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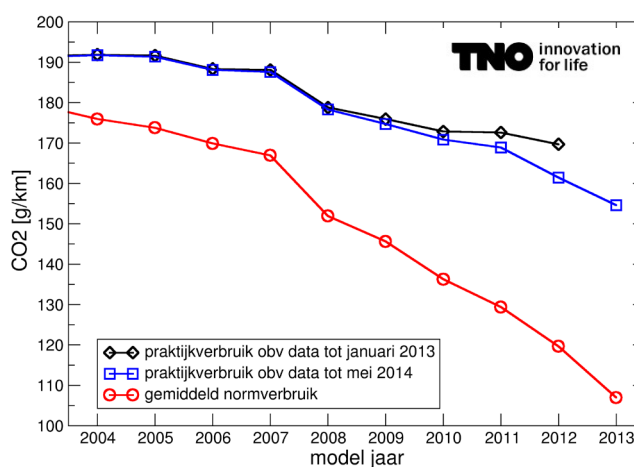
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## Samenvatting

Sinds enkele jaren stelt Travelcard Nederland BV tankpasdata ter beschikking aan TNO om inzicht te verkrijgen in het praktijkverbruik van voertuigen. TNO bepaalt op basis van de tankpasdata en technische informatie van ieder voertuig het gemiddelde verbruik voor een bepaald model personenauto. Dit rapport beschrijft de analyse van Travelcard-data van de periode januari 2013 tot en met mei 2014, als update toegevoegd aan de eerdere analyse van Travelcard-data van 2004 tot en met 2012 [TNO report 2013 R10703].

*Het verschil van norm- en praktijkverbruik blijft groeien met nieuwe voertuigen. Over de jaren is het verschil echter minder groot.*

De analyse van de tankpasgegevens van het afgelopen jaar laat zien dat het normverbruik en het praktijkverbruik steeds verder uit de pas lopen. Het verschil tussen het normverbruik en het praktijkverbruik is, echter, minder groot dan eerder werd geacht (Figuur 1). De vaste opslag op het verbruik volgens de laboratoriumtesten is niet langer geschikt voor het bepalen van het praktijkverbruik. Tankpasgegevens van een grote groep gebruikers die met de nieuwe voertuigen rijdt, geven wel een goed inzicht in het veranderende beeld.

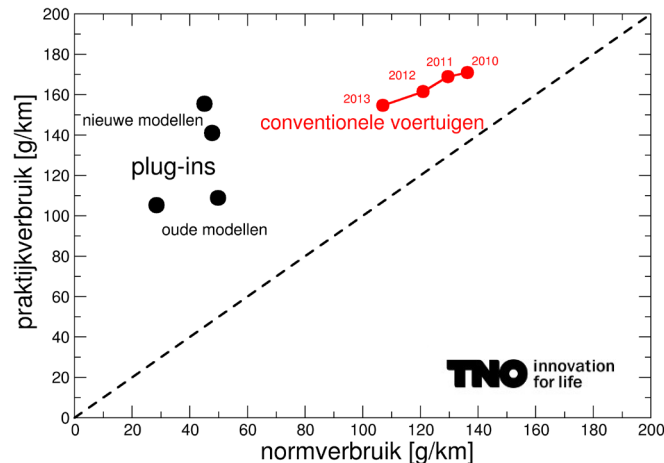


Figuur 1: Per bouwjaar van de voertuigen het groeiende verschil tussen norm en praktijk. In 2014 is het verschil voor dezelfde voertuigen kleiner dan het jaar ervoor.

### *Plug-in hybride voertuigen veroorzaken een groeiende toename*

Plug-ins bieden een goede mogelijkheid voor de auto-industrie om de gemiddelde CO<sub>2</sub>-uitstoot van auto's te verlagen en op die manier aan (toekomstige) Europese eisen te voldoen. In Nederland zijn deze auto's in grote aantallen verkocht, en dat heeft een zichtbaar effect op het gemiddelde normverbruik van auto's uit 2013.

