

Real-world fuel consumption and energy consumption of passenger cars and light commercial vehicles in the Netherlands 2024

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Summary

Nederlandse samenvatting

Travelcard B.V. is een bedrijf dat zakelijke rijders voorziet van een tankpas. Op deze manier wordt waardevolle data verzameld over het brandstofverbruik en energieverbruik in de praktijk op de Nederlandse openbare weg. Deze data kan worden gebruikt om de emissies van personenauto's en bestelbusjes uit de Nederlandse vloot in de praktijk in te schatten.

Dit rapport is gebaseerd op de Travelcard data en is het tweede rapport van TNO waarvoor voldoende WLTP jaren beschikbaar waren om de analyses alleen op de WLTP CO₂-waardes te baseren (behalve bij een terugblik tot voor 2018). Een aantal belangrijke bevindingen uit het rapport zijn als volgt.

- › De gemiddelde CO₂-uitstoot in g/km van diesel personenauto's gaat omhoog sinds 2022. Dit kan voor een groot deel worden verklaard door een toename in het gemiddelde gewicht van deze auto's. Echter, omdat de aantallen verkochte diesel personenauto's in recente jaren laag is, is het effect op de totale emissies klein.
- › Het percentuele gat tussen praktijk- en typekeur CO₂-emissies vertoonde een trend omlaag vanaf de start van de WLTP in 2018 tot 2022. Sindsdien wordt het percentuele gat tussen het praktijk- en normverbruik juist weer groter voor benzine en diesel personenauto's.
- › Als CO₂-uitstoot in de praktijk was gebruikt om de energielabels van benzine personenauto's te berekenen (in plaats van CO₂-waardes volgens de WLTP), dan zouden meer benzine personenauto's lage-uitstoot labels zoals A en B hebben gekregen, dan op basis van een WLTP-systematiek.
- › Er wordt ingeschat dat de nieuw geïntroduceerde utility factors voor plug-in hybride personenauto's op de WLTP, het gat tussen praktijk en WLTP CO₂-emissies zullen verkleinen van ongeveer 300% naar ongeveer 200% in 2027.
- › Energieverbruik in de praktijk van elektrische personenauto's neemt toe, terwijl WLTP energieverbruik tegelijkertijd daalt. Dit betekent dat het gat tussen het energieverbruik in de praktijk en op de WLTP groeit. De toename van het energieverbruik in de praktijk kan grotendeels worden verklaard door de toename in het gewicht van elektrische personenauto's.
- › De data van Travelcard kan worden geverifieerd aan de hand van Europese OBFCM data. De conclusie is dat de data van Travelcard op deze manier een goede representatie geeft van de Nederlandse vloot.
- › De data van Travelcard laat zien dat de impact van het verlagen van de maximumsnelheid van 130 km/u naar 100 km/u tussen 6u – 19u op de Nederlandse snelweg heeft geleid tot een algemene verlaging van ongeveer 3% (of ongeveer 5 g/km) in de CO₂-uitstoot van diesel en benzine personenauto's.

English Summary

Travelcard B.V. is a company that supplies business drivers with a fuelling card. Their data gives valuable insights in the real-world fuel and energy consumption of their customers on the Dutch public roads. Their data can be used to estimate real-world emissions of passenger cars and vans in the Dutch fleet.

This report based on the data from Travelcard is the second Travelcard report by TNO for which enough WLTP years were available to base the analyses solely on WLTP CO₂ values (except when looking back before 2018). Some important findings of this report are as follows.

- › On average the CO₂ emissions in g/km of diesel passenger cars are trending up since 2022, which is largely explained by their increasing average weight. However, numbers of diesel passenger cars sold in recent years are low, so the effect on total CO₂ emissions of this upward trend is small.
- › The percentage-wise gap between real-world and type approval CO₂ emissions was trending down since the WLTP start in 2018 until 2022 and has been trending up since 2022 for diesel and petrol passenger cars.
- › If real-world CO₂ had been used to calculate the Dutch energy labels of petrol passenger cars instead of type-approval CO₂ (with otherwise unchanged methodology), then more vehicles would get low-emissions energy labels such as A and B than when using a WLTP-based methodology.
- › It is estimated that the new utility factors introduced in the WLTP CO₂ values for PHEVs will decrease the gap between real-world and WLTP CO₂ from around 300% to about 200% in 2027.
- › Real-world energy consumption of the electric fleet is increasing over time, whilst WLTP energy consumption of the fleet is slightly decreasing. This means that the gap between real-world and WLTP energy consumption is increasing over time. The increase in real-world energy consumption can largely be explained by increased vehicle weight of EVs.
- › The Travelcard data can be verified with European OBFCM data and gives a good representation of the Dutch fleet.
- › The Travelcard data suggests that the impact of lowering the speed limit from 130 km/h to 100 km/h from 6h – 19h on the motorway has lead to about 3% (or about 5 g/km) lower overall CO₂ emissions for petrol and diesel passenger cars.

Contents

Summary	3
Contents	5
1 Introduction.....	6
1.1 Travelcard Dataset.....	6
1.2 Filtering and Methodology	6
1.3 Composition dataset	7
2 Background on legislation of light-duty vehicles	9
2.1 Euro 7	9
2.2 Utility factors for PHEVs.....	9
2.3 OBFCM	9
3 Real-world fuel consumption of passenger cars and vans	11
3.1 Trends in real-world CO ₂ emissions compared to WLTP-values (including increasing weight effects).....	11
3.2 The gap between real-world and type-approval CO ₂ -emissions	14
3.3 Trends in vehicle efficiency and weight for the European fleet	17
3.4 Energy labels and real-world fuel consumption	21
3.5 Catalogue price and real-world CO ₂ -emissions	25
4 Trends in fuel and energy consumption for PHEVs.....	27
4.1 Brief description of data and methodology	27
4.2 Percentage of electric driving per model	27
4.3 The effect of the new utility factors.....	30
5 Real-world energy consumption of BEVs	32
5.1 Brief description of data and methodology	32
5.2 Trends in real-world energy consumption compared to WLTP-values.....	32
5.3 Estimating real-world energy consumption per model.....	32
5.4 The effect of increasing vehicle weight	36
6 Changing circumstances and legislation	38
6.1 Comparison between Travelcard and OBFCM.....	38
6.2 The effect of 100 km/h on the motorway	41
6.3 Outliers	41
7 Conclusions.....	43
References.....	45
Signature	46
Appendix	
Appendix A: Formulas for the energy labels	47

1 Introduction

Travelcard B.V. is a company supplying businesses with fuel cards. Since 2013 TNO has analysed Travelcard fuel and energy consumption data dating back to 2004 to calculate real-world emissions and energy consumption of the Travelcard fleet¹. This data provides insights into real-world usage and can be used to estimate real-world emissions of the entire Dutch fleet. The dataset contains data about real-world fuel consumption up to 2004 and contains charge data of electric vehicles in the Travelcard fleet dating back to 2018.

1.1 Travelcard Dataset

The Travelcard data set includes the following fields:

- › **Licence plate:** The vehicle's licence plate number
- › **Time and date of transaction:** When the transaction occurred.
- › **Quantity:** The amount of fuel (in liters) or electricity (in kWh) consumed.
- › **Product:** The type of product used (petrol, diesel, electricity)
- › **Brand:** The brand of the fuel or charging station.
- › **City:** The location where the transaction took place.
- › **Odometer readings:** Manually entered by the client at the time of fuelling.

The fields Brand and City are not used in our analysis, but the others are.

This report uses the most recent Travelcard dataset, updated to include entries up to the end of June 2024. Specifically, data since the 1st of May 2023 until the 1st of July 2024, has been incorporated into the analysis.

1.2 Filtering and Methodology

1.2.1 Petrol and Diesel vehicles

Due to potential inaccuracies in the data, we applied several filters to ensure the reliability of the dataset. Transactions were excluded if the distance travelled since the last fuelling event was less than 100 kilometres or if the fuel consumption fell outside a realistic range of 2 to 50 l/100km. Additionally, statistical methods were employed to identify and remove outliers. This filtering process improves the quality of the data, enabling more robust analysis.

1.2.2 PHEVs

The dataset includes information on approximately 19 000 petrol PHEV registrations and 2 100 diesel PHEV registrations. Among these, about 7 400 petrol registrations and 80 diesel registrations include fuelling events recorded after the 31st of April 2023, adding new data points not covered in the previous report.

¹See the TNO repository for older Travelcard reports: <https://repository.tno.nl/>

1.2.3 Electric vehicles

The travelcard dataset lacks odometer readings for electric vehicles on a charge-to-charge basis. To resolve this, BEV registrations are linked to odometer data from the RDW NAP database. Missing data may occur due to factors like foreign charges that may not appear in the data or unmetered charging points such as home charging. Before the 1st of May 2023, home charging of BEVs was not available in the Travelcard data. After this date it was observed that instances of home charging had been added to the available charging events. However, it is not clear whether the home charging data in the Travelcard dataset is now complete or whether there are still home charging events structurally missing. To mitigate the risk of missing charges, careful filtering and validation was performed on the BEV data.

Matching charging and odometer data

To process the charging data, we first remove any negative charges and then segment the data into charging sequences based on uninterrupted charging periods. A sequence is considered valid if it meets specific criteria, including having a minimum number of charging events (at least 10), a timespan of at least 14 days, and no excessive gaps between charges. Once valid charging sequences are identified, they are matched with corresponding odometer data. The odometer readings are considered valid if they fall within the sequence's start and end dates or extend up to 45% beyond these dates in either direction.

If the initial matching process is successful, the energy consumption for each sequence is calculated by fitting the odometer data to the charging sequence, using linear interpolation or extrapolation where necessary. In cases where no good match between charging sequences and mileage data is available, an alternative approach is used, focusing on the longest uninterrupted charging sequence with at least 10 events. A linear regression is applied to estimate the vehicle's average annual energy consumption and kilometres driven. If the regression fits poorly (R-squared below 0,9), the vehicle data is excluded from further analysis. A more detailed description of this method can be found in last year's report [1].

Filtering

The dataset for this analysis includes 29,03 million car records, covering 131 187 unique license plates from Travelcard data. After merging with RDW data and filtering out plug-in hybrids and ICE vehicles, charging and odometer data were obtained for about 65 000 BEVs.

To filter out unrealistic data, BEVs with energy consumption values below 70% or above 250% of their WLTP values were excluded. Additionally, BEV model combinations with fewer than 10 registrations were removed, along with outliers exceeding two standard deviations. The filtering process reduced the dataset to approximately 58 000 vehicles with valid charging and odometer data. Among these, about 57 600 vehicles also included WLTP energy consumption values.

1.3 Composition dataset

The dataset we receive from Travelcard consist of 202 million car records. After filtering 82 million records remain, this is 41% of the original data. Figure 1.1 shows the composition of these records. Figure 1.2 shows us the number of unique vehicles in the filtered Travelcard dataset. In this figure, PHEV are included in respectively diesel and petrol, they are later filtered out for separated analysis. We see that on average there are 74 fuelling events for benzine vehicles, 86 fuelling events for diesel vehicles and 221 for electric vehicles in the dataset.

The dataset is updated with new data from 1st May 2023. Analysing this new data, we see that we have 2,4 million benzine fuelling events and 1,1 million diesel fuelling events added, over a period of 1 year and 2 months. This is about 8 000 fuellings, either diesel or benzine, per day.

It is worth noting that some vehicles are occasionally recorded under multiple fuel types in the Travelcard database, e.g. being listed as both diesel and petrol. Subsequent analyses compare the dataset against RDW records to assign the correct fuel type to each vehicle and this fuel type is used in all subsequent analyses. This ensures a higher degree of accuracy in the conclusions drawn from the data.

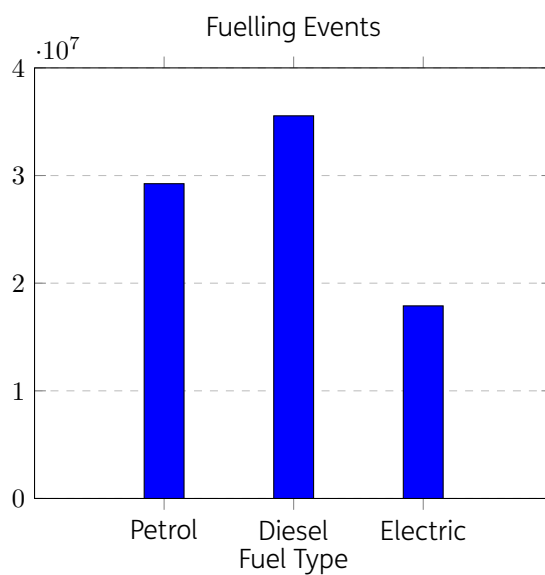


Figure 1.1: Fuelling events in the Travelcard dataset, after filtering.

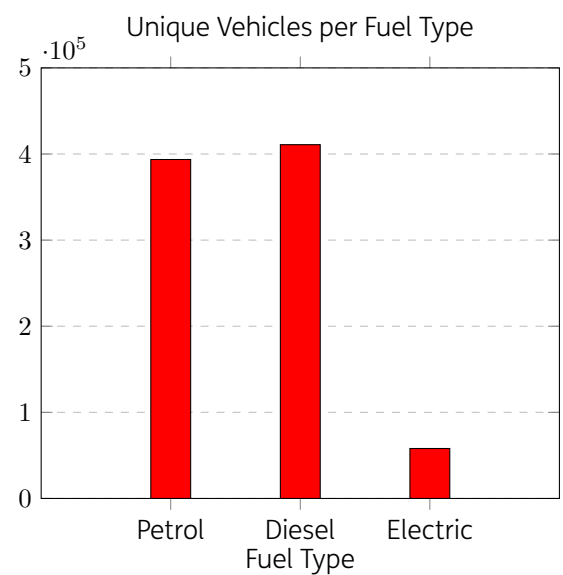


Figure 1.2: Unique vehicles per fuel type in the Travelcard dataset, after filtering.

2 Background on legislation of light-duty vehicles

2.1 Euro 7

On the 29th of May 2024 the Regulation (EU) 2024/1257 [2] entered into force introducing the framework of the new Euro 7 emissions legislation superseding the previous Euro 6 legislation for light-duty vehicles. The implementing act containing all legislative details for light-duty is expected at the end of May 2025. All new (light-duty) type approvals must comply with the Euro 7 legislation from the 29th of November 2026, and all new (light-duty) vehicles from the 29th of November 2027. Euro 7 tailpipe emissions for light-duty are identical to the Euro 6 limits except small changes in the particle number limits, e.g. PN10 instead of PN23 and no exemption for indirect injection engines. Besides tailpipe emissions, Euro 7 sets limits for evaporative, brake wear and tyre wear limits although the latter will go into force later than the first compliance dates of Euro 7. Euro 7 also introduces extended lifetime requirements and battery durability requirements. All in all, Euro 7 is expected to be the final European legislation in terms of standards on tailpipe emissions, but for other types of emissions and requirements further sharpening of Euro 7 regulations is possible.

2.2 Utility factors for PHEVs

Due to overwhelming evidence, including previous Travelcard reports by TNO, it has become clear that the gap between real-world emissions and WLTP emissions of plug-in hybrid electric vehicles (PHEVs) is large, see [3, §4.2]. For a large part, this gap is explained by the so-called utility factors for PHEVs supplying a formula to account for the amount of electric driving which does not correspond closely to driving and charging behaviour seen in practice. To counter this, the European Commission has introduced a new formula for the utility factors of PHEVs that will go into effect at the beginning of 2025 and 2027 in Regulation (EU) 2023/443 [4]. With these new utility factors the gap between real-world emissions and type-approval emissions will gradually decrease compared to the current situation. In this report, the new utility factors have been examined and their effect on the gap between real-world and type approval emissions of PHEVs.

