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TNO report

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Real-world fuel consumption of passenger cars based on monitoring of Dutch fuel pass data 2017

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Samenvatting

Inleiding

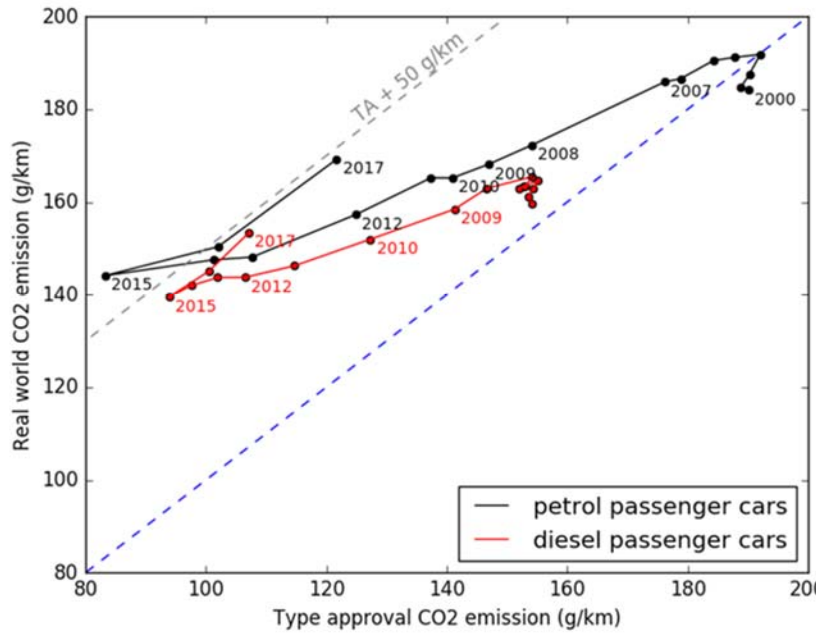
TNO monitort sinds 2008 het praktijkbrandstofverbruik van personenauto's in Nederland op basis van tankpasdata van Travelcard Nederland BV. Brandstofverbruik en de daarmee samenhangende uitstoot van CO_2 zijn in de praktijk doorgaans hoger dan de waarden die door de fabrikant worden opgegeven op basis van de typekeuringstest. Opeenvolgende rapporten hebben laten zien dat het verschil tussen het brandstofverbruik in de praktijk en de typekeuringswaarden de laatste tien jaar geleidelijk is toegenomen. Oorspronkelijk lieten vooral zuinige voertuigen in de segmenten van kleine en middenklasse voertuigen een groeiend verschil zien, maar de laatste jaren is deze ook toegenomen voor grotere voertuigen. Als gevolg daarvan dalen het gemiddelde praktijkverbruik en de gemiddelde CO_2-emissies van personenauto's minder hard dan de gemiddelde typekeuringswaarden. Dit vermindert de effectiviteit van verschillende beleidsmaatregelen die ingezet worden om de broeikasgasemissies van de transportsector te verlagen, zoals de Europese CO_2-normen voor lichte voertuigen en het Nederlandse fiscale stimuleringsbeleid voor zuinige personenvoertuigen.

In dit rapport is tankpasdata van Travelcard Nederland BV geanalyseerd over de periode 2004 t/m april 2017 voor in totaal 443.000 voertuigen. Onder deze voertuigen is een grote spreiding in jaarkilometrages, hetgeen betekent dat de database niet alleen stereotype zakelijke rijders bevat, maar ook een grote groep rijders met een relatief gering jaarkilometrage. Rond de 45% van alle nieuw verkochte personenauto's in Nederland zijn leaseauto's. Omdat deze leaseauto's gemiddeld een hoger jaarkilometrage hebben dan auto's in particulier bezit, bepalen deze leaseauto's in grote mate het gemiddeld brandstofverbruik van de Nederlandse personenautovloot. De resultaten van de monitoring worden daarom in grote mate representatief geacht voor een groot aandeel van de Nederlandse vloot.

Resultaten

Over de hele vloot in de tankpasdata voor de periode januari t/m december 2016 is het relatieve verschil tussen de CO_2-emissie in de praktijk en de typekeuringswaarden ongeveer 41%. Voor voertuigen die in 2016 op kenteken zijn gezet is het absolute verschil ongeveer 46 g/km, wat neerkomt op een relatief verschil van 46%. Plug-in-hybride voertuigen, die in deze gemiddelden zijn meegenomen, hebben een veel groter verschil tussen praktijk en typekeurwaarde: gemiddeld 90 g/km. Dit wordt, naast de algemene oorzaken, veroorzaakt door een aanname van een groter percentage elektrische kilometers bij de typekeuring dan in de praktijk.

Gemiddeld groeit het relatieve verschil tussen praktijk en typekeuring voor elk volgend bouwjaar met 1,5%-punt. Dit correspondeert met een jaarlijkse absolute groei van het verschil in CO_2-emissies met 2 g/km. Voor voertuigen die in 2015 op de weg gekomen zijn, is het relatieve verschil opvallend groot ten opzichte van de voertuigen met omliggende bouwjaren. Dit kan worden toegeschreven aan de piek in de verkoop van plug-in-hybrides.



Figuur SN1: Gemiddelde CO_2-emissies in de praktijk versus de gemiddelde typekeuringswaarde voor nieuwe benzine- en dieselvoertuigen, inclusief plug-in-hybrides, uitgesplitst naar het jaar van introductie / registratie in Nederland (waarde voor 2017 is voorlopig).

In 2016 lijkt de trend naar lagere typekeurwaarden gekeerd. In 2016 en de eerste vier maanden van 2017 liggen de gemiddelde typekeurwaarden en de gemiddelde praktijkwaarden hoger dan in 2015. De redenen zijn waarschijnlijk het terugschroeven van fiscale voordelen voor plug-in-hybrides, versobering van de bijtelling voor zuinige auto's, de aankondiging van de inwerkingtreding van de WLTP-testcyclus[1], en een algemene trend naar grotere en zwaardere voertuigen. De afstand tussen de CO_2-uitstoot in de praktijk en conform typekeuring is sinds 2014 ongeveer gelijk gebleven, behalve voor benzine/benzine-plug-in-voertuigen met introductiejaar 2015.

Voor voertuigen van een gegeven jaar van introductie blijkt er een redelijk lineair verband te zijn tussen de gemiddelde praktijkemissies van CO_2 en de typekeuringswaarden. Voor in 2016 verkochte voertuigen kunnen deze correlaties als volgt geschreven worden:

Benzine:
$$RW\_CO_2 = 0.98 * TA\_CO_2 + 45$$

Diesel:
$$RW\_CO_2 = 0.87 * TA\_CO_2 + 57$$

met RW_CO_2 (real-world = praktijk) en TA_CO_2 (type approval = typekeuring) in [g/km].

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[1] Worldwide Harmonised Light Vehicle Test Procedure, ter vervanging van de NEDC-testcyclus. Door de aankondiging zouden voertuigen vooruitlopend op de inwerkingtreding anders afgesteld kunnen zijn.

De variatie in praktijkemissies tussen verschillende bestuurders en voertuigen van dezelfde CO_2-typekeuringswaarde is typisch +/- 15 g/km. De variatie wordt kleiner bij lagere gemiddelde typekeuringswaarden. Gegeven dat het verschil tussen praktijk en typekeuring gemiddeld zo’n 46 g/km bedraagt, is het aantal voertuigen (of bestuurders) dat een praktijkverbruik realiseert dat in de buurt komt van de typekeuringswaarde zeer laag.

Summary

Introduction
Since 2008 TNO is monitoring the real-world fuel consumption of passenger cars in the Netherlands based on fuelling data obtained from Travelcard Nederland BV. Fuel consumption and CO_2 emissions in real-world driving are generally higher than the type approval figures provided by the manufacturer. Successive reports show that the average gap between real world fuel consumption and the type approval value has been gradually increasing over the last decade. Initially this was mainly the case for fuel efficient vehicles in the small and medium-size segments. In recent years the gap has also increased for larger vehicles. As a consequence, the average real-world fuel consumption and CO_2 emissions of passenger cars are decreasing much more slowly than the average type-approval values. This significantly reduces the effectiveness of various policies for reducing greenhouse gases from transport, such as the European CO_2 regulation for light-duty vehicles and national fiscal measures to stimulate the uptake of fuel efficient vehicles.

