdowns, and E10

To investigate the influence of the 100 km/h speed limit on the Dutch motorways, we selected a fixed group of around 55 000 petrol and 24 000 diesel passenger cars (no plug-ins, no vans) of manufacturing year 2017 – 2019. We evaluated their real-world energy consumption over time since 2019.

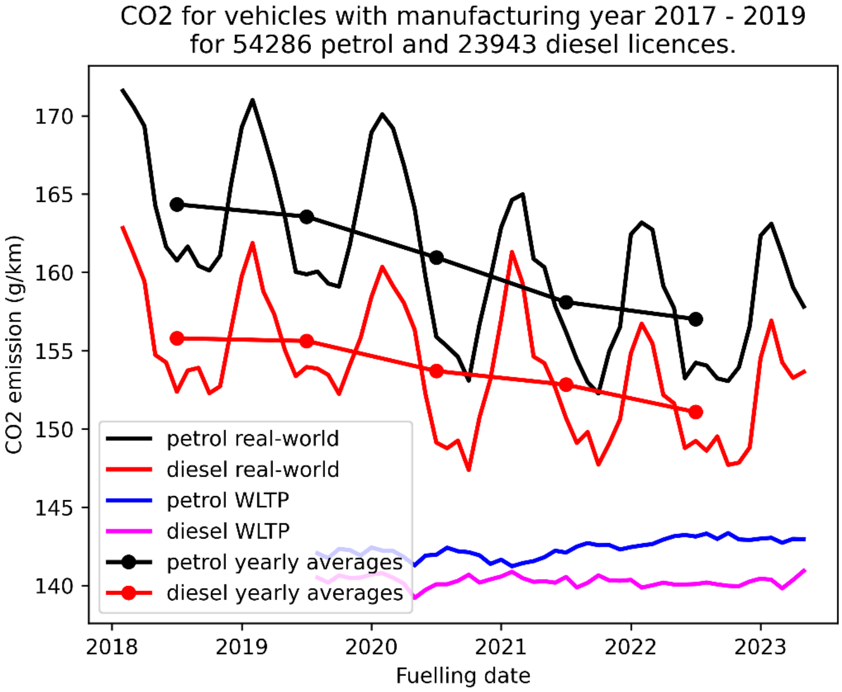

Figure 7-1: Monthly averages of real-world and WLTP CO_2-emissions for a fixed group of petrol and diesel registrations with manufacturing years 2017 – 2019. Also real-world yearly averages were included.

Indeed a strong decrease in real-world energy consumption is observed for both petrol and diesel from 2019 to 2020 and 2021. In the same period the WLTP-values remain reasonably constant indicating that although not every vehicle may have fuelled up in each month, on average the characteristics of the evaluated group do not vary too much from month to month. Therefore, this decrease is very likely caused by other factors than a changing fleet composition.

Based on this data it is hard to separate the effects of the decrease in the maximum speed limit on the Dutch motorways from the corona-effects on fuel consumption in 2020 and 2021 and other factors that may have been of influence such as biofuels. However, the above figure is a strong indication that fuel consumption has decreased in these years independent of fleet developments. It will be interesting to see whether this trend continues in 2023 and beyond, but more data is needed before these analyses can be made.

7.2 New legal framework around ISV, controls for standard use

The European Commission proposed a framework of In-Service Conformity checks of the CO_2 values of newly registered vehicles by the type-approval authorities.[9] So far, little more information have become available. In August of 2023, with Commission Implementing Decision (EU) 2023/1623, a curious conclusion was reached, with negative slopes for the target lines for different manufacturer groups for higher vehicle weights. For climate, this is a positive result, because as we see in the real-world CO_2 the mass has an important impact. However, it confirms the findings in the study that differences in declared CO_2 values have less relevance for real-world CO_2 emissions, and small vehicles may have larger CO_2 values and related taxation.

7.3 On-board fuel consumption monitoring

Vehicles are fitted with an on-board fuel consumption meter (OBFCM) of which the value is displayed on the dashboard. From July 2020 until November 2021 TNO collected OBFCM data of 84 distinct vehicles including petrol, petrol hybrid, diesel and petrol plug-in hybrid vehicles. The included vehicles were mostly relatively new with low lifetime mileage records.