2.3 OBFCM

The OBFCM (On-Board Fuel Consumption Meter) is an instrument on the vehicle. Since 2020, the European Commission has been required to monitor the fuel consumption of most new passenger cars and vans and for all new passenger cars and vans from 2021 [5]. Manufacturers must collect and record this information and provide it to the European Commission for each vehicle. The idea behind this data collection is to reduce the discrepancy between the fuel consumption provided by the manufacturers and what is obtained under real-world conditions.

The reason for including the OBFCM data in this study is to verify, in part, the validity of the data obtained from Travelcard. It can also be used to compare the performance of vehicles in the Netherlands when compared to the rest of Europe.

The OBFCM data used in this study are those from 2021 and 2022 that includes new vehicles sold in 2021 and 2022 along with their fuel consumption.

3 Real-world fuel consumption of passenger cars and vans

3.1 Trends in real-world CO₂ emissions compared to WLTP-values (including increasing weight effects)

In Figure 3.1 real-world emissions are compared with type-approval emissions for petrol and diesel passenger cars in the Travelcard fleet. For petrol passenger cars, we see a modest downward trend in both real-world and WLTP CO₂ emissions. For diesel passenger cars, we see a similar downward trend until mid-2022. From then on, we see a strong upward trend for diesel, which is caused by the increased average weight of the diesel fleet, as seen in Figure 3.2. It should be noted that in recent years low numbers of diesel passenger cars were sold in the Netherlands, making the impact of this upward trending graph for diesel passenger cars on total CO₂ emissions small.

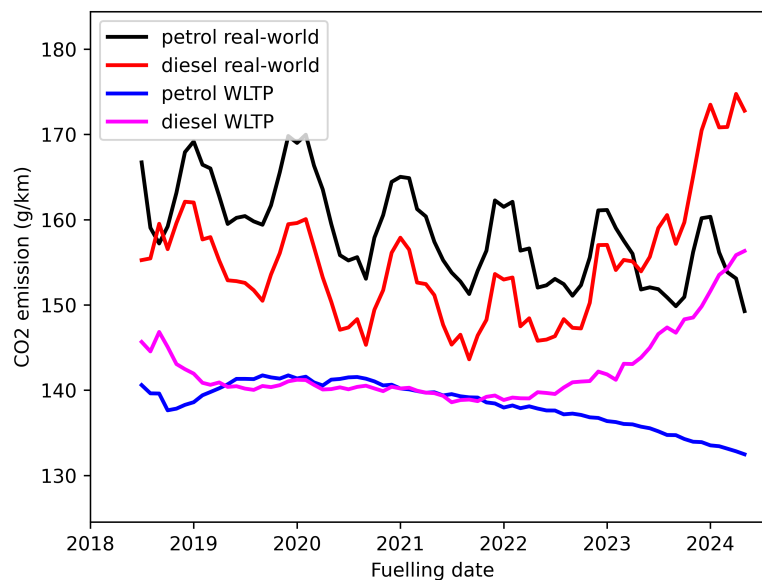


Figure 3.1: Real-world and WLTP CO₂ emissions of petrol and diesel passenger cars in the Travelcard fleet excluding diesel vans and excluding plug-in hybrid vehicles.

In Figure 3.2 WLTP CO₂ emissions are compared with the average empty vehicle mass of the Travelcard fleet over time, for petrol and diesel passenger cars. It is clearly observed that since the start of WLTP the average weight of the petrol passenger cars in the Travelcard fleet is stable, whilst average WLTP CO₂ emissions are decreasing. This is probably a combined effect

of increased powertrain efficiency (as measured by CO₂ per kg of empty vehicle weight; see §3.3) and a (further) decoupling of real-world and WLTP CO₂ emissions since 2022 (see §3.2). For diesel passenger cars, weight and WLTP CO₂ emissions are stable until mid-2022. From then onwards, we see the weight steadily increasing indicating that in recent years the Travelcard fleet of diesel passenger cars exhibits an ever stronger bias towards heavier vehicles – a trend that is also observed at a European level, see Figure 3.12.

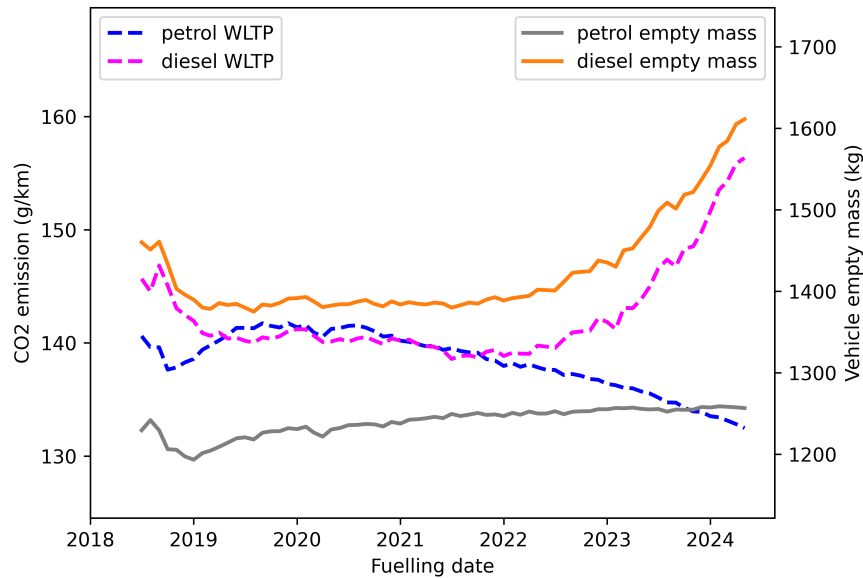


Figure 3.2: WLTP CO₂ emissions and average vehicle empty mass for petrol and diesel passenger cars in the Travelcard fleet.

In Figure 3.3 it is clearly observed that there is no significant downward trend in the real-world CO₂ emissions of plug-in hybrid electric vehicles (PHEVs). However, WLTP CO₂ emissions have been steadily declining since the start of the WLTP. Moreover, the gap between WLTP and real-world CO₂ is large, which will be addressed further in §3.2 and §4.3.

In Figure 3.4 it is observed that real-world and WLTP CO₂ emissions of diesel vans are relatively stable since 2020, possibly with a very slight upward trend.

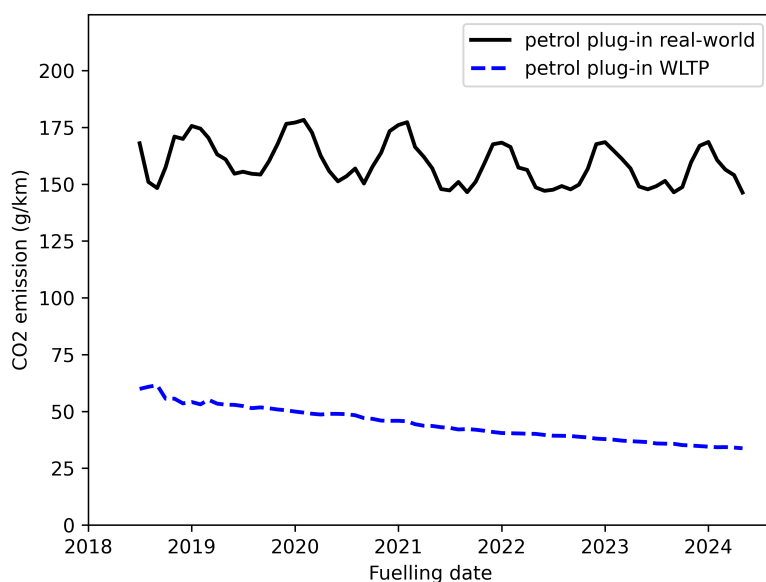


Figure 3.3: Real-world and WLTP CO₂ emissions of petrol plug-in hybrid vehicles in the Travelcard fleet. Electric energy use of the PHEV was not accounted for in this picture.

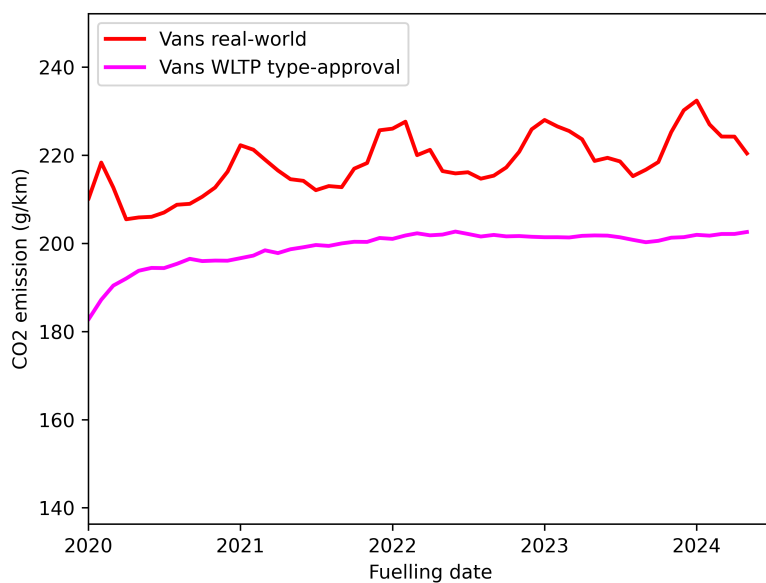


Figure 3.4: Real-world and WLTP CO₂ emissions of diesel vans in the Travelcard fleet.

3.2 The gap between real-world and type-approval CO₂-emissions

In this section the gap between type-approval CO₂ emissions and real-world CO₂ emissions is analysed in various ways.

3.2.1 Real-world vs WLTP CO₂ per year of manufacture

In Figure 3.5 and Figure 3.6, this gap is visualised as the distance to the blue dotted line per manufacturing year for diesel and petrol passenger cars. For petrol passenger cars manufactured between 2018 and 2020, the absolute deviation from type-approval emissions is nearly constant. From manufacturing year 2021 onwards, we see a yearly (absolute) increase in the gap for petrol passenger cars. This may be explained by manufacturer emission targets being based in part on the WLTP CO₂ manufacturer fleet averages of 2020 (See Annex I, Part A, point 6.0 of Regulation (EU) 2019/631 [6]). This approach implies that given higher average WLTP CO₂ emissions before 2021 a manufacturer was asked to be compliant with less ambitious reduction targets for the 2025 – 2035 period. This may have incentivised manufacturers to have relatively high WLTP CO₂ until 2020, in order to have less ambitious fleet reduction targets later on.

For diesel passenger cars, we clearly see the increased vehicle weight in Figure 3.6 for recent manufacturing years. The recent years' diesel passenger cars are somewhat distorted by vehicle types, such as diesel ambulances, that we would normally not associate with the M1-category. These are nonetheless, due to their transporting of persons instead of goods, classified as M1 in the European framework. Due to the large vehicle weight effect, it is difficult to assess whether other effects are at play for diesel passenger cars. It should also be noted that the number of diesel passenger cars sold in the Netherlands are very low in recent years, making their impact on total emissions small for recent years of manufacture.

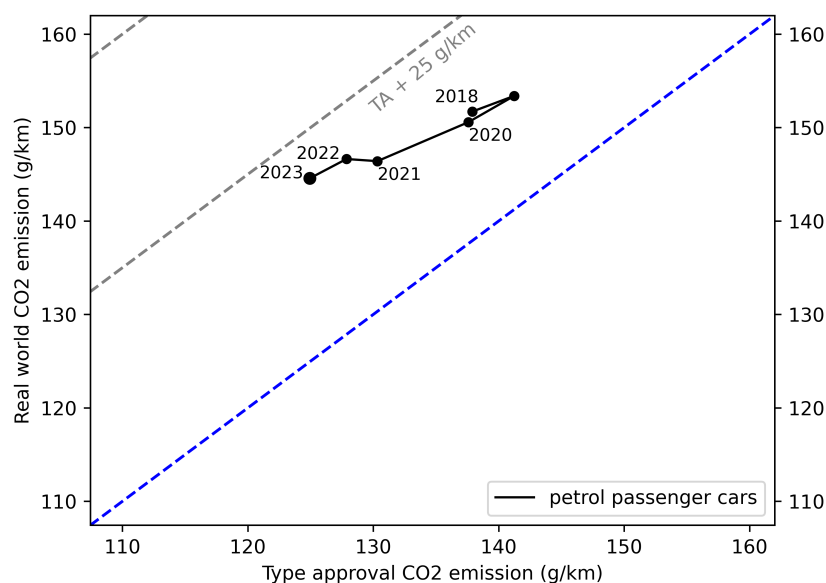


Figure 3.5: Evolution of the difference between real-world and WLTP CO₂ emissions of petrol passenger cars in the Travelcard fleet per year of manufacture (excluding plug-in hybrids).

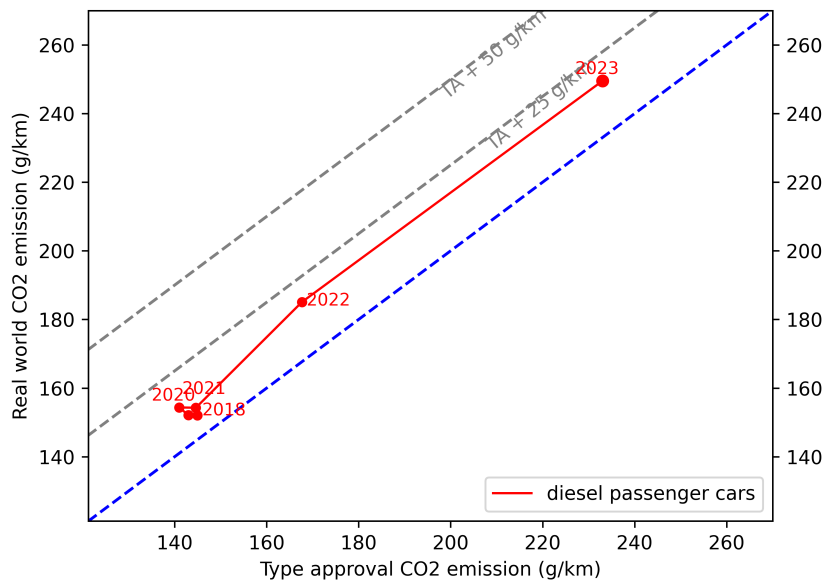


Figure 3.6: Evolution of the difference between real-world and WLTP CO₂ emissions of diesel passenger cars in the Travelcard fleet per year of manufacture (excluding plug-in hybrids).

In Figure 3.7, a similar analysis is executed for diesel vans. For diesel vans, both type approval and real-world CO₂ emissions rise sharply between manufacturing years 2018 and 2020, which is again caused by an increased vehicle weight over these years. Since the manufacturing year 2020, the picture seems more stable, although (similar to petrol passenger cars) the real-world CO₂ emissions seem to deviate a little further from the type approval CO₂ emissions with each new manufacturing year.