In the present report tank pass data, as obtained from Travelcard Nederland BV, has been analysed. The data cover the period of 2004 up to April 2017 inclusive, and include a total number of 443,000 vehicles. A large spread can be observed in the annual mileages and vehicle models, which means that the database does not only contain stereotypical business drivers, but also a large group of drivers that cover a relatively small mileage each year. Around 45% of all new cars sold in the Netherlands are leased vehicles . As these leased vehicles on average also have higher annual mileages than privately owned vehicles, these leased vehicles to a large extent determine the average real-world fuel consumption of the Dutch passenger car fleet. The results of the analysis are therefore considered meaningful for the Dutch passenger car fleet.

Results
Over the whole fleet included in the tank pass data for the period January to December 2016, the relative difference between the average real-world and type approval CO_2 emissions is around 41%. For vehicles entering the Dutch fleet in 2016 the absolute difference is about 46 g/km, which means that the relative difference is around 46%. Plug-in hybrid vehicles, which are encompassed in these averages, show a much larger difference between real-world and type approval value: 90 g/km on average. Besides the more general reasons mentioned in the introduction, this anomaly is being caused by a larger share of electric kilometres at the type approval test compared to the real world use.

On average the relative gap is found to grow with 1.5%-point for every consecutive year of construction from 2005 onwards. This is equivalent to an annual increase of around 2 g CO_2/km in the absolute gap of new vehicles. For vehicles that were introduced on the market in 2015, the gap is remarkably large compared to that of vehicles with adjacent introduction years. This result can be attributed to a peak in the sales numbers of plug-in hybrids.

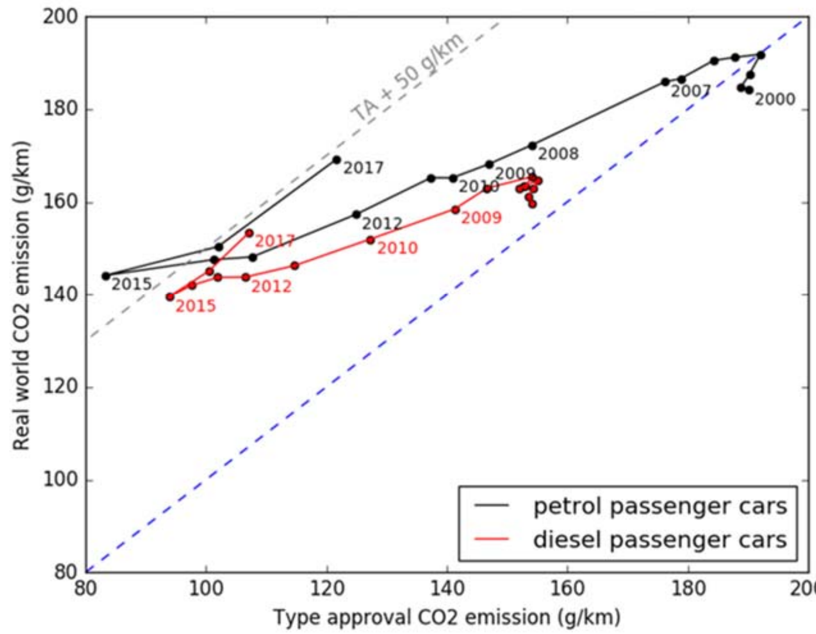

Figure SE1: Average real-world CO_2 emissions versus the average type approval value of new petrol and diesel cars, including plug-in hybrids, differentiated by the year of introduction / registration in the Netherlands (2017 value is preliminary)

In 2016, the trend towards lower type approval values seems to be reversed.
In 2016 and the first four months of 2017 the average type approval values as well as the average real-world values increased from the 2015 values. Plausible causes are the repeal of fiscal advantages for plug-in hybrids, the announcement of effectuation of the WLTP test programme[2], and a general trend towards larger and heavier vehicles.
The gap between the real-world and the type approval CO_2 emission has remained approximately equal since 2014, with the exception of petrol/petrol-based plug-in hybrid vehicles introduced in 2015.

A fairly linear relation is found between the average real-world CO_2 emissions and the type approval value.

For new vehicles sold in 2016 these correlations can be written as:

Petrol:
$$RW\_CO_2 = 0.98 * TA\_CO_2 + 45$$

Diesel:
$$RW\_CO_2 = 0.87 * TA\_CO_2 + 57$$

with RW_CO_2 (real-world) and TA_CO_2 (type approval) in [g/km].

[2] Worldwide Harmonised Light Vehicle Test Procedure, to replace the NEDC test cycle that is currently in force. As a result of the announcement, vehicles might be tuned differently to anticipate the effectuation.

There is a typical variation of +/- 15 g/km between different drivers and vehicles of the same type approval CO_2 segment. This variation is decreasing with lower type-approval values. Given an average gap of 46 g/km, the number of modern vehicles which have (or stated differently: the number of drivers that realise) a real-world fuel consumption close to the type-approval value is very small.

Contents

1 Introduction

1.1 Context

Dutch passenger cars drive annually more than 100.000.000.000 kilometres, producing over 15 megaton of CO_2. Hence, they are a significant contributor to the total annual CO_2 emission of the Netherlands. If the CO_2 emission were determined from the official fuel consumption figures, based on the type-approval values of the vehicles sold, this source of CO_2 emission would be severely underestimated. Moreover, the impact of CO_2 emission reduction policies would be overestimated if based on reduction of type-approval values rather than real-world values.

Therefore, an analysis of real-world fuel consumption of passenger cars is important to have an accurate and timely assessment of the impact of CO_2 emission reduction policies. In practice, low type approval emission values do not translate into low real-world emissions. In particular, specific technologies, like plug-in hybrid vehicles, have very large gaps between the type-approval value and their real-world performance, especially in lease cars.

1.2 History of this research

Since 2009 TNO is monitoring real-world fuel consumption. The first assessment for the Dutch policy program “schoon en zuinig” (i.e., clean and fuel efficient) showed an increasing gap between the type-approval value and the real-world fuel efficiency of new fuel efficient cars. In 2010 it was already postulated that the gap between the average type-approval value and real-world fuel consumption would increase to 40% with the trend of stimulating fuel efficient cars. The current report brings some nuance to that prediction, but the overall trend remains the same.

1.3 Database and filtering

The database used by TNO for monitoring real-world fuel consumption contains fuel transaction data made available by Travelcard Nederland BV. Per fuelling event both the amount of tanked fuel and the odometer setting are recorded as well as the time and date of the fuelling event. In total 48 million diesel fuel transactions and 32 million petrol fuel transactions are in the database. Of these data less than half are complete and plausible records.

The odometer settings are entered manually by the drivers and as a consequence these data contain many errors and missing records. The data are therefore rigorously filtered to remove implausible records[3]. On the remaining records a number of analyses were performed to establish main trends and important effects. By matching the Travelcard Nederland BV database with the registration database from the Dutch road vehicle authority RDW for each vehicle in the database the type approval fuel consumption and CO_2 values and various other technical characteristics of the vehicles are known.
In total, 911 thousand vehicles are present in the database.

[3] See [TNO 2013b] for a description of the filtering process.

After filtering of the data, a real-world fuel consumption could be determined for 443 thousand vehicles: 200 thousand petrol vehicles (of which around 8,000 plug-in hybrids) and 243 thousand diesel vehicles (of which around 1,600 plug-in hybrids).

Vehicles stay in the database for as long as they are present in the fleets that use Travelcard tank passes. Data is available since 2004, and for some vehicles indeed data is available over the entire period 2004-2017. The total mileage per vehicle therefore also varies from 0 to over 200,000 km. Figure 1 shows the frequency distribution of the monitored mileage per vehicle. The share of high-mileage vehicles is larger for diesel vehicles than for petrol vehicles. This is the result of two factors: on average diesel vehicles cover more distance per year than petrol vehicles (see paragraph 1.5), and in recent years the share of petrol cars has grown, creating a peak in the petrol vehicles on the left hand side of the graph. Plug-in hybrids are relatively new to the market, so have relatively low mileages.