Het verbruik van plug-in voertuigen, zoals de Opel Ampera, de Chevrolet Volt, de Toyota Prius plug-in, de Mitsubishi Outlander PHEV en de Volvo V60 plug-in hybrid, is in de algemene analyses van deze studie niet meegenomen, maar is apart geanalyseerd. Uit deze aparte analyse blijkt dat het praktijkverbruik van plug-in auto's grofweg een factor drie hoger is dan het normverbruik.



Figuur 2: Het praktijkverbruik van plug-ins en dat van conventionele voertuigen in vergelijking met het normverbruik. Het is duidelijk te zien dat het meerverbruik van plug-ins flink hoger ligt dan het meerverbruik van conventionele voertuigen.

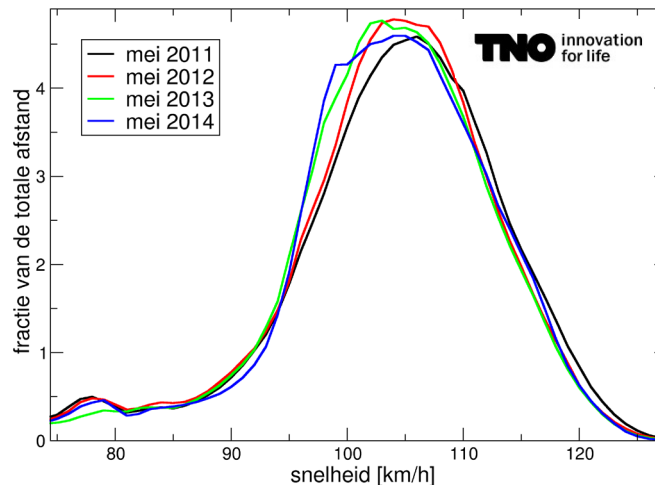
De oorzaak hiervan moet worden gezocht in het laadgedrag van de gebruikers. Het aandeel elektrisch rijden bij plug-ins ligt in de praktijk waarschijnlijk tussen de 15% en 30%, op basis van het brandstofverbruik. Dit is flink lager dan het aandeel elektrisch rijden van 50% en meer waarvan wordt uitgegaan bij het vaststellen van het normverbruik van plug-ins. Het normverbruik gaat uit van een aandeel elektrisch rijden van 50% tot 80%.

Ondanks dat het norm- en praktijkverbruik van plug-ins sterk uiteenlopen, behoort het absolute brandstofverbruik van deze groep voertuigen tot de meest gunstige categorie. De recentere plug-in modellen lijken, echter, een trend in te zetten van grotere voertuigen, met een hoger praktijkverbruik. Deze recente plug-ins zijn in de praktijk wel zuiniger dan vergelijkbare grote voertuigen, maar nauwelijks zuiniger dan zuinige conventionele voertuigen, waarbij de neergaande trend nog verder doorzet.

### *Omstandigheden waren in 2013 en 2014 gunstiger dan in 2012 en 2011*

De data analyse laat ook een nieuw opmerkelijk aspect zien: de groep in 2012 nieuw geregistreerde voertuigen heeft in 2013 gemiddeld een paar procent zuiniger gereden dan in 2012. De reden daarvoor is onduidelijk. Wel zien we dat de weersomstandigheden (in het bijzonder de temperatuur) het afgelopen jaar gunstiger waren. Mogelijk heeft ook de aandacht voor brandstofverbruik en brandstofkosten een positief effect. Ook is afgelopen jaar de filezwaarte op zijn laagst geweest sinds jaren. De gemiddelde congestie is afgenomen. Daarnaast

worden er meer kilometers op de snelweg gereden rond de 90-100 kilometer per uur in plaats van 106 kilometer per uur. Waarschijnlijk zijn de spitsstroken, met de dynamische snelheidslimieten, verantwoordelijk voor deze verschuiving.