3.2.2 Percentage-wise gap between real-world and WLTP CO₂

In Figure 3.8, the relative gap between real-world and WLTP CO₂ emissions as a percentage is analysed for petrol and diesel passenger cars in the Travelcard fleet (excluding PHEVs). The gap for petrol passenger cars is about 15% and for diesel passenger cars it is about 10%. The same phenomenon is observed in Figure 3.5, i.e. the gap is decreasing until the beginning of 2022 in terms of fuelling date. This coincides with the moment in time when year of manufacture 2021 and later start to form an ever larger share of the Travelcard fleet at every fuelling date. As these manufacturing years form a larger share, the decrease in the gap first levels off and then the gap starts to increase again. As described in §3.2.1, manufacturers may have been incentivised until 2020 to report higher WLTP CO₂ emissions. Another effect that may be at play, is the change in the motorway speed limit in March 2020 from 130 km/h to 100 km/h during the day. The effect of this measure is studied further in §6.2 This may be a secondary reason why the gap is decreasing from 2019 until 2021. However, as the gap has been increasing since (the beginning of) 2022 with unchanged legislative conditions, this gap is expected to grow further over time.

In Figure 3.9 a similar analysis is performed for petrol PHEVs in the Travelcard fleet only. As observed earlier in the chapter, WLTP CO₂ emissions of PHEVs are low and decreasing whilst real-world emissions are virtually constant and high. Therefore, we see a massive relative gap

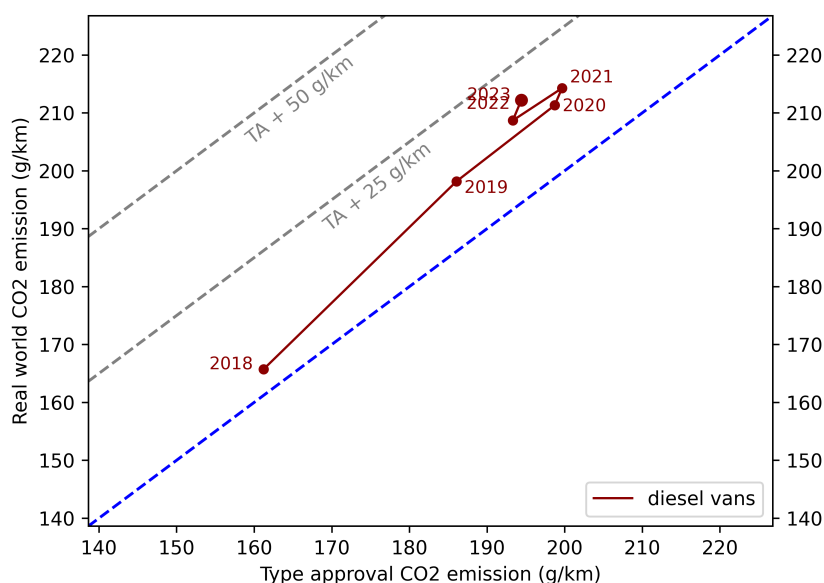


Figure 3.7: Evolution of the difference between real-world and WLTP CO₂ emissions of diesel vans in the Travelcard fleet per year of manufacture (excluding plug-in hybrids).

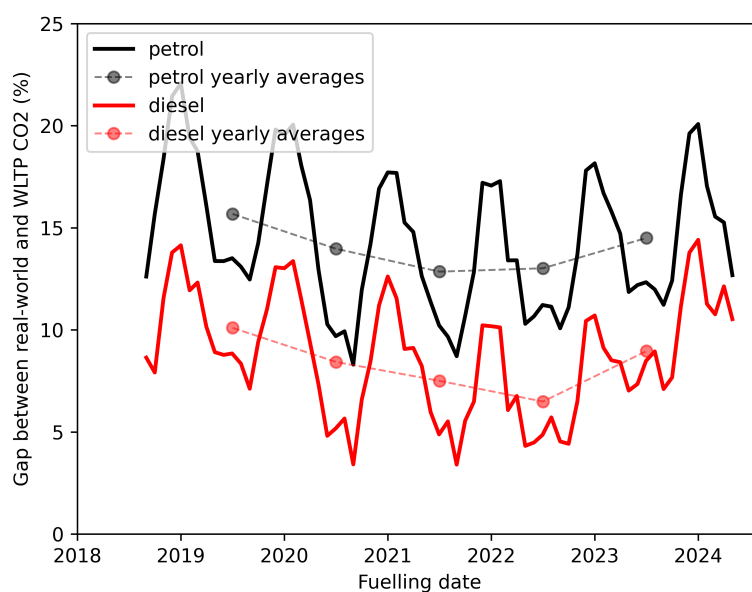


Figure 3.8: Evolution of the percentage-wise gap between real-world and WLTP CO₂ emissions of petrol and diesel passenger cars in the Travelcard fleet (excluding plug-in hybrids).

between real-world and WLTP CO₂ emissions for plug-in hybrids in Figure 3.9 – starting around 200% near the introduction of WLTP and reaching to around 350% for recent fuelling dates. To address this gap, the calculation of WLTP CO₂ is changing in 2025 and 2027, which is addressed in §4.3.

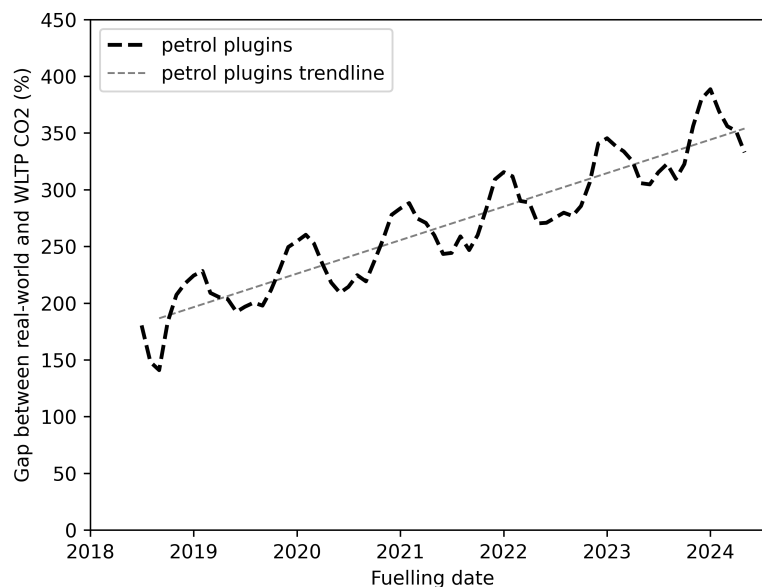


Figure 3.9: Evolution of the percentage-wise gap between real-world and WLTP CO₂ emissions of petrol plug-in hybrid passenger cars in the Travelcard fleet.

3.3 Trends in vehicle efficiency and weight for the European fleet

The European Environment Agency (EEA) publishes data of all the newly sold passenger cars and vans in Europe every year [7]. This data was used to get more insight into the developments in the European fleet of light duty vehicles. In a report published by TNO [8] in 2021, the EEA data was analysed to study the effect of weight on the WLTP CO₂ of vehicles and how the developments in the mass of the vehicles over the years has impacted the WLTP CO₂. The difference in the WLTP and NEDC emission tests was also quantified. An update was done on this analysis to check the trend in increasing mass of the vehicles in Europe and how it impacts the emissions of these vehicles. By considering WLTP CO₂ per kg of (empty) vehicle weight, we get a measure for improved vehicle efficiency over time. There are on average 12 million new passenger cars and 1 million new vans in the EEA data-set. This number is less in the last year of publication of this data (2022) mostly owing to the COVID-crisis.

It is important to note that the EEA data does not differentiate between plug-in and non-plug-in hybrids. So, in this section, hybrid would mean a mix of both plug-in and non-plug-in. This is different when compared to the rest of the report where it is specified what kind of hybrid is in question.

3.3.1 European fleet of passenger cars

The number of passenger cars in the EEA data-set [7] are as follows:

Figure 3.10 shows the upward trend in the mass of vehicles. This is more prominent for electric and petrol-hybrids than for conventional petrol and diesel vehicles. EEA data does not differentiate between plug-in and non-plug-in vehicles; therefore, the petrol hybrids contain both. It is interesting to see that hybrids are heavier than electric cars, but the increase in their

Table 3.1: Total number of passenger cars in the EEA data-set per year. Note: The EEA data does not differentiate between plug-in and non-plug-in hybrids. The hybrids in this table consists of both.

Year	DIESEL	DIESEL_HYBRID	ELECTRIC	OTHER	PETROL	PETROL_HYBRID	Total
2010	6 730 452		5 334	465 809	5 919 489		13 121 084
2011	7 047 957		14 299	167 258	5 506 517		12 736 031
2012	6 591 649	165	12 950	248 565	5 129 288	5 420	11 988 037
2013	5 896 408	8 482	23 046	805 449	5 049 313	21 767	11 804 465
2014	6 638 320	7 335	36 659	237 351	5 532 963	60 983	12 513 611
2015	7 125 806	14 190	55 585	230 879	6 227 315	90 702	13 744 477
2016	7 262 163	6 377	62 795	353 463	6 906 330	87 335	14 678 463
2017	6 731 983	5 958	97 295	209 846	7 927 495	119 358	15 091 935
2018	5 513 738	3 359	149 889	244 278	9 069 863	149 966	15 131 093
2019	4 921 172	13 230	342 509	252 119	9 708 463	181 252	15 418 745
2020	2 981 185	252	669 297	205 630	6 488 372	473 589	10 818 325
2021	2 007 304	207	886 797	250 772	5 185 978	754 939	9 085 997
2022	1 369 089	184	901 955	259 899	3 919 013	642 699	7 092 839

weight is slightly less than electric vehicles. This means that although hybrid vehicles are heavier than electric vehicles in the data up to 2022, they are getting heavier more slowly than electric vehicles. The increase in mass of conventional petrol and diesel cars is about half as fast hybrids/electric vehicles. It should however be noted that the mass definitions have also changed with the change from NEDC to WLTP measurements.

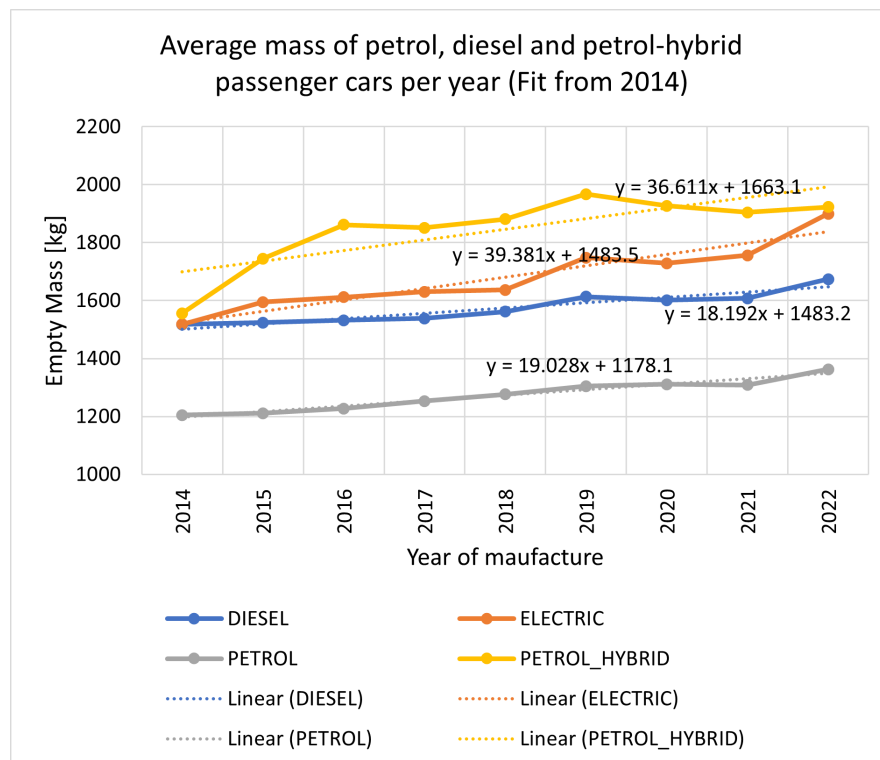


Figure 3.10: Average mass of passenger cars over the years in Europe per fuel-type. The linear fit is to show the overall trend. The EEA data does not differentiate between plug-in and non-plug-in hybrids. The hybrids in this figure consists of both.

To quantify the effect of transition from NEDC to WLTP CO₂ values, Figure 3.11 shows that the offset is quite large. It was chosen to have a trendline until 2017 since the majority of values reported were NEDC CO₂ while from 2020, the majority reported were WLTP CO₂ values. The years in between have a mix of both; hence, the trend line does not take this transition into consideration.

The first conclusion that can be drawn is that after the change in standards under the WLTP, type approval CO₂-values are at the level they were at roughly 10 years (resp. 6 years) earlier under the NEDC for diesel passenger cars (resp. petrol passenger cars). This is consistent with the findings in earlier Travelcard reports as well [1].

The minor fuel efficiency changes observed in the data are as follows:

- › Petrol passenger cars : -0,0028 g/(km*kg*year)
- › Diesel passenger cars: -0,00225 g/(km*kg*year)

As before, under the assumption that the average mass of a petrol passenger car is 1300 kg and that of a diesel passenger car is 1600 kg (see Figure 3.10), some fuel efficiency improvements can be calculated:

- › Petrol passenger cars: 3,64 g/km CO₂ reduction per year
- › Diesel passenger cars: 3,6 g/km CO₂ reduction per year

Therefore, it can be concluded that the petrol and diesel vehicles are improving at the same rate although the diesel cars have a larger offset than petrol cars – 1,3 times as high.

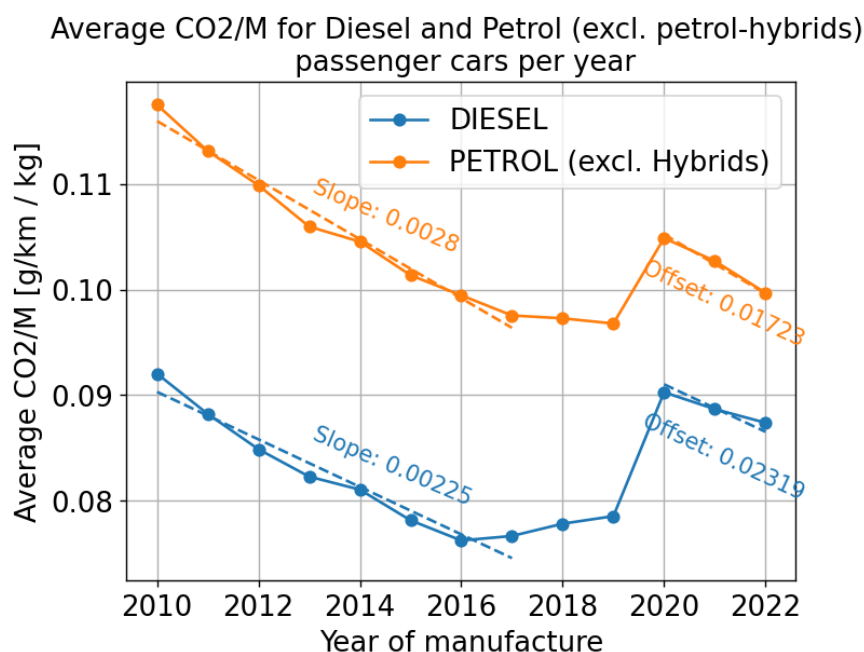


Figure 3.11: CO₂/M for petrol and diesel passenger cars. The offset shows the effect of WLTP CO₂ values from the NEDC CO₂ values.