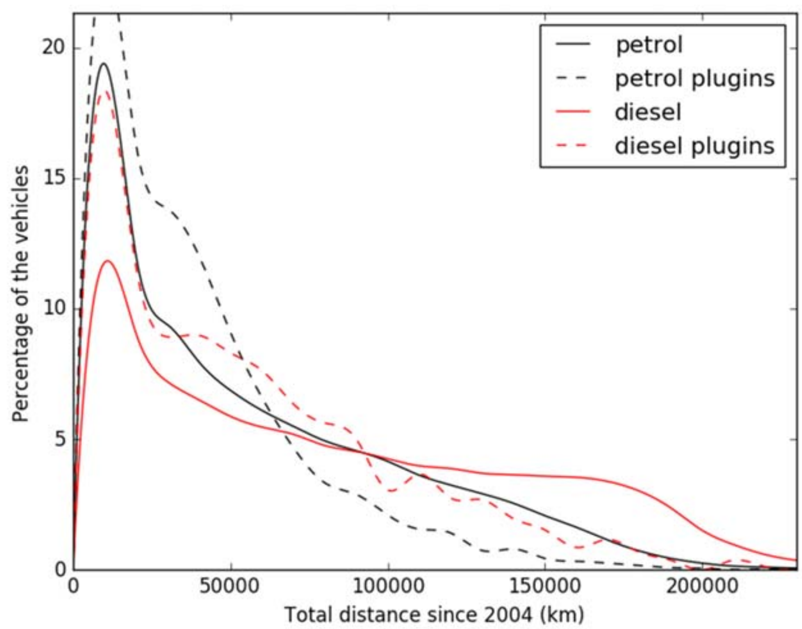

Figure 1: Histogram of the number of vehicles as function of the total mileage over which the vehicle is monitored

1.4 Methodology

By combining data from consecutive fuelling events the distance driven between two fuelling events is calculated. Fuel consumption is calculated by dividing the amount of tanked litres by the driven distance.

The method of deriving average fuel consumption figures from the data per fuelling event has changed compared to previous reports. The differences are explained below. Impacts of this change in methodology are discussed in section 2.5.

Method used in this report
The method used in this report is equal to the one used in the previous report of 2016 [TNO 2016], and can be described as follows:

The average fuel consumption (overall, or e.g. per bandwidth of type approval CO_2 values for a given fuel) is determined by dividing the sum of all tanked litres by the sum of all kilometres driven for the selection of tank events for which the average is determined. This produces the average over a selection of vehicles whereby the results for individual fuel events or vehicles are weighted over the kilometres driven.

This approach increases the impact of vehicles with low real-world fuel consumption on the overall average and reduces the contribution of vehicles with relatively high real-world fuel consumption. This approach also eliminates rounding errors associated with the fact that vehicle users do not consistently fill the tank to the same level at every tank event. As a result of both effects, the average fuel consumption values as calculated with this approach are lower than the values based on the approach followed in reports of before 2016, leading to a lower estimate of the gap between real-world fuel consumption and type approval values. More information can be found in [TNO 2016].

The results presented in this report, including the emission trends over time, are consistent: the average fuel consumption has been (re-)calculated for the entire Travelcard database containing data from 2004 up to 2017.

From fuel consumption to CO_2 emissions
Fuel consumption can be directly related to the “direct” CO_2 emissions of a vehicle, i.e. the CO_2 emitted through the exhaust[4]. The amount of CO_2 emitted per litre of fuel, related to the carbon content of the fuel, is more or less fixed. Per litre of petrol about 2370 gram CO_2 is emitted, while for diesel this value is 2650 gram CO_2 per litre. These values, as well as the energy content of the fuels, have been assumed constant for the period over which data are available.

NEDC tests of Euro 5 and Euro 6 vehicles had (and have) to be carried out with market fuels, which means that the biofuel admixture is around 5 vol%. In the Netherlands, the blend percentages have been around 5 vol% as well in recent years. Therefore, the emission factors, and carbon and energy content, which vary slightly with varying biofuel content, do not have to be adjusted in this research.

Future developments
The Worldwide Harmonised Light Vehicle Test Procedure (WLTP) will replace the New European Driving Cycle (NEDC) as a type approval procedure. Newly introduced models have to comply to the WLTP from September 2017, existing models from September 2018. Although the CO_2 emission will also be communicated as calculated NEDC values based on WLTP test data until 2021, the vehicles will likely be tuned differently to perform optimally in the new WLTC test cycle that is part of the WLTP. Hence, this NEDC value may not be related to the present one.

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[4] This report only analyses direct CO_2 emissions. This is different from some definitions of “Tank-to-Wheel” emissions in which the direct CO_2 emissions resulting from biofuels are counted as zero, and from “Well-to-Wheel” emissions which include the CO_2-equivalent value of all greenhouse gases emitted in the production chain of the fuel.

It is unknown what will be the lasting effect on the real world fuel consumption of the new type approval tests. Currently no fuel consumption data of WLTP vehicles are available. When the transition from NEDC to WLTP is in effect, additional analyses and methodological updates will be introduced to investigate the effect of this transition on the real world fuel consumption. Only since December 2017 WLTP tested vehicle models have been sold in the Netherlands.

1.5 Representativeness of the results

The suggestion is often made that the analyses based on tank pass data from Travelcard Nederland BV is biased for a particular group of users and a particular type of use. Tank passes are used by “business drivers” who mostly drive a leased car provided by their company. As their fuel bill is paid for by the company, these drivers are not considered to have an incentive to drive in a fuel efficient manner. So, some bias towards higher than average fuel consumption values may indeed be expected. However, an analysis of the annual mileages of vehicles in the database (see Figure 2) shows that the database does not only contain stereotypical business drivers. Moreover, there is no systematic difference in the results between the typical vehicle brands used by business drivers, compared to the more family oriented brands.There is a large spread in annual mileages and the database also contains a significant share of vehicles with relatively low annual mileages.

From Figure 2 it is clear to see that the average mileage of vehicles in the database is well above the average for the Dutch passenger car fleet (10,700 and 23,800 km/year for petrol and diesel [CBS 2017]).

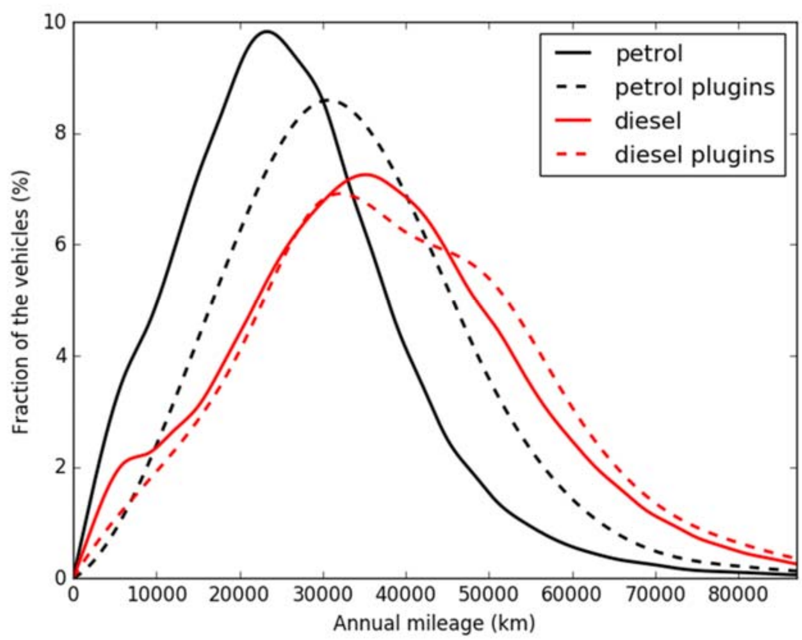

Figure 2: Distribution of the annual mileages of vehicles in the Travelcard database

The statistics are included in Table 1.

Table 1: Annual mileages per fuel/drivetrain-combination

	Most common annual mileage (km)	Average annual mileage (km)
Petrol	23.300	26.700
Petrol plugin	30.700	33.900
Diesel	35.200	37.600
Diesel plugin	32.100	40.200

Alternative databases generally also have some sort of bias. Databases containing fuel data that are recorded voluntarily by participating vehicle owners / drivers will e.g. tend to have a bias towards lower than average fuel consumption values as only people that care about their fuel consumption or fuel costs will spend time recording their fuelling data. But also drivers with concerns over there vehicle fuel efficiency may record the fuelling data voluntarily.