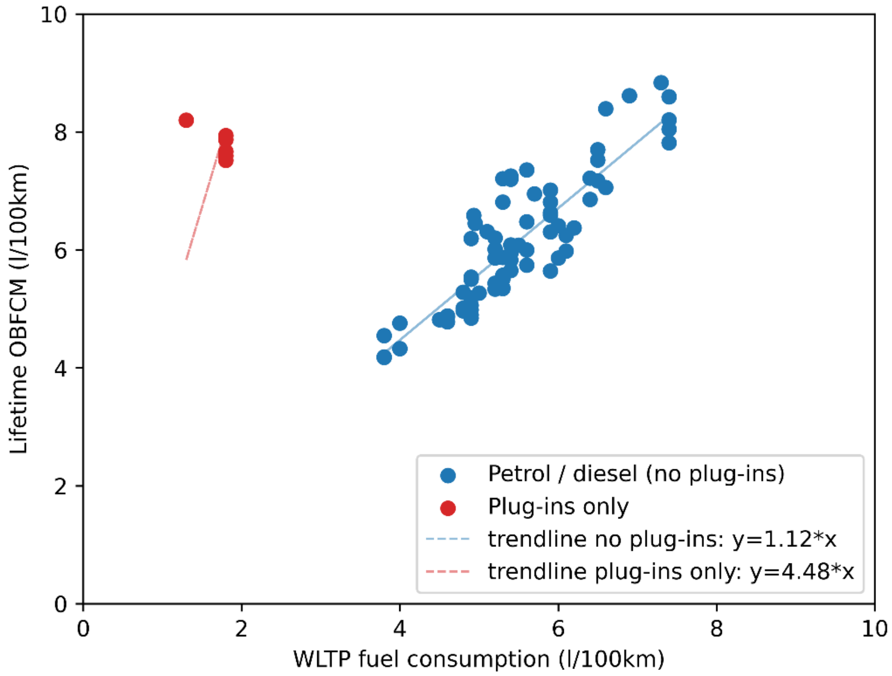

Figure 7-2: Comparing WLTP fuel consumption with OBFCM lifetime fuel consumption for non-plug-ins and PHEVs separately.

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[9] Support for the in-service verification of CO2 emissions of new light- and heavy-duty vehicles - Publications Office of the EU (europa.eu) and CO2 in-service verification test campaign and methodology development for light-duty vehicles - Publications Office of the EU (europa.eu)

The above scatter plot shows that the lifetime OBFCM readings of fuel consumption in l/100km are about 12% higher than the WLTP fuel consumption values for non-plug-in vehicles. For PHEVs the OBFCM readings are about 350% higher than the WLTP fuel consumption values. This is in line with the findings from the fuelling data for conventional vehicles, but deviates substantially for PHEVs, i.e., a factor 4.48 instead of 3. But the sample of PHEVs is small.

For 54 measurements except for lifetime OBFCM readings, also recent OBFCM readings are available. These are on-board readings of recent trips with the vehicle. It is interesting to study the variation in recent OBFCM readings as compared to lifetime readings.

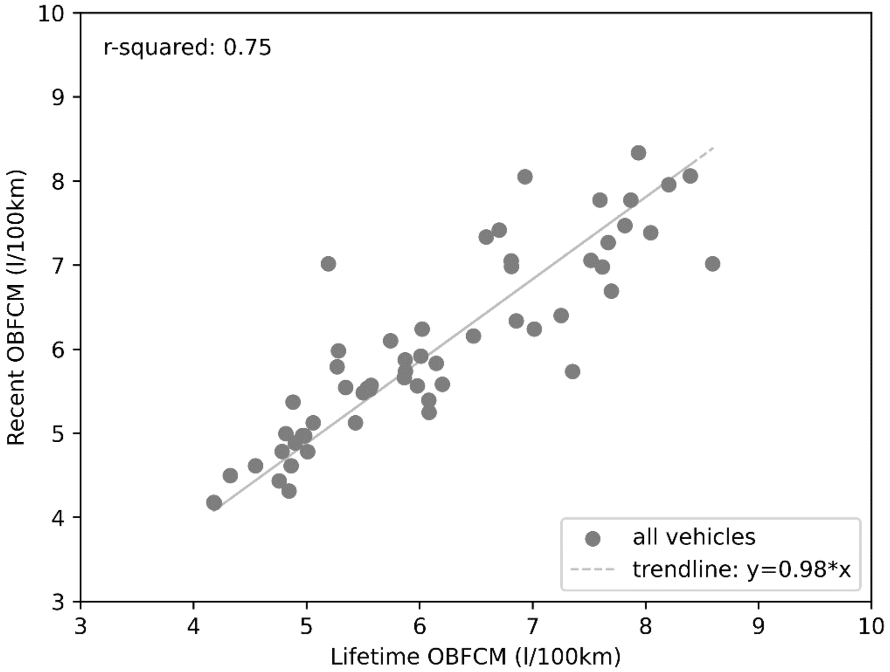

Figure 7-3: Lifetime OBFCM versus recent OBFCM including a measure of variation.