3.3.2 European fleet of vans

Similar analysis can be done for vans. The number of vans in the EEA data-set are as in Table 3.2.

Table 3.2: Total number of vans in the EEA data-set per year of first registration. Note: The EEA data does not differentiate between plug-in and non-plug-in hybrids. The hybrids in this table consists of both.

Year	DIESEL	DIESEL_HYBRID	ELECTRIC	OTHER	PETROL	PETROL_HYBRID	Grand Total
2012	1 074 036		5 706	16 723	20 086		1 116 551
2013	1 132 553		6 681	76 904	24 394	5	1 240 537
2014	1 404 653	1	7 601	12 859	30 711	27	1 455 852
2015	1 445 525	2 160	8 705	11 862	27 959	278	1 496 489
2016	1 462 566	2	10 411	19 473	30 972	247	1 523 671
2017	1 605 232	6	14 187	14 326	41 208	44	1 675 003
2018	1 649 839	7	19 239	19 683	63 723	44	1 752 535
2019	1 645 053		24 998	23 423	60 124	229	1 753 827
2020	1 358 227	2	32 262	17 041	37 568	1 021	1 446 121
2021	1 203 292	425	44 980	20 407	48 227	1 740	1 319 071
2022	955 607	80	64 521	12 856	59 232	1 939	1 094 235

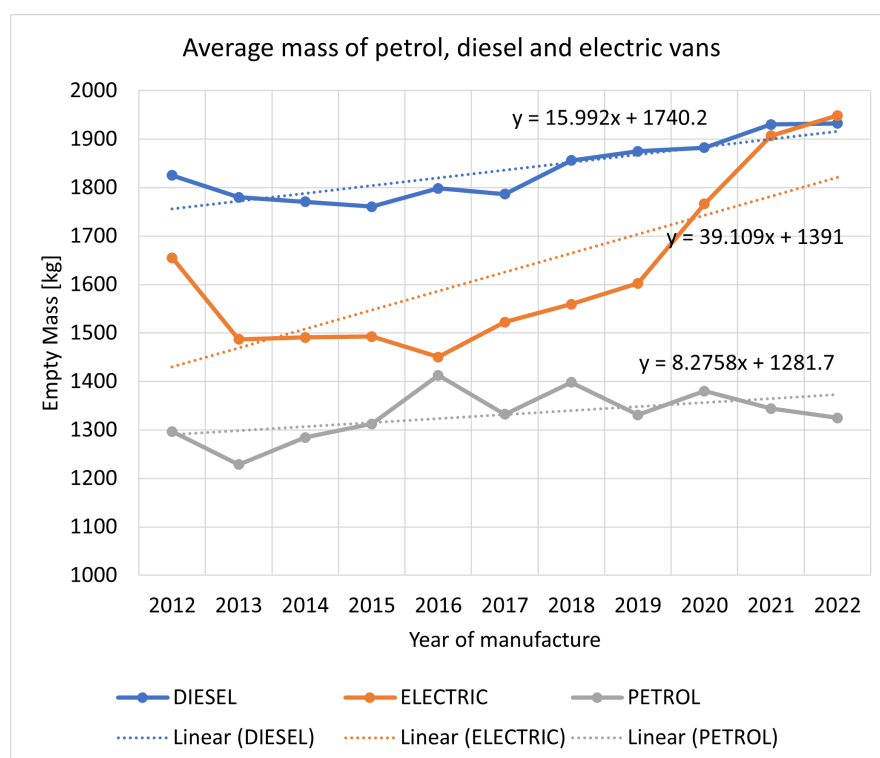


Figure 3.12: Average mass of vans over the years in Europe per fuel-type. The linear fit is to show the overall trend.

Figure 3.12 shows the trend in mass of vans. It can be seen that the mass of diesel vans has been increasing steadily while that of petrol vans (which are very small in number) has been steady. Diesel vans are, on average, getting heavier by 23,5 kg each year while electric vans are getting 63 kg heavier each year. This is almost a factor 2,7 higher than diesel vans. In the most recent years, the weight of diesel and electric vans is quite similar.

Figure 3.13 shows the downward trend of CO₂/M of vans. Similar to the case of passenger cars, NEDC CO₂ values were used for analysis until 2019 and WLTP CO₂ values were used after 2019.

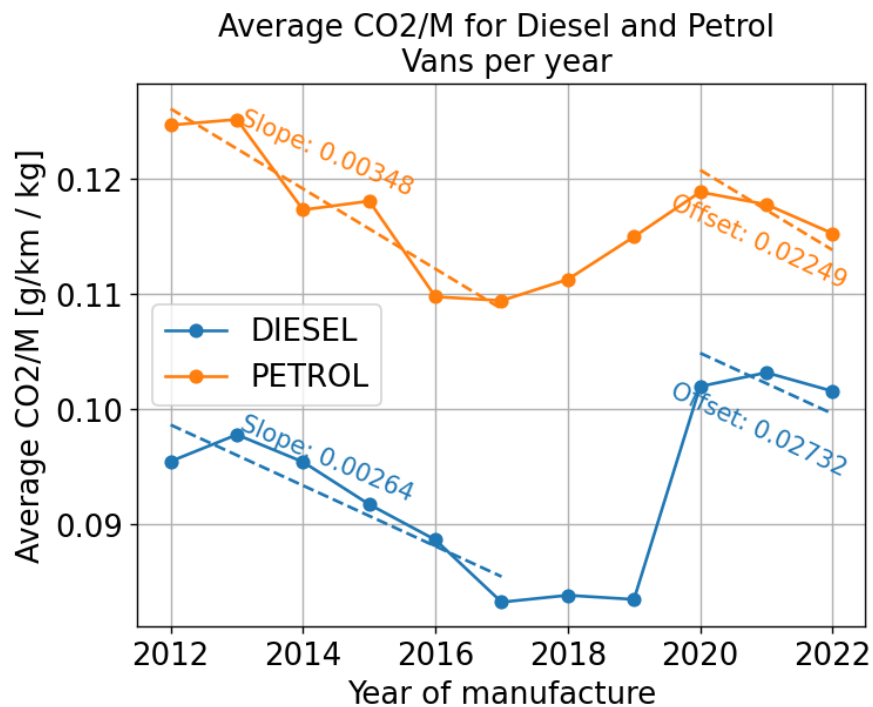


Figure 3.13: Average CO₂/M of vans over the years in Europe per fuel-type. The linear fit is to show the overall trend.

Similar to the case of passenger cars, the offset from NEDC to WLTP values leads to backward shift of a number of years. For petrol vans, the offset leads to a setback of 5-6 years while for diesel the offset is much larger. It leads to a shift backwards of over 10 years.

The fuel efficiency changes observed in the data are as follows:

- › Petrol vans: -0,00348 g/(km*kg*year)
- › Diesel vans: -0,00264 g/(km*kg*year)

Assuming an average mass of a petrol van to be 1300 kg and that of a diesel van to be 1850 kg (see Figure 3.12), the fuel efficiency improvements can be calculated:

- › Petrol vans: 4,5 g/km CO₂ reduction per year
- › Diesel vans: 4,88 g/km CO₂ reduction per year

The offset for diesel vans is higher than that of petrol vans - about 1,2 times higher, but because of the heavier mass of diesel vans, they are improving faster than petrol vans. It should be noted that the fleet of petrol vans is quite limited.

3.4 Energy labels and real-world fuel consumption

In this section, the Dutch energy label of passenger cars is analysed. Other EU countries may use different methodologies for calculating their energy label.

An energy label is a label that provides information to the consumer about energy consumption of a passenger car. An energy label is defined based on the relative energy

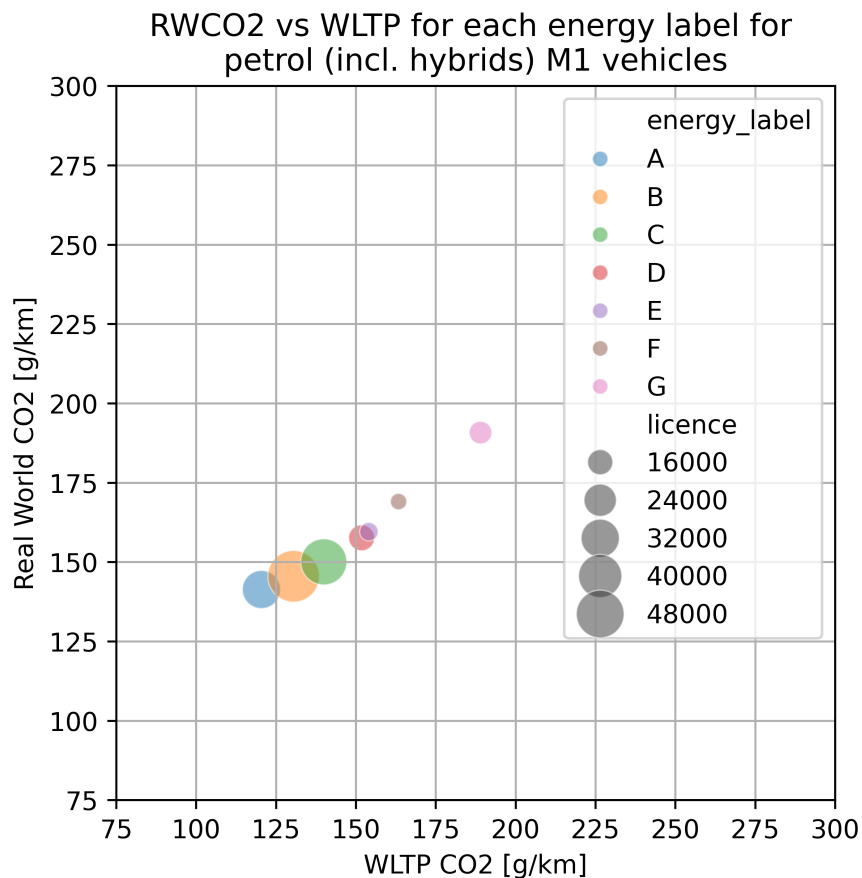


Figure 3.14: Real-world vs. WLTP CO₂ of petrol passenger cars (including hybrids and plug-in hybrids) using the 100% relative energy label formula. The size of the scatter depicts the number of vehicles in that group.

efficiency of the vehicle in question when compared to a reference petrol or diesel vehicle. The calculation of the relative energy efficiency is based on a set of regression formulas as defined in the directive for energy label [9]. The formulas can also be found in the Appendix A.

Due to the low numbers of diesel passenger cars sold in recent years, in this section only petrol passenger cars will be considered. The original formula contains a correction (see Equation A.1) in which only 75% of the vehicles' WLTP CO₂ value counts towards its energy label – the other 25% is an absolute factor for all passenger cars of that year of manufacturing. To highlight the relative effects of the energy label formula, in this section the relative energy efficiency of the vehicle without the 25% absolute correction factor is considered, i.e. a 100% relative energy label.

In Figure 3.14 the relationship between real-world and WLTP CO₂ is studied for the different energy labels (using the 100% relative formula). It is observed that although WLTP CO₂ and real-world CO₂ decrease with cleaner energy labels, as expected, the difference is not constant. The picture shows that the gap between WLTP CO₂ and real-world CO₂ is larger for energy labels A, B and C than for the other energy labels. For energy label A this is, in part, caused by plug-in hybrids with much higher real-world than WLTP CO₂ emissions.

In Figure 3.15 it is seen that the average vehicle footprint (length × width) increases with lower energy labels (using the 100% relative formula), except for energy label A. For energy label A,

Vehicle footprint for each energy label for petrol (incl. hybrids) M1 vehicles

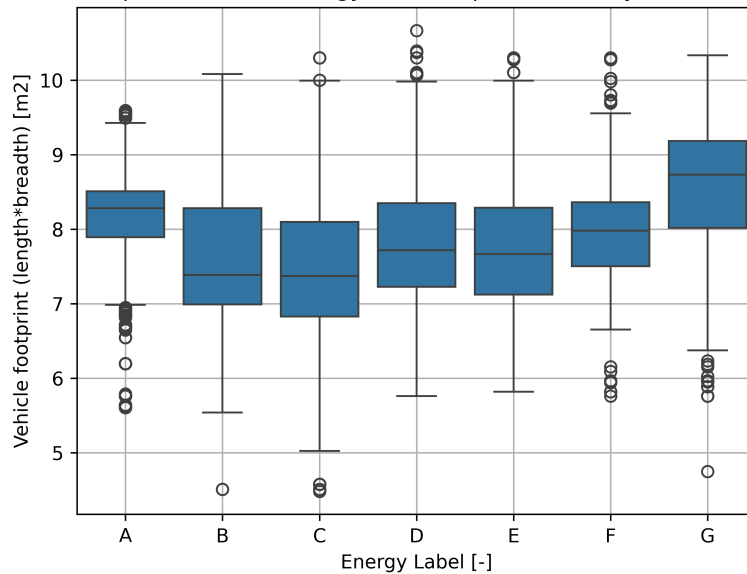


Figure 3.15: Average vehicle footprint and its variation per energy label for petrol passenger cars (including hybrids and plug-in hybrids) using the 100% relative energy label formula.

the hybrids and plug-in hybrids with low WLTP CO₂ values, but large vehicle footprint, are causing the average footprint to be substantially higher than for label B.

A further analysis is performed in Figure 3.16 of the relative energy efficiency of vehicles w.r.t. WLTP CO₂ as compared to real-world CO₂. The original energy label formula (see Appendix A) is based on a degree 2 polynomial regression fit that uses the vehicle footprint to predict the vehicle's WLTP CO₂. The vehicle's relative energy efficiency is then calculated as the (percentual) deviation of the vehicle's WLTP CO₂ as compared to the regression line. This is a value between, say, -50% and 150% indicating whether the vehicle has a high or low WLTP CO₂ value compared to what one would expect based on the fleet and the vehicle footprint.

A similar analysis may be performed, but rather use the vehicle footprint to predict the real-world CO₂. If these regression coefficients are calculated, by the same methodology as the energy label, we obtain a 'real-world relative energy efficiency'. In Figure 3.16 the real-world energy efficiency is compared to the WLTP energy efficiency of petrol passenger cars with year of manufacture 2023. It is observed that real-world energy efficiency calculated in this way on average gives lower percentages than the WLTP energy efficiency (see Table A.1). For petrol passenger cars with year of manufacture 2023, the conversion factor is about

$$\text{RelativeEnergyEfficiency}_{\text{RW-CO}_2} = 0,76 * \text{RelativeEnergyEfficiency}_{\text{WLTP-CO}_2}$$

Other years after the start of the WLTP have similar conversion factors for petrol passenger cars. It is emphasised that this does not imply that vehicles are performing better in the real-world than on the WLTP – in fact, this report shows they are performing worse. However, it may be concluded that the 'real-world energy label' (calculated using real-world CO₂ instead of WLTP CO₂) on average is cleaner than the original energy label of a petrol passenger car.