An important advantage of using tank pass data, is the homogeneity of the group of drivers. These drivers do change their cars every couple of years but not their use patterns. Hence the trends over time are well-established, and are not disturbed by changes in the underlying use patterns. These trends over time are the most important outcome of the study.

Within the database it can be seen that for individual drivers the deviation between real-world fuel consumption and the type-approval value is strongly related to their specific use pattern and driving style, but it is not to be expected that this use pattern and driving style will change much over time. Nevertheless, some influence of variations in the level of congestion, e.g. related to the economic crisis in recent years or national measures to increase road capacity, on the fuel consumption of vehicles in the database cannot be excluded.

An additional argument in favour of using tank pass data is that 45% of all new cars sold in the Netherlands are leased vehicles[5]. As these leased vehicles on average also have higher annual mileages than privately owned vehicles, these leased vehicles to a large extent determine the average real-world fuel consumption of the Dutch passenger car fleet.

[5] Source: www.vna-lease.nl

2 Results

2.1 Overall trends

Figure 3 shows the evolution of the relative difference between the average real-world fuel consumption and the type approval values of vehicles in the database since 2004. It is clear that the relative gap between real-world fuel consumption and the type approval value is not yet stabilizing, but instead has increased further with the introduction of new passenger cars on the Dutch roads. The gap for petrol vehicles, which used to be consistently smaller than for diesel vehicles in the last few years, appears to have increased a lot in both 2016 and 2017. A larger share of petrol plug-in hybrids among vehicles entering the fleet is one of the contributing factors. The gap for petrol and diesel vehicles is now similar and around 45%. Also visible in Figure 3 is the large seasonal variation, between the highest fuel consumption over the winter period in December and January, and the lowest fuel consumption just after the summer holidays.

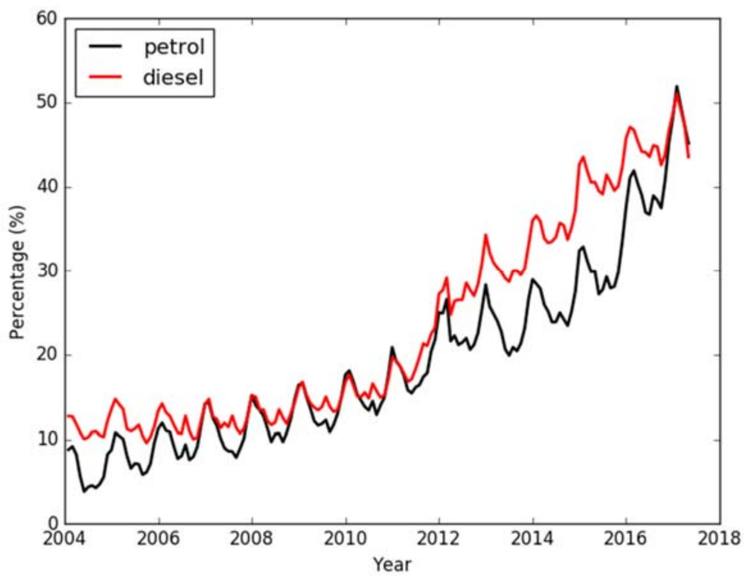

Figure 3: The evolution of the relative difference between the fleet average real-world fuel consumption and the average type-approval value, based on weekly averages of the fuelling data: the total amount of fuel and the total distance. This data is based on a fleet of vehicles, all using Travelcard tank passes, which consists mainly of vehicles younger than four years. Plug-in hybrids are included in the petrol and diesel data.

The growing gap of Figure 3 is shown in more detail in Figure 4 (vehicles without a plug) and Figure 5 (plug-in hybrids), both showing the absolute real-world and type approval emission levels per kilometre. Indeed, for the group of conventional vehicles and hybrids without a plug, the average real-world fuel consumption decreases much more slowly than the average type-approval value. For plug-in hybrids, the average real-world CO_2 emission has increased since they entered the market in 2013. The type approval values have stabilised since 2015 at 48 g/km for diesel plug-ins and 42 g/km for petrol plug-ins.

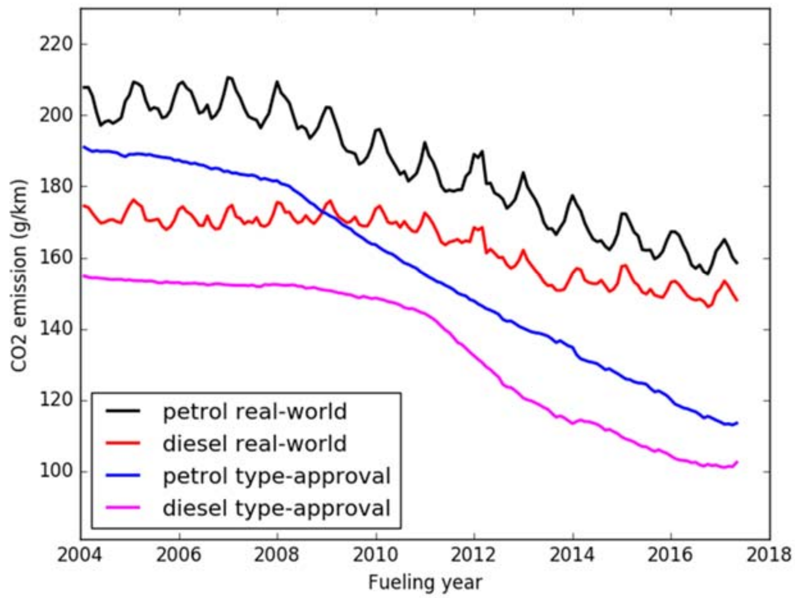

Figure 4: Average real-world and type approval tailpipe CO_2 emission of conventional and non-plug-in hybrid petrol and diesel vehicles in the database. Both the real-world and the type-approval CO_2 emissions have decreased since 2004. The different rates of reduction result in an increasing gap.

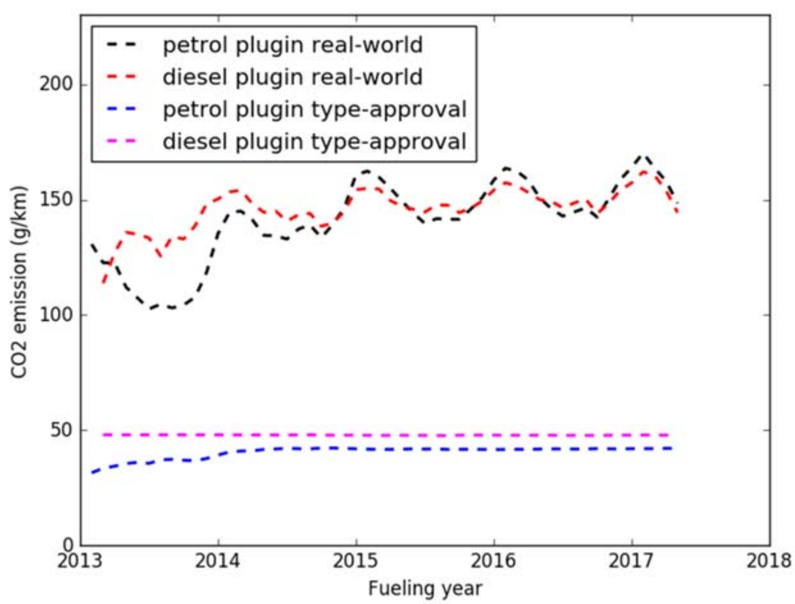

Figure 5: Average real-world and type approval tailpipe CO_2 emission of plug-in hybrid vehicles on petrol and diesel in the database. The real-world CO_2 emissions have increased since 2013, while the type-approval CO_2 emissions remained relatively constant. The increasing real-world emissions lead to an increasing gap.

The results in Figure 4 and Figure 5 represent the total vehicle fleet, which at any moment in time includes vehicles of different ages, and therefore changes over time. To evaluate changes in the characteristics of new vehicles over time, it is better to look at the average fuel consumption as function of the year of introduction of the different vehicles in the fleet (date of registration). Figure 6 shows the real-world CO_2 emission as a function of the average type approval value for petrol (+ plug-in) and diesel (+ plug-in) passenger cars of different years of introduction / registration in the fleet. Per year of introduction all data have been averaged over the entire period that vehicles are present in the database. This representation more clearly shows the how the gap evolves over time for new vehicles.