Figuur 3: Percentage dat bij verschillende snelheden gereden wordt op de snelweg in de maand mei van opeenvolgende jaren. De verschuiving naar lagere snelheden en een piek bij 95 en 100 km/h zijn ontstaan. De congestie is in deze maanden per jaar ook afgenomen van 3.1% tot 2.6% van de kilometers.

Er is niet met zekerheid vast te stellen dan deze veranderingen de vermindering van het brandstofverbruik volledig verklaren, maar een gedeelte ervan zeker wel.

De verwerking van de nieuwe cijfers geeft voor dezelfde auto's een wat lager meerverbruik, dan eerder werd gegeven. Dit verschijnsel heeft invloed op alle auto's waarvoor nieuwe gegevens beschikbaar zijn, in het bijzonder op auto's uit de periode 2010-2012, die nog steeds volop in de leasemarkt meedraaien. Omdat het om maar een paar procent gaat, is het effect niet nader te specificeren naar groepen. De data van 2013 wordt toegevoegd aan de data van 2005 tot 2012, zodat er per voertuig een zo compleet mogelijk beeld ontstaat.

### *Opvallende voertuigmodellen die afwijken van de trends*

Met de gegevens van dit jaar is het duidelijk dat enkele voertuigmodellen populair waren, alleen omdat deze voertuigen net onder de grens van het belastingvoordeel vielen - zonder het bijbehorende lagere praktijkverbruik. Vorig jaar werd bij de grenzen van de fiscale voordelen (120 g/km voor benzine en 95 g/km voor diesel) een extra hoog meerverbruik waargenomen. Voorheen was het alleen duidelijk dat SUV's (terreinwagens) negatief afsteken bij de algemene trend: het meerverbruik is nog hoger dan op basis van het normverbruik verwacht kon worden.

De groep zuinige diesels, met een uitstoot van 95 g/km CO<sub>2</sub> en minder, werd in 2012 gedomineerd door een beperkt aantal voertuigmodellen. Het meerverbruik in deze groep ten opzichte van het normverbruik sprong er vorig jaar extra negatief uit. In 2013 zijn er meerdere voertuigmodellen beschikbaar met een CO<sub>2</sub>-uitstoot

van tussen de 90 en 100 g/km. In deze groep is het meerverbruik in lijn met de algemene trend van een hoger meerverbruik bij een lager normverbruik en later voertuigmodel. De sterke toename van het meerverbruik voor zuinige diesels is door de nieuwe gegevens iets naar beneden gecorrigeerd; wel blijft het meerverbruik voor deze categorie voertuigen in de orde van 50%.

### *Andere brandstoffen spelen nog nauwelijks een rol*

LPG is een beperkte groep, waarvoor de hoeveelheid beschikbare data sterk afneemt. Daarnaast is er een verschuiving zichtbaar van retrofit-installaties naar affabriek LPG-modellen. Dat maakt een aanpassing van het meerverbruik voor LPG noodzakelijk. De verwachting is dat het meerverbruik bij LPG vergelijkbaar is met het meerverbruik bij benzine. De CO<sub>2</sub>-norm moet hierbij wel worden gecompenseerd voor de ongeveer 10% lagere koolstofinhoud van de LPG-brandstof. Voorheen betrof LPG vooral de retrofit van met name oudere en grotere voertuigen, waarvan het meerverbruik slechts beperkt hoger was. Maar met de komst van LPG in alle marktsegmenten - waarschijnlijk vanwege het CO<sub>2</sub> voordeel - is het niet langer houdbaar om de verbruiksdata van veelal oudere voertuigmodellen te extrapoleren naar zuinige auto's.