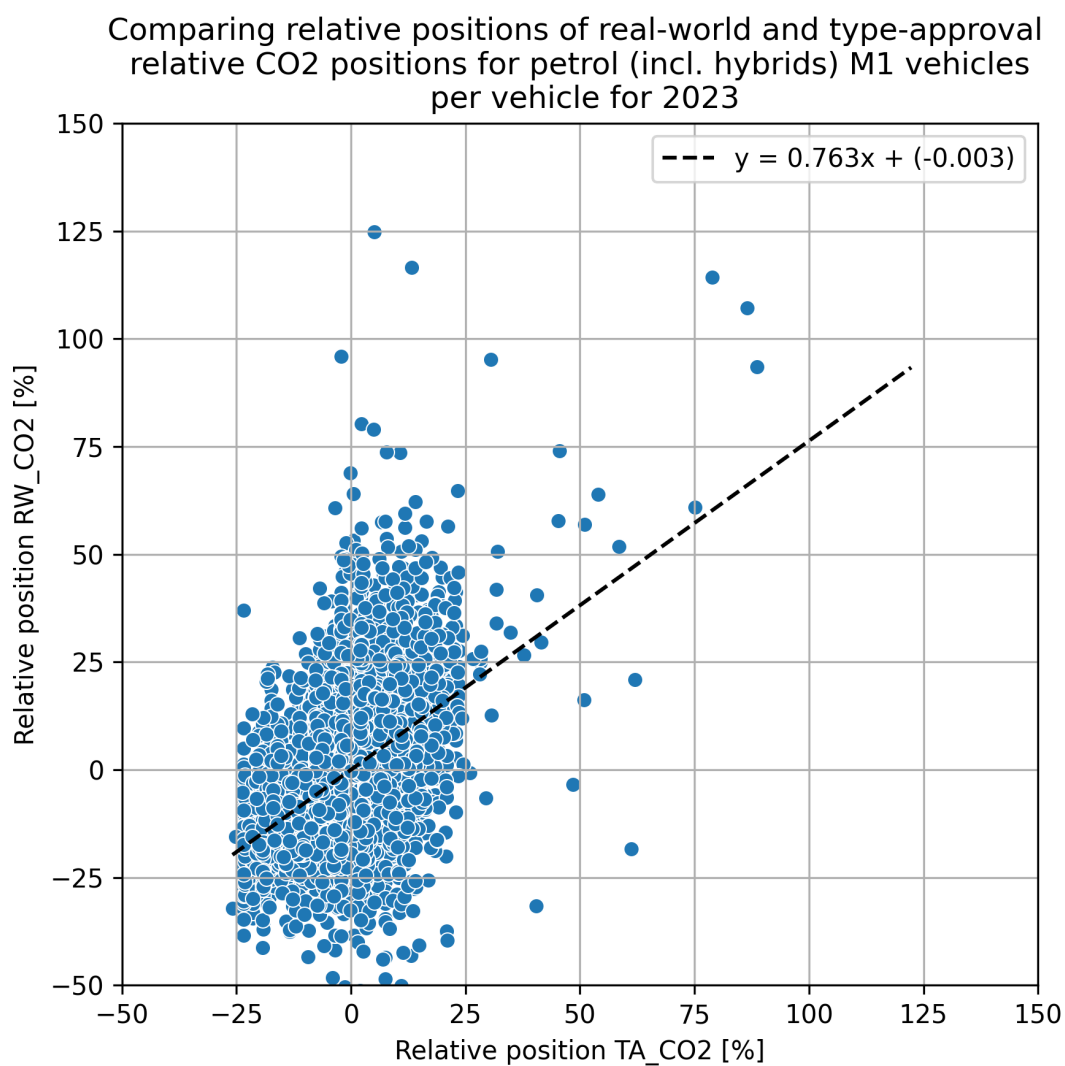


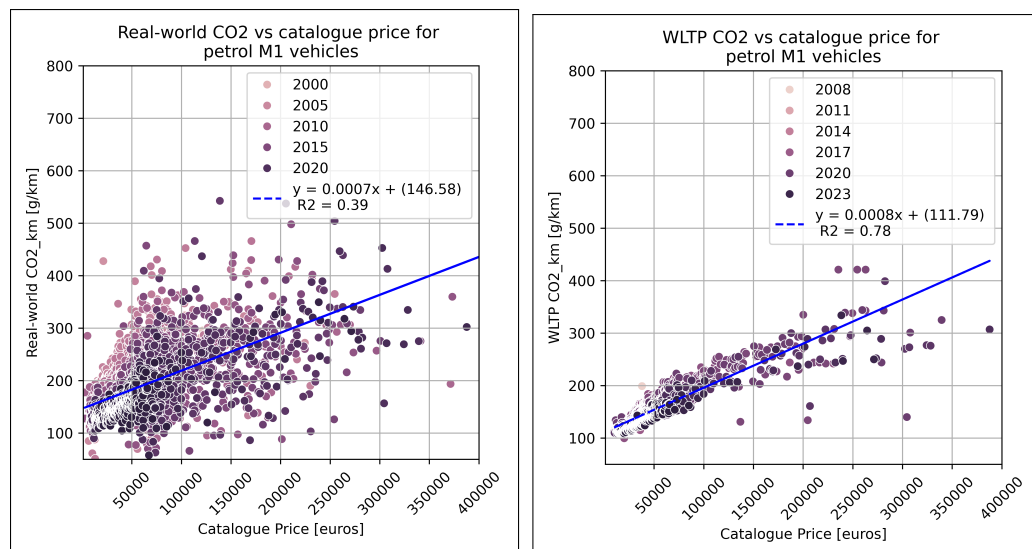
Figure 3.16: The relative energy efficiency of the real-world CO₂ vs. WLTP CO₂ per petrol passenger car (including hybrids and plug-in hybrids) with year of manufacture 2023.

3.5 Catalogue price and real-world CO₂-emissions

The RDW data gives insight into the catalogue price of a vehicle which could be compared to the WLTP CO₂ emissions and the real world CO₂ emissions. This section elaborates further on the relation between these variables.

Figures 3.17 through 3.19 show the trend of increasing CO₂ emissions (both real-world and WLTP) with increasing catalogue price for different years of construction of passenger cars and vans. There is a wider spread in emissions when measured in real-world as compared to the WLTP emissions. The trendline also remains almost the same with the difference in the intercept representing the difference in WLTP and real-world CO₂.

In case of passenger cars, as can be seen in Figure 3.17 and Figure 3.18, it can be seen that the real-world emissions and WLTP emissions have a very similar relation to the catalogue price. This is valid for both, petrol and diesel cars. The intercept shows the average difference between WLTP and real-world emission values.



(a) Real-world CO₂ vs. catalogue price for petrol passenger cars (b) WLTP CO₂ vs. catalogue price for petrol passenger cars

Figure 3.17: Real world and WLTP CO₂ comparison of catalogue price for petrol passenger cars.

For the case of vans, as seen in Figure 3.19, the real-world emissions rise less sharply with increasing catalogue price when compared with WLTP emissions. However, the slope value does not differ too much from passenger cars. This difference will get larger if newer vans are considered and compared - since the lighter dots representing older vans - will reduce in number - thereby also reducing the spread in real-world values.

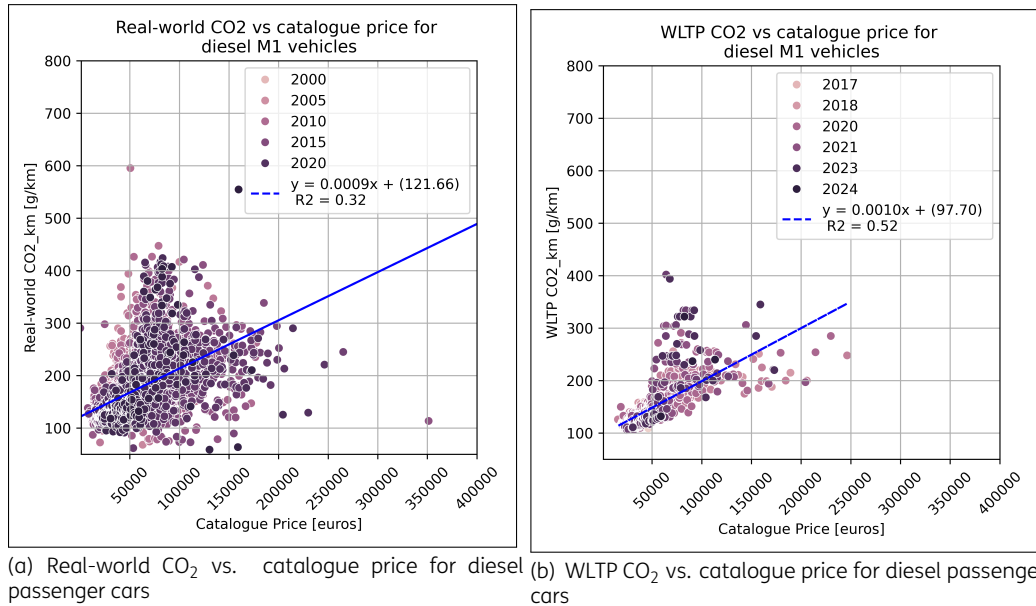


Figure 3.18: Real world and WLTP CO₂ comparison of catalogue price for diesel passenger cars.

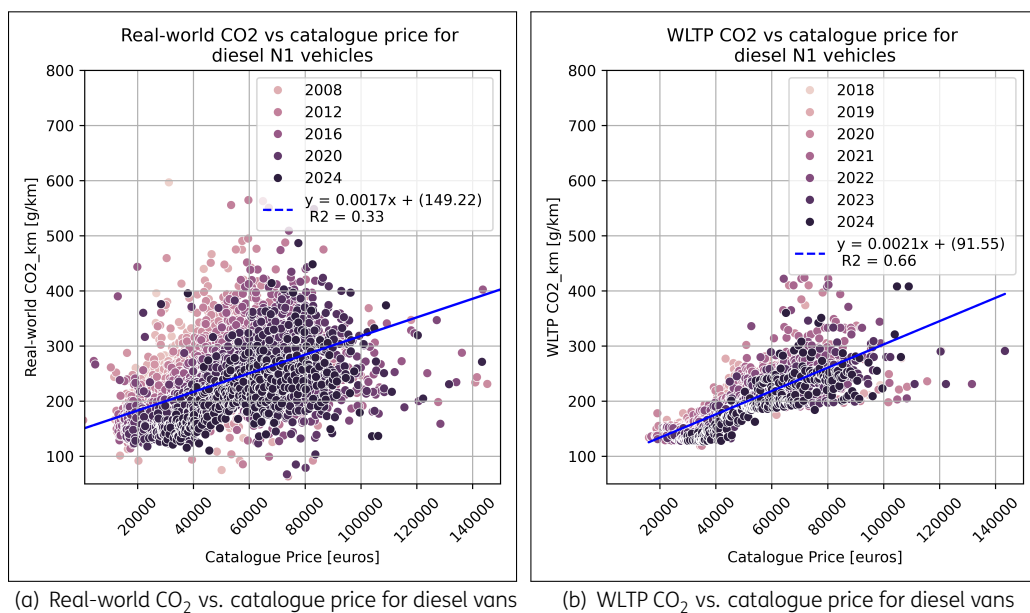


Figure 3.19: Real world and WLTP CO₂ comparison of catalogue price for diesel vans.

4 Trends in fuel and energy consumption for PHEVs

4.1 Brief description of data and methodology

This chapter evaluates trends in plug-in hybrid electric vehicles (PHEVs) based on the travelcard dataset.

4.2 Percentage of electric driving per model

This section analyses the percentage of electric driving on a model-by-model basis, focussing exclusively on models with over 1 500 fuelling events in the Travelcard dataset to ensure reliable results for each model.

PHEVs operate in three primary modes:

- › **Full EV Mode:** The vehicle is propelled entirely by the electric motor, with energy consumption sourced solely from the battery.
- › **Charge Sustaining Hybrid Mode:** Energy from regenerative braking and the engine is used to maintain a constant battery charge. In this mode, the electric motor supplements the internal combustion engine, enabling more efficient driving compared to a traditional internal combustion engine vehicle. This is similar to the operation of a hybrid vehicle without a plug.
- › **Charge Depleting Hybrid Mode:** In this mode, the battery's charge is gradually depleted. The vehicle's control prioritises using stored energy where it can most effectively reduce fuel consumption.

A frequency distribution of all fuelling events of a vehicle model is plotted in Figure 4.1 with its fuel efficiency (in kilometres per litre) on the x-axis. Similarly to a histogram, this graph shows the relative frequency of specific km/l value bins observed for a given PHEV model across available fuelling events. For example, if the Toyota Prius Plug-in Hybrid shows a frequency of 10% at 20 km/l, it means that 10% of the observed fuelling events for all Toyota Prius registrations had a fuel efficiency of 20 km/l.

When a vehicle operates solely in charge sustaining hybrid mode, the frequency graph appears symmetrical around its peak. Asymmetry in the graph reflects increased usage of full EV mode or charge depleting hybrid mode. From this distribution, the average fuel consumption in charge sustaining hybrid mode and overall fuel consumption can be inferred. These values are then used to calculate the percentage of electrically driving kilometres for each model.

Table 4.2 presents fuel efficiency (in l/100km) for PHEVs by model, showing both efficiency during internal combustion engine operation and overall driving. The percentage of electrically driven kilometres is calculated as the difference between these two values, expressed as a percentage of overall fuel efficiency. The analysis includes only models with at least 1 500 fuelling events recorded in the Travelcard dataset.

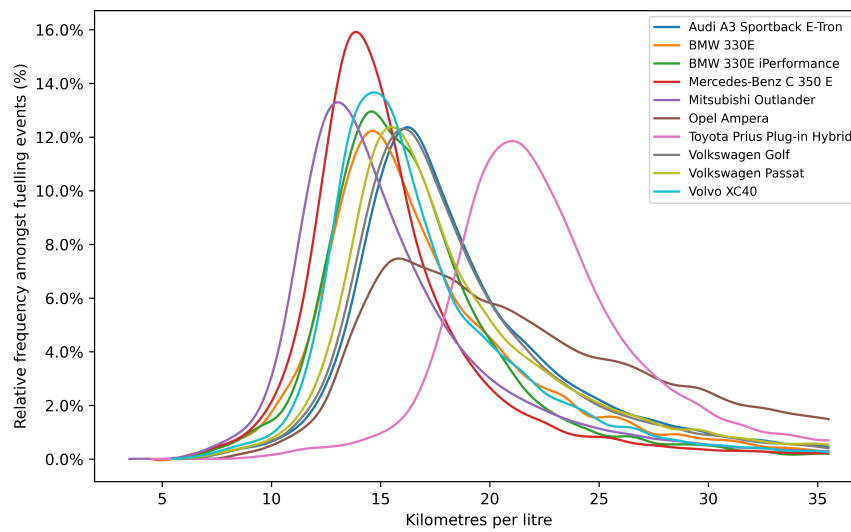


Figure 4.1: Relative frequencies of fuel consumption for PHEVs amongst all fuelling events by model. Only models with more than 10 000 fuelling events have been displayed.