During the period 2007-2015 the reduction in real-world CO_2 emissions has been smaller than the reduction in the average type approval CO_2 emissions. As a result the gap has continuously increased, up to 45 and 55 g/km for diesel and petrol respectively. The strong increase of the gap for petrol vehicles in the period 2013-2015 is, as stated above, due to the introduction of a large amount of petrol plug-in hybrids in the fleet. Figure 7 demonstrates this effect: if plug-ins are left out, the increase of the gap for petrol cars is much more moderate. For the sales of plug-ins dropped to almost zero recently, the “plug-in effect” on the preliminary 2017 values is negligible.

In 2016 and 2017[6], the average type approval CO_2 emission of new vehicles has increased again, for both petrol and diesel. The reasons can probably be found in the cutback on fiscal advantages for plug-in hybrids, the announcement of the enforcement of the WLTP test cycle, which might have led to different tuning of vehicles in anticipation, and a trend towards heavier and larger cars as a result of increased economic prosperity. The first reason has led to a reduced gap between type approval and real world emission levels for petrol vehicles. For diesel on the other hand, the gap has increased slightly. The changes in fiscal treatment of fuel efficient vehicles, introduced by January 2016, led to a significant shift in sales / registrations where vehicles that would normally have been bought in 2016 were now purchased or registered at the end of 2015, allowing users to still benefit from tax advantages.

[6] Preliminary values for 2017, up to and including April

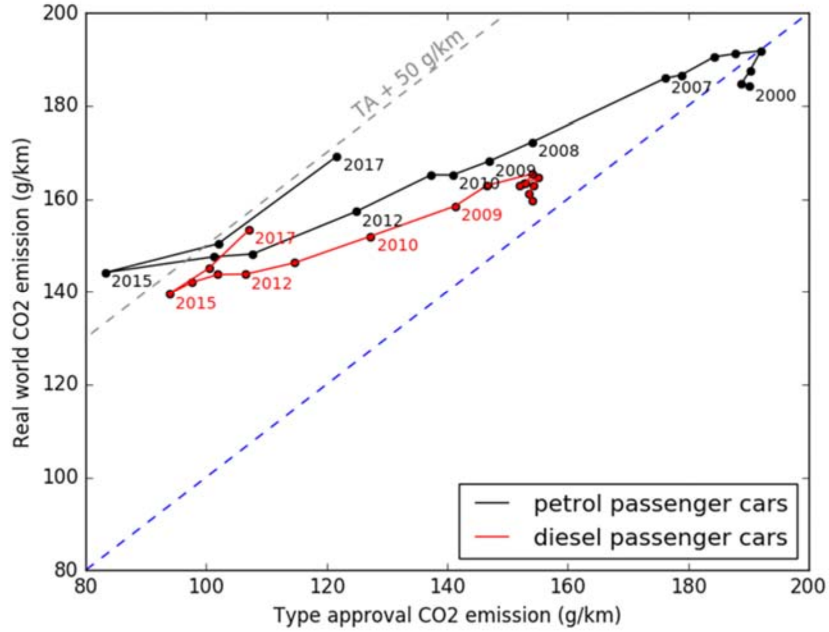

Figure 6: Average real-world CO_2 emissions versus the average type approval value of new petrol and diesel cars, **including plug-in hybrids**, differentiated by the year of introduction / registration in the Netherlands (data for 2017 are preliminary)

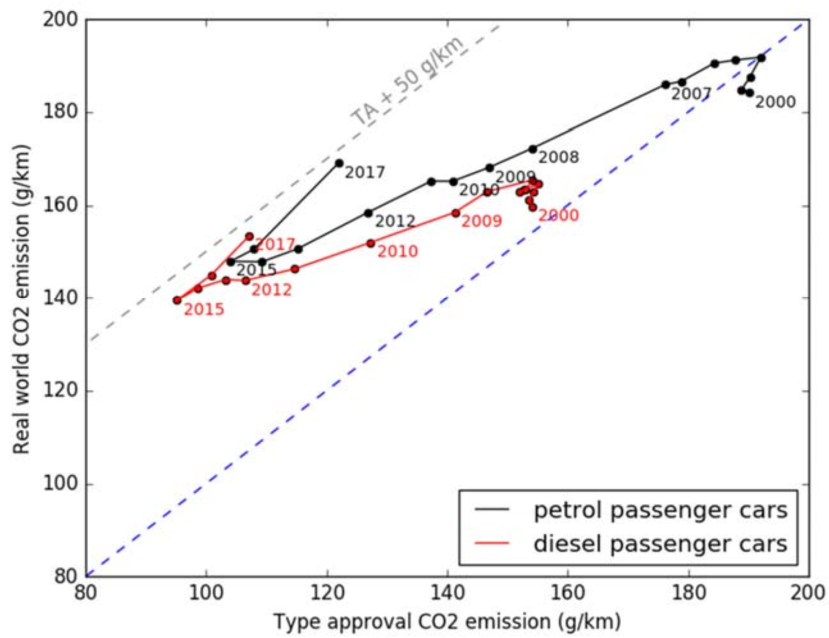

Figure 7: Average real-world CO_2 emissions versus the average type approval value of new petrol and diesel cars, **excluding plug-in hybrids**, differentiated by the year of introduction / registration in the Netherlands (data for 2017 are preliminary)

The actual gap varies from vehicle to vehicle, and is partially related to the absolute type approval CO_2 emission. In paragraph 2.3 a further split is made in the results for groups of vehicles with similar type approval CO_2 emissions.

2.2 Gap related to introduction year

In [TNO 2014] a first indication is given of a trend that for existing vehicles in the fleet the gap appears to reduce over time, possibly related to trends in external influencing factors such as average weather conditions or traffic intensity. The gap as shown in Figure 6 was derived for up to four months of data for 2017 vehicles (the data set contains preliminary data for 2017, up to April), up to one year and four months of data for 2016 vehicles, and so on, and may be biased by this trend. Following vehicles in time this trend should become apparent. Figure 8 and Figure 9 show this evolution for vehicles with different years of introduction.

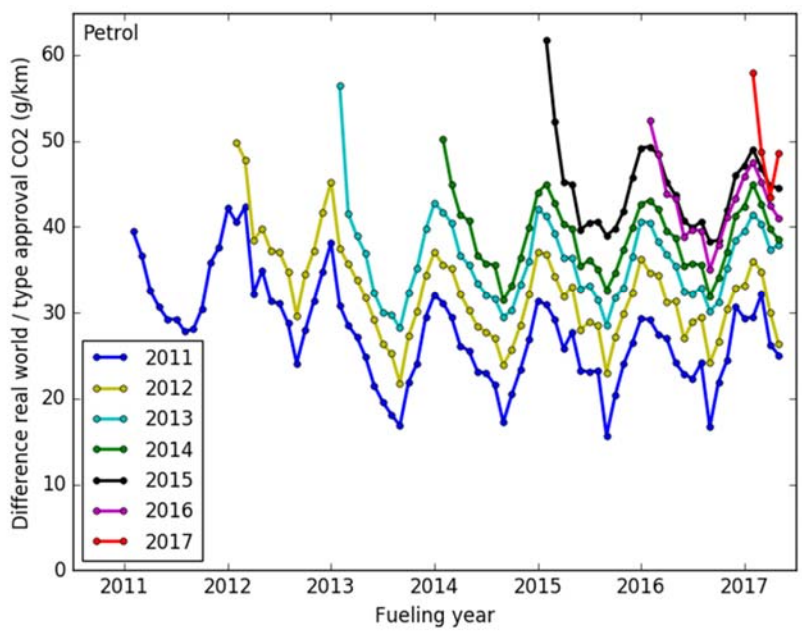

Figure 8: Evolution over time of the gap between real-world and type approval CO_2 emissions for petrol vehicles with different years of introduction in the Netherlands.