In the above scatter plot, a nice correlation between lifetime and recent OBFCM readings is found as one would expect, albeit partly because both data have an overlap in underlying trips. The variation in the data as compared to the average is measured by the coefficient of determination R^2. For this dataset, an R^2 of 0.75 is found implying that there is still a reasonable amount of variation in the data. This may be determined by seasonal conditions and driving behaviour (including external factors such as urban driving or motorway driving) amongst other things.

8 Conclusions

In this chapter the most important results are summarized, and placed in context of the series of studies.

8.1 Structural availability of CO_2 emission factors

With many recent requests, partly related to new policies on CO_2 reduction of the existing fleet and local authorities who want to assess the climate actions, TNO will from now on make CO_2 emission factors available, consistent with the emission factors for air quality (in CIMLK, Centraal Instrument Monitoring Luchtkwaliteit) and nitrogen deposition (in AERIUS). This is based on the average fleet composition on different road types for different years, including forecasts based on the KEV studies. These emission factors will be updated annually around the 15 of March, which is the legal date for updating the emission factors for air-quality. The changes in CO_2 emissions factors, as they are derived from this and other studies are incorporated.

8.2 Suitability of WLTP for real-world use

WLTP CO_2 values are higher than the NEDC CO_2 values, thus closer to the real-world CO_2 values and in principle the WLTP CO_2 values are better on average. However, the same conclusion does not hold for individual vehicles. A lower CO_2 WLTP value does not guarantee a lower real-world CO_2 emission. Deviations are larger. This seems to suggest that the WLTP is not so much more representative than the NEDC, but it has higher CO_2 values for different reasons, like the shares of urban, rural, and motorway driving, or the test mass. Therefore, WLTP is less of an indicator, or ranking, for real-world fuel efficiency than the NEDC was in the past.

8.3 Increasing energy gap for electric vehicles

The trends for petrol and diesel cars, with an increasing difference between type-approval and real-world is now observed for the energy efficiency of electric cars. This is strongly correlated with the increase in vehicle weight, that completely reduces the increase in energy efficiency of electric cars. This is outside the additional effects like charging losses and energy consumers in the vehicle that also play a large role in the gap of energy usage, as, for example can be observed from seasonal effects. With a more detailed model for real-world energy use of electric vehicles, differences and trends can be analysed further.

8.4 The big squeeze in CO_2 range

The “big squeeze” continues. The declared CO_2 values are getting closer together every year for the last ten years. In the past, differences of over 50% in CO_2 values, mainly between small and large petrol cars were very common. Now the gap closes, with the large cars likely having more CO_2 reducing measures on board, that may be more effective on the WLTP than in real use.

The bandwidth in WLTP CO_2 values is limited and there is limited discernibility left in the declared values. This is of course also linked to the reduced correlation with real-world CO_2 values on individual vehicles. On average, the WLTP is a better reflection of real-world CO_2 emissions, but in individual cases a lower WLTP value may not correspond with a lower real-world fuel consumption.

8.5 The lowering of the motorway speed limit

The lowering of the speed limit led to a small reduction in CO_2 emissions per kilometre driven. Not all kilometres are driven on the motorway, therefore the effect is limited to few percent, retained after the end of the lockdowns, which interfered with this change. A reduction in overall CO_2 emissions of light-duty vehicles of a few percent still results in a substantial reduction of GHG emissions of 400-600 kton CO_2.

8.6 Candidates for ISV testing

So far, there are no specific outliers, with larger than usual gasps, between the declared and real-world CO_2 values. A deviation of more 25 g/km could be considered an additional reason to select a vehicle for ISV testing, based on the risk of underdeclared values. However, currently, it seems for appropriate to gain more understanding in the difference between the real-world and type-approval CO_2. This would also provide a better basis to use OBFCM data, than currently is available. Very likely, with the CO_2 targets based on the WLTP only to be in effect in 2025, or with large tax benefits as seen in the period 2012 to 2014, unlikely to occur again with the focus on the transition to electric vehicles.

9 Bibliography

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Signature

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