Table 4.1:

Model	Fuel	Fuel efficiency on internal combustion engine [l/100km]	Fuel efficiency overall [l/100km]	Percentage electrically driven kms
AUDI A3	Petrol	6,77	5,44	19,6
AUDI A6	Petrol	7,57	6,28	17
AUDI Q3	Petrol	7,74	6,23	19,5
AUDI Q5	Petrol	8,53	6,61	22,5
BMW 225XE	Petrol	7,59	6,17	18,8
BMW 320E	Petrol	7,43	5,86	21,2
BMW 330E	Petrol	7,59	6,13	19,2
BMW 530E	Petrol	7,47	6,37	14,8
BMW 740E	Petrol	8,32	7,14	14,1
BMW 740LE	Petrol	8,19	7,41	9,5
BMW 745E	Petrol	8,06	7,11	11,8
BMW X1	Petrol	7,18	5,61	21,9
BMW X3	Petrol	8,50	6,62	22,1
BMW X5	Petrol	11,30	7,79	31
CHEVROLET VOLT	Petrol	6,48	4,53	30,1
CITROEN C5	Petrol	7,54	5,61	25,5
CUPRA FORMENTOR	Petrol	7,45	6,02	19,2

Continued on next page

Table 4.1: (Continued)

DS 7	Petrol	8,33	6,14	26,2
FORD C-MAX	Petrol	6,38	5,21	18,4
FORD KUGA	Petrol	6,39	5,02	21,4
HYUNDAI SANTA	Petrol	8,11	6,10	24,8
HYUNDAI TUC-SON	Petrol	7,42	5,96	19,7
JEEP COMPASS	Petrol	7,70	5,89	23,6
KIA CEED	Petrol	5,58	4,87	12,7
KIA NIRO	Petrol	5,39	4,75	11,7
KIA SORENTO	Petrol	7,91	6,20	21,6
KIA SPORTAGE	Petrol	7,62	5,83	23,5
KIA XCEED	Petrol	5,45	4,72	13,3
LAND ROVER RANGE ROVER	Petrol	9,17	7,66	16,4
LYNK&CO 01	Petrol	8,15	6,07	25,6
MAZDA CX-60	Petrol	8,47	6,48	23,6
MERCEDES-BENZ A250	Petrol	6,79	5,10	25
MERCEDES-BENZ C300	Petrol	7,75	5,78	25,4
MERCEDES-BENZ C350	Petrol	8,05	6,67	17,3
MERCEDES-BENZ CLA250	Petrol	6,73	5,21	22,6
MERCEDES-BENZ E300	Petrol	7,60	5,68	25,2
MERCEDES-BENZ E350	Petrol	8,06	7,06	12,5
MERCEDES-BENZ GLC300	Petrol	9,14	6,96	23,8
MERCEDES-BENZ GLC350	Petrol	9,94	7,90	20,6
MITSUBISHI ECLIPSE	Petrol	8,33	6,78	18,7
MITSUBISHI OUTLANDER	Petrol	8,61	6,52	24,3
OPEL AMPERA	Petrol	6,92	4,44	35,8
OPEL ASTRA	Petrol	6,35	5,14	19

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Table 4.1: (Continued)

OPEL GRANDLAND	Petrol	7,25	5,69	21,5
PEUGEOT 3008	Petrol	7,36	5,85	20,5
PEUGEOT 308	Petrol	6,99	5,75	17,7
PEUGEOT 508	Petrol	7,18	5,86	18,4
PORSCHE CAYENNE	Petrol	11,95	9,07	24
PORSCHE PANAMERA	Petrol	11,95	8,73	27
RENAULT CAPTUR	Petrol	5,59	5,10	8,8
RENAULT MEGANE	Petrol	6,46	5,26	18,6
SEAT LEON	Petrol	6,41	5,57	13
SEAT TARRACO	Petrol	7,72	6,23	19,3
SKODA OCTAVIA	Petrol	6,14	5,09	17,1
SKODA SUPERB	Petrol	6,89	5,60	18,7
TOYOTA PRIUS	Petrol	5,11	4,45	12,9
VOLKSWAGEN ARTEON	Petrol	6,95	5,62	19,1
VOLKSWAGEN GOLF	Petrol	6,87	5,53	19,4
VOLKSWAGEN PASSAT	Petrol	7,12	5,54	22,1
VOLVO S60	Petrol	8,00	5,69	28,9
VOLVO V60	Petrol	7,98	6,00	24,8
VOLVO V90	Petrol	7,90	6,07	23,2
VOLVO XC40	Petrol	7,56	6,02	20,4
VOLVO XC60	Petrol	8,29	6,51	21,4
VOLVO XC90	Petrol	9,86	7,72	21,7
VOLVO V60	Diesel	6,30	5,10	19

4.3 The effect of the new utility factors

As described in §2.2 on the 1st of January 2025 and on the 1st of January 2027 new utility factors are introduced by the European commission with the goal of decreasing the gap between real-world emissions and WLTP CO₂ emissions. The utility factors determine the percentage of kilometres driven in ‘charge depleting mode’ of the PHEV as opposed to ‘charge sustaining mode’ – note that for some PHEVs charge depleting mode may be equivalent to full EV mode. Initially, estimations of these electrically driven kilometres were too optimistic and the European commission has made a stepwise changes in the formula determining the utility

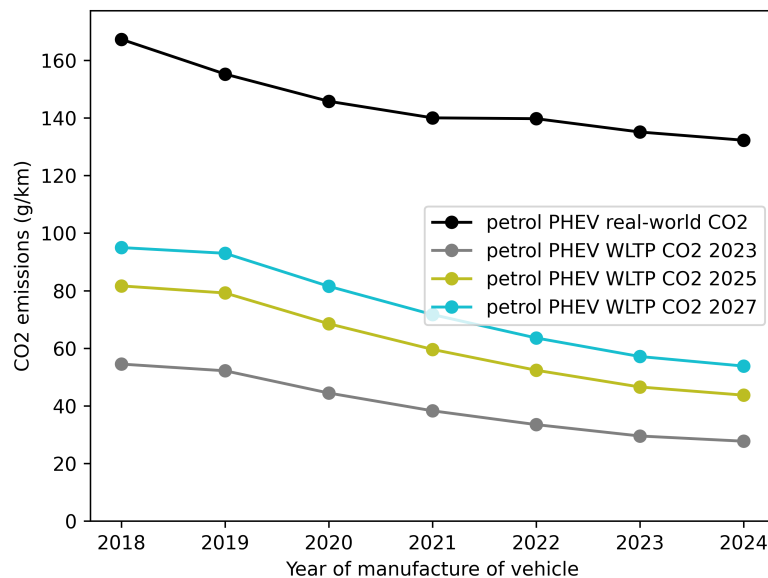


Figure 4.2: The estimated effect of the new utility factors on the gap between real-world and WLTP CO₂ for different years of manufacture.

factor of a vehicle to come to slightly less optimistic estimates.

In [1, §4.4] a detailed description is given of the estimation of the utility factor from the all electric range of the vehicle. To calculate WLTP CO₂, we need to run a charge sustaining cycle and a charge depleting cycle. Then WLTP CO₂ can be calculated as

$$CO2_{WLTP} = UF \cdot CO2_{CD} + (1 - UF) \cdot CO2_{CS},$$

where $CO2_{WLTP}$ is the combined WLTP CO₂, UF is the utility factor of the vehicle and $CO2_{CD}$ (resp. $CO2_{CS}$) is the charge depleting (resp. charge sustaining) CO₂ value. Since only the overall WLTP CO₂ emissions and an (estimated) utility factor are available for the Travelcard PHEVs, an assumption is needed about the ratio $CO2_{CD}/CO2_{CS}$. This ratio varies between 5% and 50% for different vehicles, so a constant (reasonable) value of **25%** was chosen.

Under these assumptions, it is calculated in Figure 4.2 what the WLTP CO₂ would have been under the current “2023” utility factors as well as the “2025” and the “2027” utility factors. It can be seen the gap does decrease, but remains significant. Whereas the gap was around 300% under the “2023” utility factors, it is seen that the gap would have been decreased but remains at around 200% if the “2027” utility factors had been used.

5 Real-world energy consumption of BEVs

5.1 Brief description of data and methodology

This chapter examines real-world energy consumption of battery electric vehicles (BEVs).

5.2 Trends in real-world energy consumption compared to WLTP-values

Similarly to the previous chapters, energy consumption over time is evaluated for the BEVs. Unlike vehicles with internal combustion engines, BEVs lack fuelling dates paired with odometer readings. Instead, valid charging sequences are used as an alternative data source. For each charging sequence, the midpoint is considered as a replacement for the fuelling date. While this approach might produce uneven results for individual vehicles or sequences, it provides a robust framework for analysing trends across the fleet.

The analysis reveals trends in energy consumption and the gap between real-world and WLTP values. As shown in [Figure 5.1](#), WLTP energy consumption exhibits a slight downward trend over the evaluation period. This decline indicates an average improvement over time of BEVs on the WLTP test cycle in terms of energy consumption. In contrast, real-world energy consumption shows a clear upward trend over the same period showing a further decoupling of type approval and real-world energy consumption. The combination of these opposing trends drives the percentage gap between real-world and WLTP energy consumption.

This divergence is further visualised in [Figure 5.2](#), where the percentage gap between real-world and WLTP energy consumption steadily increases over time. Starting at around 15% at the beginning of 2020, the gap rises to roughly 25% by mid 2024. It is striking that as a percentage this gap is almost twice as large for BEVs as it is for ICEs.

5.3 Estimating real-world energy consumption per model

As in previous reports, the real-world energy consumption of common BEV models is analysed from the Travelcard dataset. However, most models nowadays come in various makes, such as different battery capacities, 2WD, 4WD, AWD and performance versions. These variations are expected to significantly impact the vehicle's real-world energy consumption, but they were not accounted for in the initial approach.

Therefore, we can use the following formula that considers many more aspects than just the model of the vehicle. With more data available now, we can make the analysis even more accurate.

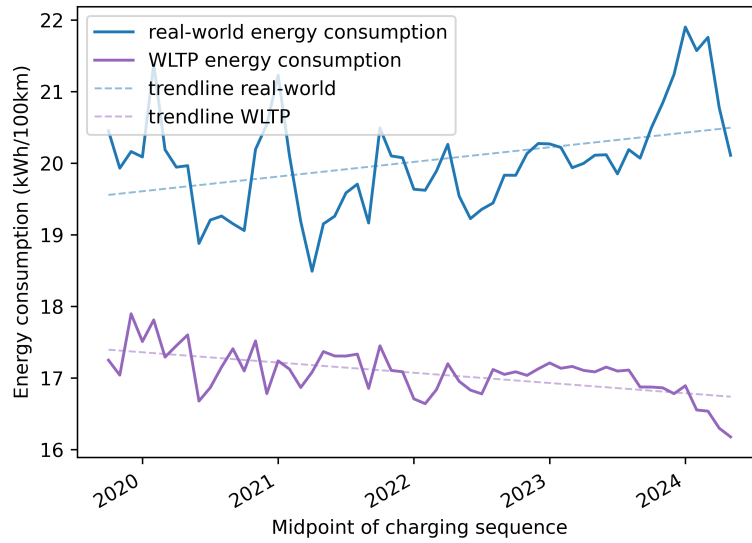


Figure 5.1: Monthly averages of real-world energy consumption and WLTP energy consumption for all BEVs in the Travelcard fleet (after filtering and validation checks).

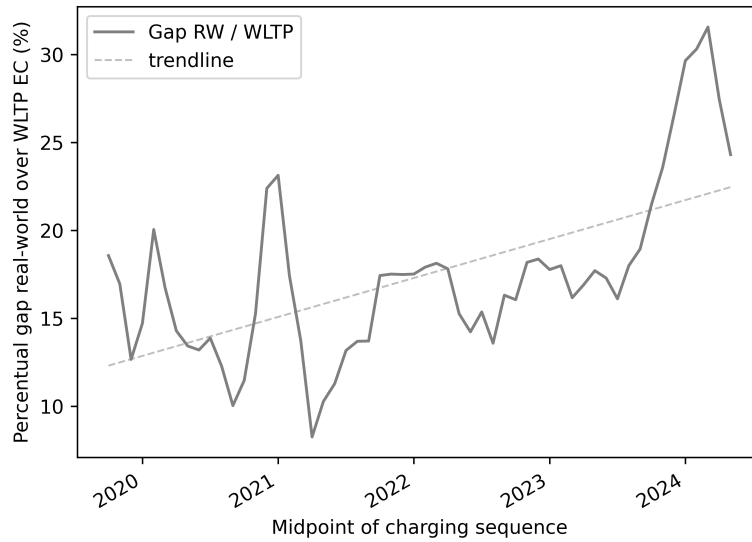


Figure 5.2: Monthly averages of gap between real-world energy consumption and WLTP energy consumption as a percentage of the WLTP value.

$$RWEC \left[\frac{kWh}{100km} \right] = 0,0009 \times m[kg] + 1,4195 \times A[m^2] + 0,0805 \times EC_{WLTP} \left[\frac{Wh}{km} \right] + 0,0124 \times P[kW] + M + 0,1568,$$

where

- › RWECE stands for real-world energy consumption including charging losses;
- › m is the vehicle empty mass;
- › A is the *width* $\times$ *height* of the vehicle;
- › EC_{WLTP} is the energy consumption according to the WLTP test;
- › P is power;
- › M is a model specific factor.

All variables in the formula are available in the RDW open data portal² [10], except the model specific factor M . The factor M contains model specific effects not captured by the rest of the formula such as being more or less aerodynamic than expected or having a more or less efficient powertrain than expected. A list of the specific factor M for all available models is given in Table 5.3.

Table 5.1:

Model	M
AIWAYS U5	2,232667617
AUDI E-TRON	-0,671322768
AUDI Q4	-0,148955548
AUDI Q8	2,786989388
BMW I3	-0,913300216
BMW I3S	-1,193561356
BMW I4	-0,413964189
BMW I5	2,814196562
BMW I7	0,711653385
BMW IX	-0,139406739
BMW IX1	0,26496173
BMW IX3	-1,039745677
BYD ATTO	2,609580654
CITROEN E-C4	0,797661944
CITROEN JUMPY	8,078535344
CUPRA BORN	1,68962476
DACIA SPRING	1,962733267
DS 3	2,230128481
FIAT 500	1,883800014
FORD MUSTANG	0,048097836

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²More specifically under the column names 'massa ledig voertuig', 'breedte', 'hoogte voertuig', 'elektrisch verbruik enkel elektrisch wltip', 'nominaal continu maximumvermogen', respectively.