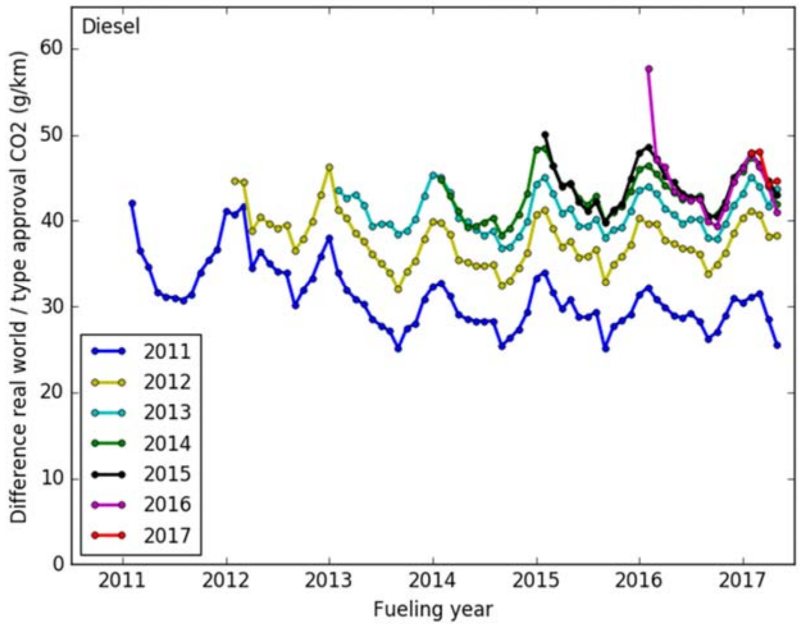

Figure 9: Evolution over time of the gap between real-world and type approval CO_2 emissions for diesel vehicles with different years of introduction in the Netherlands.

The following trends can be observed:

- The gap is always larger for newer vehicles than for older vehicles. The difference changes from year to year and appears to level off for newer vehicles;
- Between 2012 and 2013 vehicles of all years of introduction into the fleet show a distinct drop in the gap;
- After 2013 the gap remains largely constant again for existing vehicles;
- Since 2015, the gap has not decreased further. New vehicles in 2016 and 2017 show a similar distance to their type approval values as 2015 vehicles.

Changes over time in the average gap for vehicles of a given year of introduction can be caused by changes in the gap for individual vehicles, e.g. caused by variations in ambient conditions, traffic circumstances and driving styles, as well as by changes in the composition of the group of vehicles with the same year of introduction in the database. The gap change between 2012 and 2013 is further analysed in [TNO 2016].

A change in the composition of the group of vehicles with the same year of introduction in the Travelcard Nederland BV database is likely to happen three or more years after the year of introduction. Many leased vehicles, for which fuel passes are employed, are used as company car for three to five years, after which they are sold to private owners or, often, exported. It is likely that the vehicles with the highest annual mileages remain in the database for the shortest time.

The group of vehicles of a given year of introduction that remains in the fuel pass database after four or five years will thus be smaller than in the first years and will consist of a higher share of vehicles with low annual mileages and driving patterns that differ from those of the group of vehicles with high mileages. Also the average type approval value of the remaining vehicles may be different than the initial average in the year of introduction.

2.3 Real-world to type approval gap for different vehicle classes

The large amount of vehicles in the database allows for a reliable determination of the difference between real-world and type-approval CO_2 emissions for vehicles with (ranges of) different CO_2 type-approval values and different years of introduction. For years of introduction and CO_2 emission classes for which the database contains more than 300 vehicles the average relative difference is given in Table 2. Both for later years of introduction and for lower type-approval CO_2 values a larger relative gap can be observed. Interestingly, petrol and diesel vehicles follow the same trend. Even the magnitude of the relative differences based on the CO_2 emission classes is very similar.

The large increase of the difference between real-world and type approval CO_2 emissions as function of the type approval value is somewhat exaggerated in the relative numbers in Table 2. For a lower type-approval CO_2 emission the same amount of additional CO_2 emissions represents a larger relative gap. In Table 2, which presents the absolute difference in type-approval and real-world CO_2 emissions, trends in the year-by-year change of the gap are more clear. Both for petrol and diesel the gap has increased annually by 1 to 3 g/km for vehicles with similar type approval CO_2 emissions. In 2015 the gap has suddenly increased by up to 9 g/km for petrol vehicles, and decreased again in 2016. This is a temporary effect caused by the introduction of a large number of new plug-in hybrid vehicles in 2015. The exceptionally high value of 64.6 g/km for the 70-79 g/km petrol vehicles is a result of the mix of vehicles in this category: mostly small hybrid cars (45-50 g/km gap) and a selection of luxury plug-in hybrids (120-150 g/km gap).

Furthermore it can be seen from Table 3 that the absolute gap was initially most prominent in vehicles with low type approval values and small or absent for larger and less fuel efficient vehicles. In more recent years, however, it has become substantial over all type approval CO_2 segments. Finally it can be seen that especially for diesels the shift towards vehicles with lower type approval CO_2 values is accompanied by a clear narrowing of the bandwidth of CO_2 values.

Table 2: The relative difference between real-world and type-approval CO_2 emissions (or equivalently fuel consumption) of petrol (upper) and diesel (lower) passenger cars, differentiated for the year of first registration and the type-approval CO_2 emission value and averaged over the entire period that vehicles within a category are present in the Travelcard database.

petrol	**type-approval CO2 [g/km]**												
year	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	150-159	160-169	170-179	180-189	190-199
2006				20.6%			12.7%	12.6%	9.1%	6.6%	2.9%	1.8%	1.0%
2007				21.9%			18.4%	12.4%	9.7%	6.1%	3.6%	2.0%	2.3%
2008				25.9%			18.7%	16.7%	12.5%	9.6%	6.0%	4.0%	1.6%
2009			38.2%	27.6%	25.6%		20.8%	17.1%	12.2%	9.8%	7.8%	5.1%	3.4%
2010		40.8%	39.0%	27.1%	27.7%	23.9%	20.1%	17.0%	13.0%	11.0%	9.4%	9.4%	8.0%
2011		46.8%	44.7%	28.6%	26.1%	26.5%	20.7%	19.5%	14.7%	12.4%	11.9%	11.3%	11.1%
2012		46.1%	37.2%	34.1%	27.5%	26.0%	22.7%	19.7%	16.0%	13.2%	9.7%		
2013		54.2%	39.3%	38.3%	32.9%	25.5%	23.5%	19.7%	19.5%				
2014		50.8%	40.3%	35.7%	28.7%		25.3%	22.0%					
2015	85.2%	55.4%	42.5%	41.8%	36.9%	30.6%	26.6%	27.0%					
2016		49.8%	43.7%	43.9%	37.7%	31.9%	33.4%	30.1%					
diesel	**type-approval CO2 [g/km]**												
year	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	150-159	160-169	170-179	180-189	190-199
2006					17.3%	17.4%	12.5%	10.2%	5.1%	3.4%	0.2%	-1.6%	-2.8%
2007					19.7%	17.6%	13.4%	9.2%	6.7%	3.8%	3.0%	-1.6%	-0.1%
2008					25.7%	18.4%	11.8%	11.5%	7.7%	5.9%	3.9%	-0.3%	0.1%
2009				31.0%	23.7%	16.4%	12.5%	10.2%	7.3%	5.9%	3.2%		
2010		44.9%	40.6%	31.8%	25.0%	18.1%	15.8%	11.8%	8.1%		2.8%		
2011		46.0%	40.8%	30.1%	27.6%	21.7%	17.6%	15.0%	12.3%				
2012		45.3%	49.8%	29.4%	28.6%	22.3%	20.6%	14.7%					
2013		52.0%	41.2%	33.7%	30.9%	25.8%	21.3%	14.9%					
2014		55.3%	43.5%	38.0%	31.9%	24.5%							
2015	57.4%	58.2%	44.4%	39.3%	35.5%								
2016		55.0%	47.0%	42.6%	37.3%								

Table 3: The absolute difference between real-world and type-approval CO2 emissions of petrol (upper) and diesel (lower) passenger cars, differentiated for the year of first registration and the type-approval CO2 emission value and averaged over the entire period that vehicles within a category are present in the Travelcard database.