Table 5.1: (Continued)

FORD TRANSIT	4,008950418
HYUNDAI IONIQ	-0,954145423
HYUNDAI IONIQ5	-0,783472381
HYUNDAI IONIQ6	-0,105770916
HYUNDAI KONA	-1,109908139
JAGUAR I-PACE	1,391999868
JEEP AVENGER	1,663741917
KIA EV6	-0,69069136
KIA EV9	0,805038377
KIA NIRO	-0,930307356
KIA SOUL	-0,474830792
LEXUS UX300E	1,348297803
MAZDA MX-30	-0,963238751
MERCEDES-BENZ EQA	0,233312713
MERCEDES-BENZ EQB	0,482299481
MERCEDES-BENZ EQC	0,586116706
MERCEDES-BENZ EQE	-0,282784723
MERCEDES-BENZ EQS	0,832360328
MERCEDES-BENZ EQV	1,962355411
MERCEDES-BENZ EVITO	5,773609109
MG 4	1,583449745
MG 5	1,287907651
MG MARVEL	-3,058172883
MG ZS	-0,616845166
MINI COOPER	-0,497150035
NISSAN ARIYA	1,312297214
NISSAN E-NV200	-2,226596183
NISSAN LEAF	-1,507205934
OPEL AMPERA-E	0,450144135
OPEL COMBO-E	1,20865766
OPEL CORSA	2,06318786
OPEL MOKKA	1,187002913
OPEL VIVARO	2,573772765
PEUGEOT 2008	0,112761211
PEUGEOT 208	1,811345382
PEUGEOT EXPERT	8,356470913

Continued on next page

Table 5.1: (Continued)

PEUGEOT PARTNER	-2,018155213
POLESTAR 2	0,981040267
PORSCHE TAYCAN	2,027742397
RENAULT KANGOO	2,856929001
RENAULT MEGANE	0,775581886
RENAULT TWINGO	0,517490221
RENAULT ZOE	1,324034688
SEAT MII	2,05292968
SKODA CITIGO	1,744969916
SKODA ENYAQ	-0,018707263
SMART EQ	-1,9139593
TESLA MODEL3	0,21719127
TESLA MODELS	0,125390025
TESLA MODELX	-0,350449827
TESLA MODEL Y	-0,190604139
TOYOTA BZ4X	2,441971998
TOYOTA PROACE	3,493492805
VOLKSWAGEN GOLF	-1,946831245
VOLKSWAGEN ID.3	0,864686732
VOLKSWAGEN ID.4	-0,3006483
VOLKSWAGEN ID.5	1,111994316
VOLKSWAGEN ID.BUZZ	4,07967583
VOLKSWAGEN UP!	1,600943008
VOLVO C40	0,509581009
VOLVO EX30	1,945940387
VOLVO XC40	-0,568189439
XPENG G9	1,643170987

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

5.4 The effect of increasing vehicle 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 [Figure 5.3](#).

It has been observed that trends in real-world energy consumption closely follow trends in

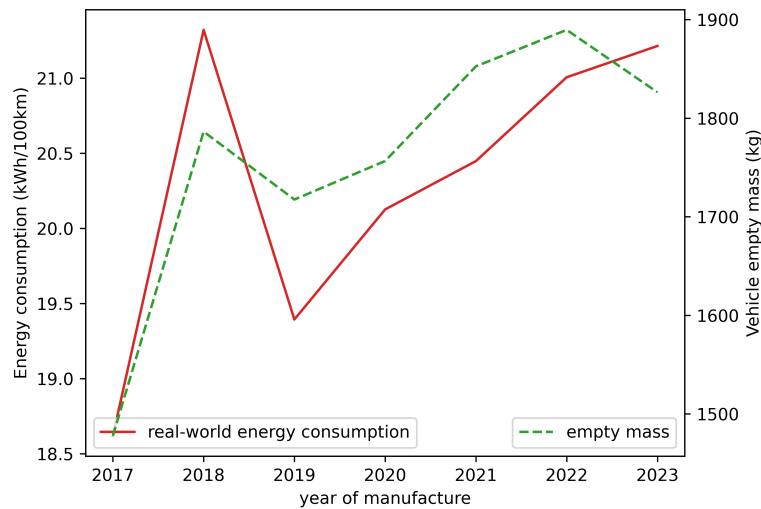


Figure 5.3: Average real-world energy consumption and vehicle empty weight by year of manufacture for BEVs in the Travelcard dataset (after filtering).

average weight. When we normalise for weight, we obtain energy consumption per tonne of vehicle empty mass. This weight-normalised real-world energy consumption is no longer increasing but is instead very slightly decreasing. This indicates that there may have been small efficiency gains over the past few years. However, these gains have not resulted in lower overall energy consumption due to the significant increase in the average weight of electric vehicles.

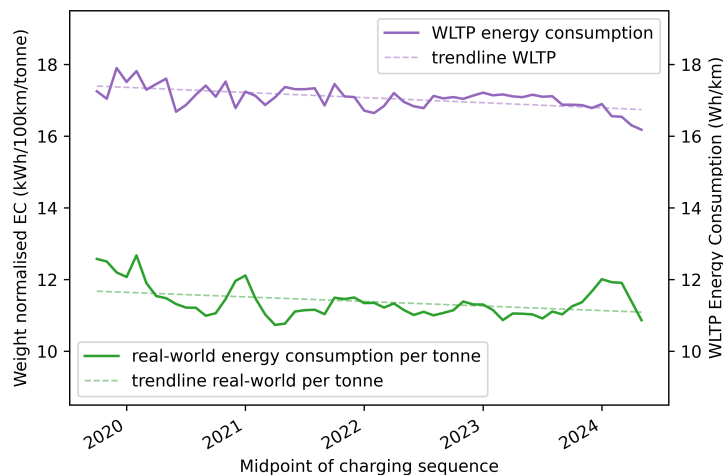


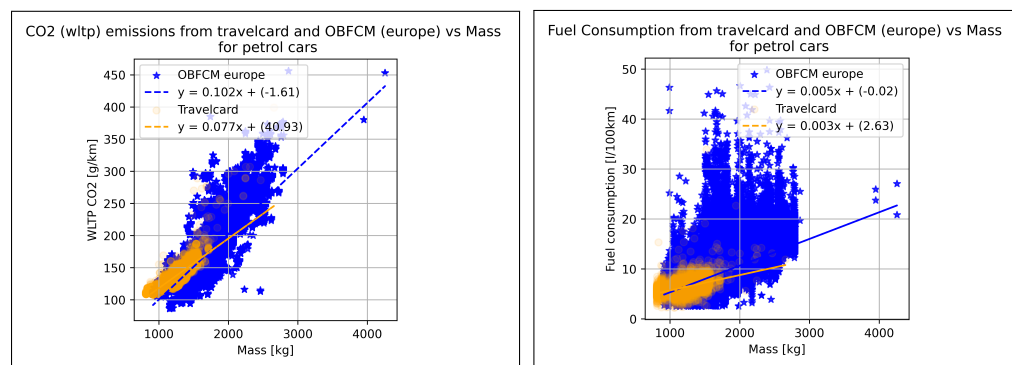
Figure 5.4: Monthly averages of real-world energy consumption per tonne of empty vehicle mass and WLTP energy consumption. The real-world energy increase is linked to the weight increase, as per weight limited effect remains. Note that the real-world energy consumption only appears lower in the graph than the WLTP energy consumption because the units on the axes are different.

6 Changing circumstances and legislation

6.1 Comparison between Travelcard and OBFCM

The data from OBFCM [5] was used to compare the vehicles from all of Europe to those in the Netherlands. It was also used as a cross check of the data from Travelcard with a second data source.

Figure 6.1 shows the WLTP CO₂ and the real world fuel consumption as a function of mass for petrol passenger cars. It can be seen that the cars in the Netherlands (Travelcard) are on average lighter than in Europe but also have a higher WLTP emission value, see Figure 6.2. In the case of diesel passenger cars, see Figure 6.2, this difference is slightly less prominent. Although the intercept is larger, indicating a slightly higher WLTP value, the trendline is very similar. It should be noted that the OBFCM data has new cars sold in 2021 and 2022. Hence, the Travelcard data was also filtered to only include vehicles that were first registered in 2021 and 2022.



(a) WLTP CO₂ vs. mass for petrol passenger cars for Europe (b) Real-world fuel consumption vs. mass for petrol passenger cars for Europe

Figure 6.1: Real-world fuel consumption and WLTP CO₂ comparison for petrol passenger cars in Europe.

Figure 6.3 shows that in case of (diesel) vans, the trend of WLTP CO₂ and real-world fuel consumption is quite similar to that in the OBFCM data. This is mainly because heavier vans also exist in the Netherlands thereby making the WLTP emission value and also fuel consumption very similar to that of an average van in Europe.

The OBFCM data when filtered for only the vehicles registered in the Netherlands is a way to validate the data in the Travelcard. When comparing the Dutch registrations in the OBFCM to the Travelcard data, it can be observed that the Travelcard data is a good representation of the vehicles in the Netherlands for passenger cars with a lower mass. The Travelcard data does not have a lot of comparable data for passenger cars with a higher mass.

Figure 6.4 and Figure 6.5 show that the trendline (slope) for both the Netherlands data in the OBFCM and the Travelcard data is very similar for diesel passenger cars but varies more for

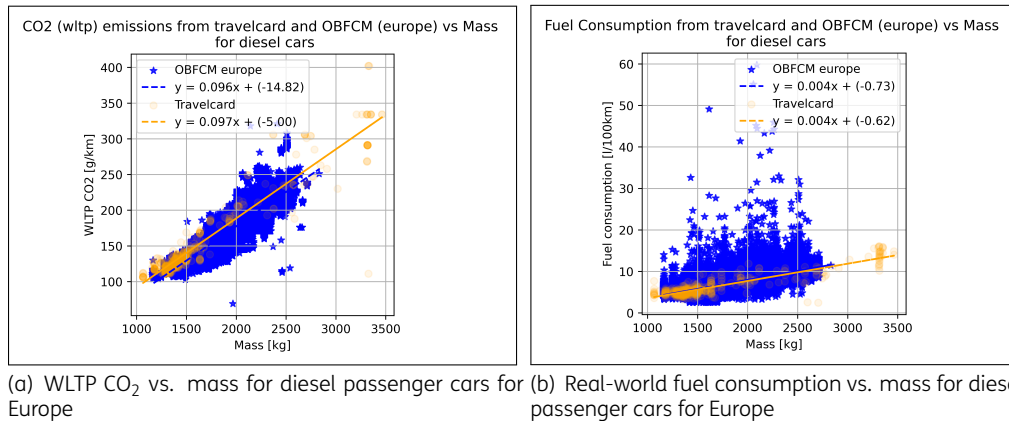


Figure 6.2: Real-world fuel consumption and WLTP CO₂ comparison for diesel passenger cars in Europe.

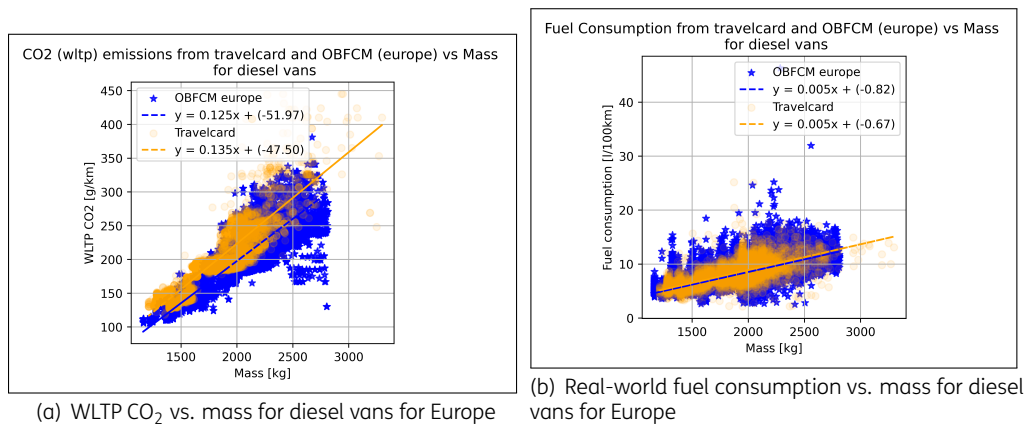


Figure 6.3: Real-world fuel consumption and WLTP CO₂ comparison for diesel vans in Europe.

petrol passenger cars. In the case of the latter, the Travelcard cars are lighter with a higher WLTP CO₂ than what the OBFCM reports. This difference becomes less prominent for the real world fuel consumption.

Figure 6.6 shows that the Travelcard data is a good representation of vans. The trendline from the OBFCM Netherlands data is, again, very similar to that of the Travelcard data as there are enough heavier vans in the dataset allowing for the variance of WLTP and real world fuel consumption values.

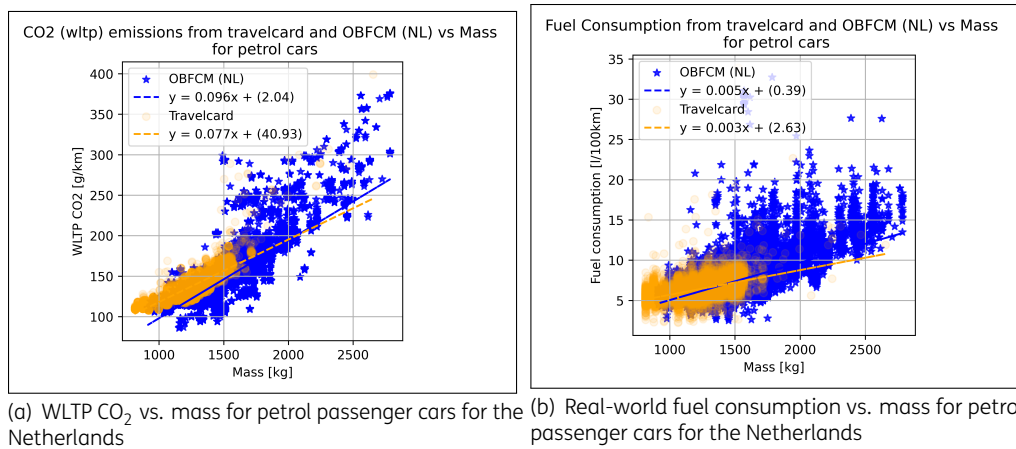


Figure 6.4: Real-world fuel consumption and WLTP CO₂ comparison for petrol passenger cars in the Netherlands.

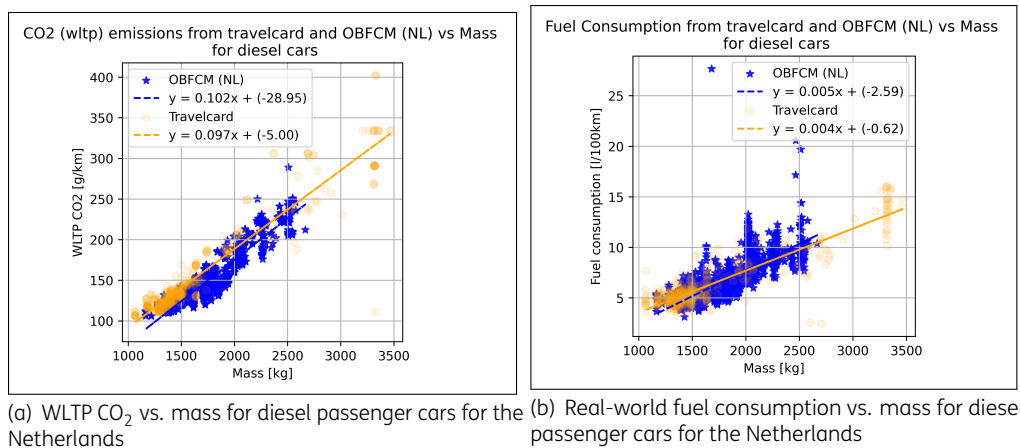


Figure 6.5: Real-world fuel consumption and WLTP CO₂ comparison for diesel passenger cars in the Netherlands.

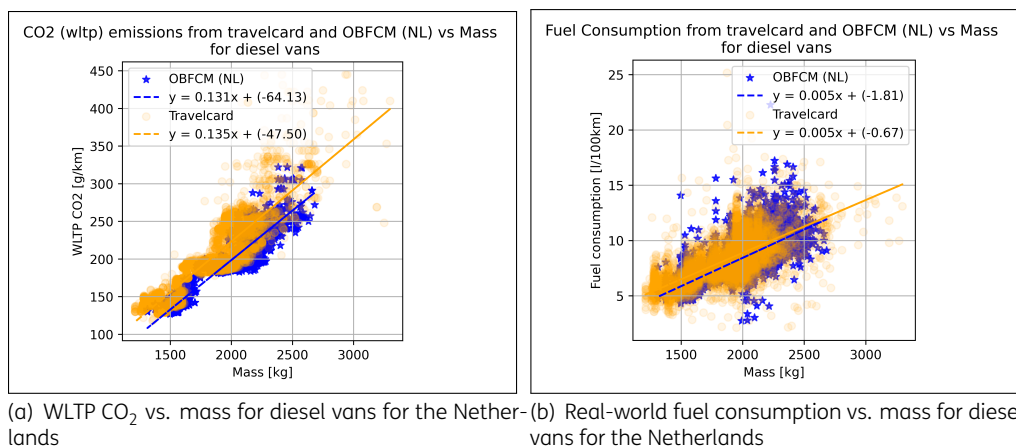


Figure 6.6: Real-world fuel consumption and WLTP CO₂ comparison for diesel vans in the Netherlands.

6.2 The effect of 100 km/h on the motorway

In 2020 the Dutch government announced that as of the 16th of March 2020 during daytime (i.e. 6am until 7pm) the motorway speed limit would be lowered from 130 km/h to 100 km/h. In Figure 6.7, it is determined that this lowered real-world CO₂ emissions in terms of gramme per driven kilometre of petrol and diesel passenger cars by about 3%.

For this conclusion to be valid some care must be taken to eliminate other factors. To eliminate the effects of a continually developing Travelcard fleet, only look at a fixed set of petrol and diesel licences in the Travelcard fleet with manufacturing year from 2017 until 2019 is considered. However, not each of these licences fuelled up every month between the start of 2018 and today. Particularly, for diesel passenger cars only the heavier vehicles were left in the fleet after the beginning of 2023. Therefore, also a weight of max. 1600 kg is imposed on both petrol and diesel passenger cars to be considered in Figure 6.7. This leave a representative sample of 54 101 (resp. 22 405) petrol (resp. diesel) passenger cars which are followed over time.

This results in a picture in which we see stable emissions during 2018 and 2019. In 2020 (only part of the year under 100km/h) and 2021 (full year under 100km/h) real-world emissions decrease. In 2022 and 2023 real-world emissions stabilise again – the slight uptick for diesel passenger cars at the end is caused by the weight of the diesel fleet increasing and not by changes circumstances. This gives convincing evidence for the effect of the 100 km/h measure on real-world CO₂ emissions of petrol and diesel passenger cars being about –3%.

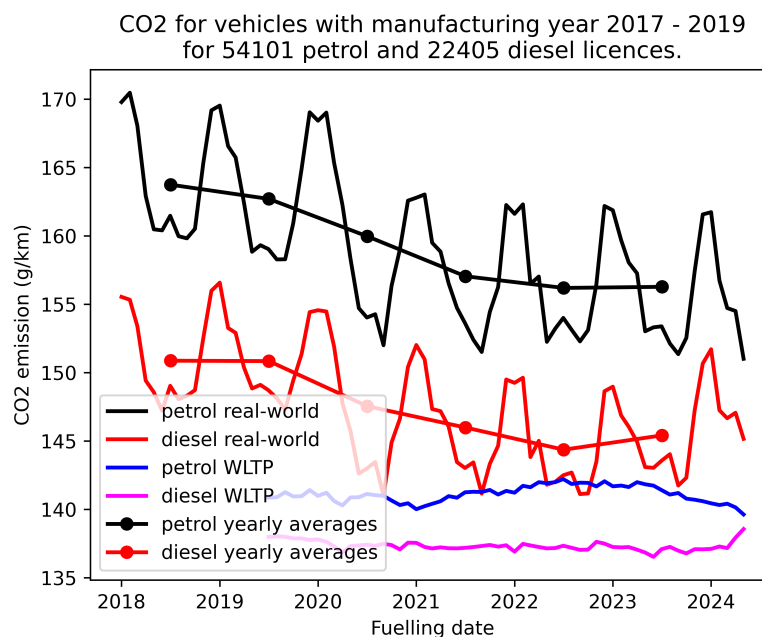


Figure 6.7: Following real-world and WLTP CO₂ emissions over time of a fixed group of petrol and diesel licences with year of manufacture 2017 to 2019 and empty weight 1600 kg or lower.

6.3 Outliers

In Figure 6.8, an analysis is done of the vehicle models of petrol and diesel passenger cars for which the relative deviation between real-world and WLTP CO₂ emissions is the largest. We require that at least 25 vehicles of this model are available in the Travelcard fleet and display

the vehicles for which the distance-weighted percentual gap between real-world and WLTP CO₂ is the largest. The category of MAN TGE “vans” consisting entirely of ambulances (and therefore classified as M1 vehicles) have been removed from Figure 6.8.

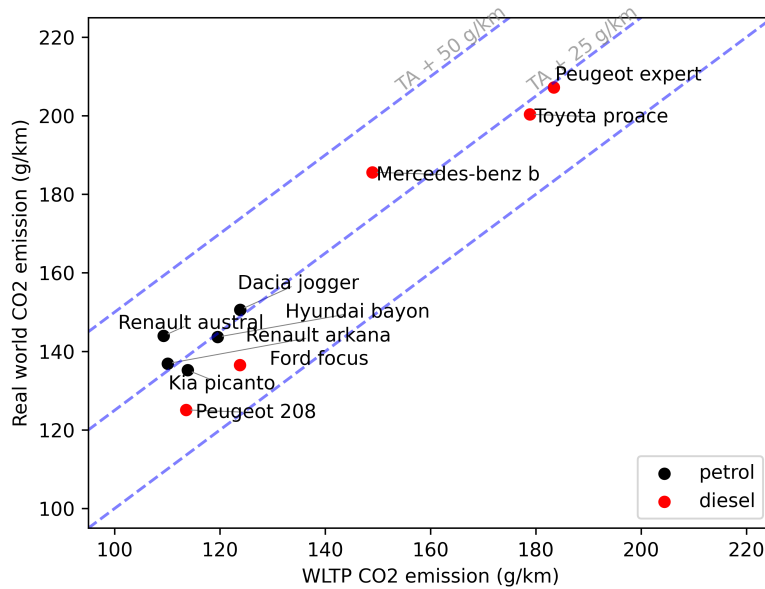


Figure 6.8: For petrol and diesel passenger cars, vehicle models for which the relative deviation of real-world CO₂ emissions with type approval CO₂ emissions is the largest.

7 Conclusions

The data from Travelcard B.V. continues to be very valuable to gain insights into real-world performance of passenger cars and vans on the Dutch public roads. Some important findings in this report are as follows.

- › On average the CO₂ emissions in g/km of diesel passenger cars are trending up since 2022, which is largely explained by their increasing average weight. However, numbers of diesel passenger cars sold in recent years are low, so the effect on total CO₂ emissions of this upward trend is small.
- › The percentage-wise gap between real-world and type approval CO₂ emissions was trending down since the WLTP start in 2018 until 2022 and has been trending up since 2022 for diesel and petrol passenger cars.
- › If real-world CO₂ had been used to calculate the Dutch energy labels of petrol passenger cars instead of type-approval CO₂ (with otherwise unchanged methodology), then more vehicles would get low-emissions energy labels such as A and B than when using a WLTP-based methodology.
- › It is estimated that the new utility factors introduced in the WLTP CO₂ values for PHEVs will decrease the gap between real-world and WLTP CO₂ from around 300% to about 200% in 2027.
- › Real-world energy consumption of the electric fleet is increasing over time, whilst WLTP energy consumption of the fleet is slightly decreasing. This means that the gap between real-world and WLTP energy consumption is increasing over time. The increase in real-world energy consumption can largely be explained by increased vehicle weight of EVs.
- › The Travelcard data can be verified with European OBFCM data and gives a good representation of the Dutch fleet.
- › The Travelcard data suggests that the impact of lowering the speed limit from 130 km/h to 100 km/h from 6h – 19h on the motorway has lead to about 3% (or about 5 g/km) lower overall CO₂ emissions for petrol and diesel passenger cars.

Whereas the Travelcard data can be used to identify these phenomena, more research is needed to explain some of them. For example, the gap between real-world energy consumption and WLTP energy consumption for BEVs widening is worrisome. Whilst the increase in real-world energy consumption of BEVs is largely explained by their weight increase, their decreasing WLTP energy consumption (under increasing weight) is particularly puzzling. It is recommended that this be the topic of further research. Similarly, we see the gap between real-world and type approval CO₂ widening again for petrol and diesel passenger cars since 2022 and care should be made that this gap does not become as large as it used to be under the NEDC.

Going into the future, a larger percentage of the Dutch light duty vehicles will have an on-board fuel consumption meter (OBFCM) for which data is annually published by the EEA. However, the approach through the Travelcard data has a couple of advantages over using the EEA data. Travelcard gives insight into the fuel consumption at the moment of fuelling, whereas the EEA data is averaged by licence plate over a whole year. More importantly, though, TNO can use the

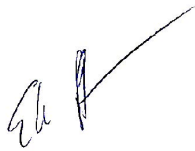
Travelcard licences to link the fuel consumption to all the available fields in the RDW open data database allowing for a much richer dataset than the one supplied by the EEA. Since the EEA data is already anonymised at time of publication, no enrichment of this data is possible. Nonetheless, future Travelcard reports should not attempt to do analyses which may be done using the EEA OBFCM dataset which is likely more complete and less noisy. Therefore, going forward it may be interesting to consider including both OBFCM-based analyses on the fleet and year level and Travelcard-based analysis on the vehicle and month level side by side in the Travelcard reports.

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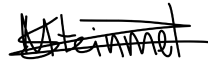
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Signature

TNO › Mobility & Built Environment › Den Haag › 29 April 2025



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Appendix A

Formulas for the energy labels

The relative energy efficiency is defined based on a regression formula, the constants of which are updated every two years. The directive for energy label [9] elaborates further on the parties involved and the regulation behind the calculation of energy labels. Energy labels are defined based on relative energy efficiency as in Table A.1.

Table A.1: Relation between energy labels and relative energy efficiency.

Energy label	Relative Energy Efficiency
A	relative energy efficiency < -15%
B	-15% ≤ relative energy efficiency < -5%
C	-5% ≤ relative energy efficiency < 5%
D	5% ≤ relative energy efficiency < 15%
E	15% ≤ relative energy efficiency < 25%
F	25% ≤ relative energy efficiency < 35%
G	35% ≤ relative energy efficiency

$$\text{Relative energy efficiency} = \frac{CO_2\text{-emissions} - CO_2\text{-emissions}_{\text{ref.}}}{CO_2\text{-emissions}_{\text{ref.}}} * 100\%$$

where the CO_2 -emissions of the vehicle in question is considered to be the NEDC CO_2 value until 2019 and the WLTP CO_2 value after 2019. The reference $CO_2\text{-emissions}_{\text{ref.}}$ is defined for petrol as follows. The formulas for diesel cars remain exactly the same but with the coefficients of diesel passenger cars.

$$CO_2\text{-emissions}_{\text{ref., petrol}} = 0.75 \times CO_2\text{-emissions}_{\text{avg., petrol}} + 0.25 \times CO_2\text{-emissions}_{\text{total avg. petrol}} \quad (\text{A.1})$$

The constants $CO_2\text{-emissions}_{\text{total avg. petrol}}$ can be found with all other constants below in tables A.2 and A.3. The $CO_2\text{-emissions}_{\text{avg., petrol}}$ are defined as follows:

$$CO_2\text{-emissions}_{\text{avg., petrol}} = C_{1, \text{petrol}} + C_{2, \text{petrol}} \times (\text{length} \times \text{width})_{\text{corrected}} + C_{3, \text{petrol}} \times [(\text{length} \times \text{width})_{\text{corrected}}]^2$$

The $(\text{length} \times \text{width})_{\text{corrected}}$ can be calculated as follows:

$$\text{length} \times \text{width}_{\text{corrected}} = [0.7 \times \text{length} + 0.3 \times \text{length}_{\text{avg.}}] \times \text{width},$$

where width is the width of the vehicle.

If

$$\text{length} \times \text{width}_{\text{corrected}} < -0.5 \times \frac{C_{2, \text{petrol}}}{C_{3, \text{petrol}}},$$

then

$$\text{length} \times \text{width}_{\text{corrected}} = -0.5 \times \frac{C_{2,\text{petrol}}}{C_{3,\text{petrol}}}.$$

Finally, $\text{length}_{\text{avg.}}$ can be calculated as:

$$\text{length}_{\text{avg.}} = C_{1,\text{length}} + C_{2,\text{length}} \times \text{width} + C_{3,\text{length}} \times (\text{width})^2$$

As mentioned earlier, these formulas remain the same for diesel passenger cars only with different coefficients. All the coefficients mentioned in the formulas above can be found in the table below in Table A.2 and Table A.3.

Firstly, for petrol passenger cars, the coefficients for the regression formula can be found in Table A.2:

Table A.2: Coefficients for the regression formulas to calculate relative energy efficiency for petrol passenger cars

Years	$C_{1,\text{length}}$	$C_{2,\text{length}}$	$C_{3,\text{length}}$	$C_{1,\text{petrol}}$	$C_{2,\text{petrol}}$	$C_{3,\text{petrol}}$	$\text{CO}_2\text{-emissions}_{\text{total avg. petrol}}$
[-, 2009]	3,874	-4,396	2,619	45,809	3,618	1,454	145,3
[2010, 2011]	-1,2412	1,7737	0,7693	166,3563	29,8408	3,9167	163,232
2012	-6,3494	7,4517	-0,8131	180,5932	-35,407	4,0907	143,0455
2013	-3,6399	4,3065	0,0993	162,6583	-29,9911	3,7475	146,7956
[2014, 2015]	-6,6714	7,7147	-0,8582	159,1075	-28,2906	3,311	133,6496
[2016, 2017]	-11,8931	13,6053	-2,5217	231,3831	-50,4445	4,7195	122,4467
[2018, 2019]	-8,8069	10,1774	-1,5705	221,1425	-48,2347	4,5254	116,4755
[2020, 2021]	-9,971	11,6417	-2,0367	280,0667	-57,4968	5,1393	143,9546
[2022, 2023]	-7,3987	8,7426	-1,2231	194,9311	-32,4005	3,2611	139,8076
[2024, 2025]	-4,3336	5,1965	-0,2115	99,5924	-4,1509	1,0147	127,7073

And for diesel passenger cars, the coefficients for the regression formula can be found in Table A.3:

Table A.3: Coefficients for the regression formulas to calculate relative energy efficiency for diesel passenger cars

Years	$C_{1,\text{length}}$	$C_{2,\text{length}}$	$C_{3,\text{length}}$	$C_{1,\text{diesel}}$	$C_{2,\text{diesel}}$	$C_{3,\text{diesel}}$	$\text{CO}_2\text{-emissions}_{\text{total avg. diesel}}$
[-, 2009]	3,874	-4,396	2,619	-5,875	11,059	0,868	148,9
[2010, 2011]	-1,2412	1,7737	0,7693	344,5974	-78,3711	6,7313	135,7337
2012	-6,3494	7,4517	-0,8131	260,1231	-67,2854	6,3152	108,5052
2013	-3,6399	4,3065	0,0993	180,9843	-45,6015	4,9404	114,9923
[2014, 2015]	-6,6714	7,7147	-0,8582	502,1596	-123,649	9,311	98,8941
[2016, 2017]	-11,8931	13,6053	-2,5217	831,237	-205,8433	14,2111	88,6286
[2018, 2019]	-8,8069	10,1774	-1,5705	498,0245	-118,5477	8,5011	88,3642
[2020, 2021]	-9,971	11,6417	-2,0367	565,3687	-123,477	8,6611	129,0316
[2022, 2023]	-7,3987	8,7426	-1,2231	328,2514	-70,7743	5,8458	130,9858
[2024, 2025]	-4,3336	5,1965	-0,2115	616,5673	-140,0225	9,7649	117,2813

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