petrol	**type-approval CO2 [g/km]**												
year	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	150-159	160-169	170-179	180-189	190-199
2006				22.0			17.5	18.1	14.1	10.8	5.1	3.4	2.0
2007				23.7			25.4	17.8	15.0	10.1	6.4	3.7	4.5
2008				27.7			25.8	24.1	19.4	15.9	10.4	7.4	3.1
2009			35.3	29.4	29.5		28.6	24.7	19.1	16.3	13.5	9.4	6.7
2010		36.3	36.0	28.6	31.6	29.9	27.4	24.7	20.3	18.3	16.5	17.4	15.6
2011		41.5	41.8	29.9	29.7	32.9	28.2	28.1	23.0	20.6	20.9	20.9	21.7
2012		40.7	35.7	35.8	31.8	32.4	31.0	28.4	25.0	21.9	16.9		
2013		47.0	37.3	40.1	38.0	31.5	31.9	28.6	30.2				
2014		44.3	38.6	37.9	33.0		34.3	31.8					
2015	64.6	46.6	40.8	44.5	42.0	38.3	35.9	39.0					
2016		43.3	42.4	45.7	43.3	39.7	45.1	43.5					
diesel	**type-approval CO2 [g/km]**												
year	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	150-159	160-169	170-179	180-189	190-199
2006					20.3	21.6	16.9	14.6	8.0	5.6	0.4	-2.9	-5.4
2007					23.3	22.0	18.0	13.3	10.4	6.2	5.3	-3.0	-0.2
2008					30.6	23.1	16.0	16.7	12.0	9.6	6.7	-0.5	0.1
2009				33.0	27.9	20.6	16.9	14.9	11.4	9.6	5.6		
2010		39.9	39.1	34.1	28.7	22.7	21.6	17.0	12.6		5.0		
2011		40.9	38.8	32.4	31.6	27.1	23.9	21.8	19.1				
2012		40.1	45.9	31.7	32.6	27.9	27.9	21.6					
2013		45.5	39.8	35.9	35.1	32.5	28.8	21.8					
2014		46.8	42.6	40.3	35.9	30.6							
2015	45.3	47.9	42.9	41.4	39.8								
2016		47.2	45.4	44.2	42.7								

There is a fairly linear relation between the average real-world CO_2 emissions and the type approval values, as displayed in Figure 10. For new vehicles sold in 2016 this correlation can be written as:

Petrol:

$$RW\_CO_2 = 0.98 * TA\_CO_2 + 45$$

Diesel:

$$RW\_CO_2 = 0.87 * TA\_CO_2 + 57$$

With:

RW_CO_2: real-world CO_2 emission in g/km
TA_CO_2: type approval CO_2 emission in g/km

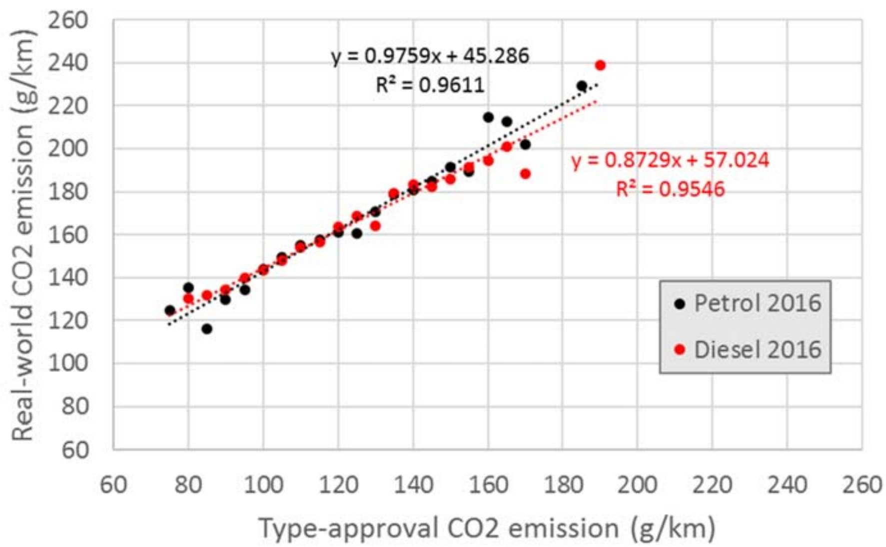

Figure 10: Correlation between absolute real-world CO_2 emissions and the average type approval value per segment, for new vehicles sold in 2016.

2.4 Gap variation among manufacturers

The average gap between type approval and real-world CO_2 emission differs from brand to brand. Figure 11 and Figure 12 show the average real-world CO_2 emissions against the average type approval CO_2 emissions per brand, for petrol and diesel vehicles sold in 2016. Plug-in hybrids are shown separately below.

The blue lines in the graph indicate different levels of the absolute gap between type approval and real-world values. For most brands the gap is around 45 g/km, irrespective of the fuel. It can be observed that the gap size has no relation to the absolute type approval CO_2 emission. In other words: the gap is not bigger or smaller for BMW than for Toyota. Volkswagen stands out for petrol vehicles with a relatively small gap, while Opel has the largest gap among the top-10 selling brands for petrol vehicles. For diesel the large gap for Volvo (50 g/km) is significant.

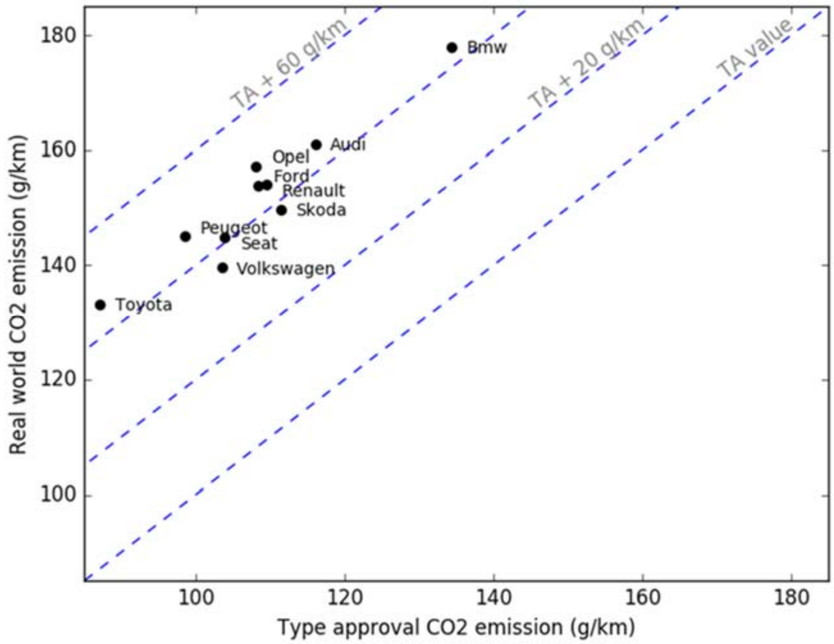

Figure 11: Average type approval and real-world CO_2 emission of **petrol vehicles** sold in 2016 for the 10 top selling brands. Plug-in hybrids are excluded.

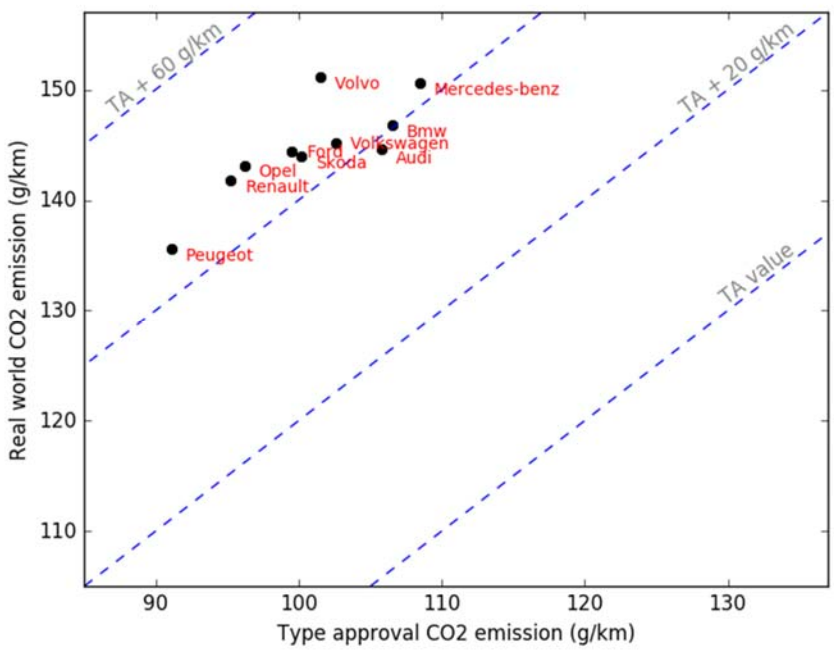

Figure 12: Average type approval and real-world CO_2 emission of **diesel vehicles** sold in 2016 for the 10 top selling brands. Plug-in hybrids are excluded.

For plug-in hybrid vehicles the difference between type approval and real-world CO_2 emissions per km is without exception much larger than for vehicles without a plug, as becomes apparent from Figure 13.

These large differences are partially caused by the larger share of electric kilometres in the NEDC test compared to real-world use of the vehicles. Volvo plug-ins have the highest absolute real-world emissions per kilometre as well as the largest distance to the type approval value. Volkswagen and Audi petrol-based plug-in hybrids are closest to their type approval values, although also for these vehicles the average gap amounts 90 g/km. The vehicles with a higher type approval emission (i.e. 49 g/km) seem to have a larger gap than vehicles with a lower type approval emission (38 g/km).

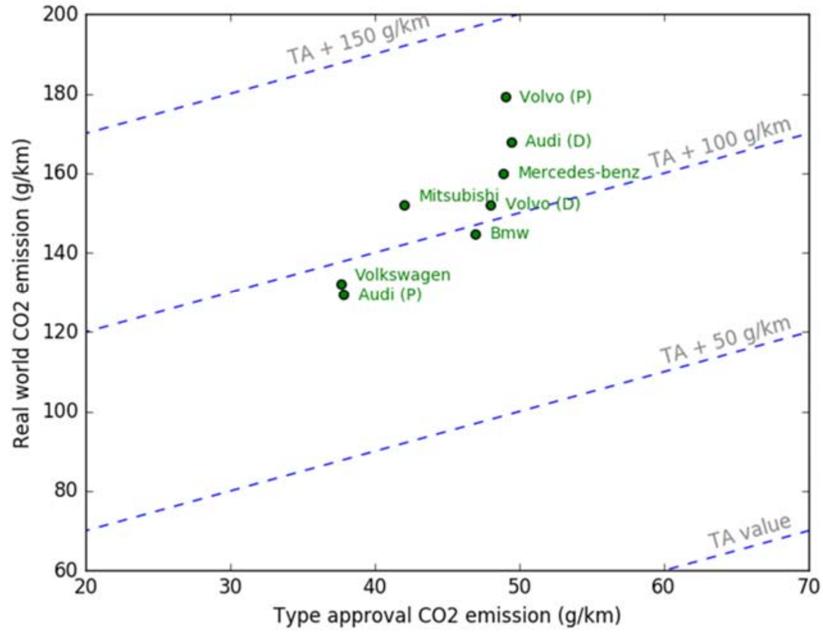

Figure 13: Average type approval and real-world CO_2 emission of **plug-in hybrid vehicles** sold in 2016 for the 10 top selling brands. P: petrol, D: diesel.

The large gap between type-approval values and real-world fuel consumption and CO_2 emissions of plug-in hybrids finds its main origin in the difference between the share of kilometres driven on electricity in real-world use compared to on the type approval test. On the NEDC test this share is significantly larger, from 50% upwards, which leads to the low type-approval fuel consumption. If for example the electric distance is one-third in real-world driving instead of two-third on the NEDC, the fuel consumption doubles. Roughly, this is the case for the plug-in vehicles in this sample. TNO studies on plug-in hybrids in the past also included other datasets which has led to slightly larger electric ranges. Around 30% electric range seems typical for a Dutch plug-in vehicle in actual use.

For different vehicle models in these data the share of electric kilometres can be estimated separately. Table 4 lists the input values for the kilometre per litre fuel consumption when driving on the combustion engine and the resulting electric distance fractions that are derived from comparison of the actual real-world fuel consumption and the fuel consumption when driving on the combustion engine[7]. Typically, modern plug-ins in this database drive about 25% of the total distance on electricity. The Ampera and the Volt, with a relatively large battery, cover a larger share of their kilometres electrically.

The Prius plug-in has a small battery, covering only half the distance in the type-approval test electrically. As a result, for the Prius, the real-world fraction of electrically driven distance is significantly lower than the average of 25%.

Table 4: Estimates of the real-world share of electric kilometres, driven by various plug-in hybrid vehicle models, based on analysis of the frequency distribution of real-world fuel consumption.

Plug-in vehicle model	Fuel consumption of combustion engine [km/l]	Electric distance
Mercedes C 350 E	12.9	19%
Opel Ampera	15.1	34%
Ford C-MAX Energi	15.2	23%
Audi A3 Sportback e-tron	14.5	24%
Volkswagen Golf	14.6	22%
Mitsubishi Outlander	11.8	27%
Volkswagen Passat	14.2	24%
Toyota Prius Plug-in Hybrid	19.6	13%
Volvo V60 Twin Engine	15.6	17%
Chevrolet Volt	14.4	37%
Volvo XC90 T8 Twin Engine	10.0	25%

With the new WLTP test procedures many aspects will change for the type-approval CO_2 values of plug-in vehicles. It is, however, unclear if this will make a large difference for the gap between type-approval value and real-world CO_2 emission. It is expected that the electric distance in the type-approval will remain much larger than the situation observed in this study for lease cars in Netherlands.

[7] The calculation method is elaborated in: TNO 2016 - Monitoring van plug-in hybride voertuigen (PHEVs) april 2012 t/m maart 2016, Norbert E. Ligterink, Richard T.M. Smokers, TNO 2016 R10938

3 Conclusions

The analysis of tank pass data in this report gives insight in the difference between real-world fuel consumption and CO_2 emissions of passenger cars and their type-approval values (the "gap"). This gap continues to develop, but is being influenced lately by the share of plug-in hybrid vehicles in passenger car sales.

Data was obtained from Travelcard Nederland BV, covering the period of 2004 up to 1 May, 2017. In total, data are available for 443 thousand vehicles, including plug-in hybrid vehicles. An analysis of the annual mileages of vehicles in the database shows that the database does not only contain stereotypical business drivers. There is a large spread in annual mileages and the database, which also contains a significant share of vehicles with relatively low annual mileages. Combined with the notion that leased vehicles drive a large share of the total annual number of kilometres by passenger cars in the Netherlands, the results of the analysis are therefore considered meaningful for the entire Dutch passenger car fleet.

Over the whole fleet included in the tank pass data for 2016 the relative difference between the average real-world and type approval CO_2 emissions is 41%.
For vehicles entering the Dutch fleet in 2016 the absolute difference is about 46 g/km, which means that the relative difference is around 46%.

Averaged over the whole period that vehicles are present in the database, the relative gap on average grows with 1.5%-point per year as function of the year of introduction / registration of the vehicles in the fleet. This is equivalent to an annual increase of around 2 g/km in the absolute gap. A larger than average increase of the gap between new vehicles sold in 2015 was followed by a "correction" in 2016, for which the gap was found similar to that of 2014 vehicles. The temporary excursion can be attributed to the high sales of plug-in hybrid vehicles in 2015, for which the gap is much larger than for non-plug-ins.

Looking at the development over time of the gap for vehicles with the same year of introduction / registration, the gap has remained steady since 2013. From 2012 to 2013 a distinct drop in the gap of around 6 to 8 g/km is seen for most groups of vehicles of the same year of introduction into the fleet. From an analysis in [TNO 2014] the combination of mild winter weather, the low levels of congestion in 2013 due to the economic crisis in combination with improved infrastructure, and the introduction of dynamic speed limits in 2012-2013 in combination with extra lanes on the motorway ("spitsstroken") was considered a plausible cause for the observed reduction of the gap. This coincidence of temporary causes still appears to be a plausible explanation. Independent of the observed changes over time, the gap is always larger for newer vehicles than for older vehicles. This trend seems to level off for newer vehicles (2015-2017).

For the top-10 brands for petrol and diesel vehicles sold in 2016, the gap between real-world and type-approval CO_2 emissions is around 45 g/km, irrespective of the manufacturer or the fuel. Also, no relation has been observed between the absolute emission and the gap size.

For plug-in hybrid vehicles the NEDC test yields very low type approval CO_2 emission values, because a large part of the test can be driven on electricity. The real world CO_2 emission is dependent on the performance of the combustion engine and the real share of electric kilometres which depends in part on the driving patterns of users and in part on the extent to which they keep the battery charged. For plug-ins the observed gap between type approval and real world CO_2 emissions ranges from 90 g/km and 130 g/km, varying from brand to brand. The vehicles with a higher type approval emission (i.e. 49 g/km) seem to have a larger gap than vehicles with a lower type approval emission (38 g/km).

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5 Signature

The Hague, 17 May 2018

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