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# 1 Introduction

Since 2008 Travelcard Nederland BV and TNO collaborate to determine the real-world fuel consumption of modern vehicles. The difference between the official type-approval value and the actual fuel consumption has been reported over the years. The fact that both numbers do not coincide is not surprising, since the official type-approval test for determining fuel consumption does not properly represent the real-world vehicle usage. However, the increasing gap between both numbers is remarkable. From year to year, the type-approval value decreases with new vehicle models. The real-world fuel consumption, on the other hand, is only *slightly* lower. Also for the same type-approval value the real-world fuel consumption is higher with newer vehicles.

In 2014, Travelcard made available a new fuel consumption data set. Based on this set TNO investigated trends in fuel consumption for passenger cars over a period that now covers 2004 to 2014. The study focuses on real-world fuel consumption and the extent to which this is different from the type-approval fuel consumption.

The difference between the type-approval fuel consumption and the real-world fuel consumption mainly depends on three aspects: the fuel type, which is mainly diesel or petrol; the type-approval fuel consumption and CO<sub>2</sub> emission itself, and the model year. The study reconfirms the trend that cars with a lower the type-approval value in general show larger differences between real-world fuel consumption and this type-approval value. Additionally, the ten-year data set clearly shows that recent vehicle models have a larger 'gap' between real-world and type-approval fuel consumption.

## 1.1 An increase in fuel consumption with newer vehicle models

Comparing the vehicle models from 2012 with those of 2013, over the same period, the latest vehicle models with the same type-approval have a higher real-world fuel consumption. This effect is present over the whole range of type-approval values and fuels types. The notable exception are diesel passenger cars with a CO<sub>2</sub> emission of 90-100 g/km. These vehicles had, until recently, a road-tax benefit. Some of the first models satisfying the 95 g/km criterion were performing much worse than the current spectrum of vehicle models around the 3.5 litres/100 km type-approval fuel consumption. For diesel cars, a fuel consumption of 3.5 litres/100 km corresponds to a CO<sub>2</sub> emission of 95 g/km.

## 1.2 Lower overall fuel consumption for the same vehicles in 2013

Rather unexpectedly, as it did not occur in the data from 2004 till 2012, the fuel consumption decreased for vehicles for which last year fuelling data was already analysed. The estimated fuel consumption of 2011 and 2012 vehicle models is a few percent lower than was estimated last year, up to 4.5%. This was analysed in different ways to establish the true effect. Indeed the fuel consumption of a fixed set of vehicles in 2013 and spring 2014 is lower than a year earlier. It affects mainly the vehicles which are used in 2012 and 2013. These are vehicle models from 2010 till 2012, as vehicles are typically used up to four years in the business use. For the vehicle of 2012, about half a year of data was available. In the new analysis this has

increased to two years. Hence, with the new analysis the 2012 vehicles are dominated by the more recent data, while 2011 vehicles are based on a more equal amount of older and newer data, yielding a smaller effect on average.

### **1.3 Plug-ins electric driving remains limited**

Due to the special technology and electric charging, the fuel consumption of plug-in hybrid vehicles has been analysed separately. The type-approval value is based on a large amount of electric driving, on the battery charged through the electric mains. In practice, with current vehicle models, the share of electric driving with plug-in vehicles is only limited. Typically only 15% to 30% of the distance is covered on the energy charged through the electricity network. Consequently, the real-world fuel consumption is typically threefold the type-approval value. Despite the attention it received in the media in the spring of 2013, the 2014 fuel consumption data only indicate little improvement in the amount of electric driving.

### **1.4 General trends**

Last year it was noted that the difference between type-approval values and real-world fuel consumption increased for all type-approval values. For petrol cars this is still the case. The real-world factor is an overall 45-50 g/km additional CO<sub>2</sub> emission. For diesel it seems that the additional CO<sub>2</sub> emission for higher type-approval values is somewhat lower than in years before. However, over the range of the common makes and vehicle models the variation is limited.



## 2 Increase in fuel consumption with latest vehicle models

For each model year and each range of CO<sub>2</sub> type-approval value, the additional real-world emission can be determined. Table 1 shows the data for petrol cars; in Table 2 the additional fuel consumption of diesel cars is shown. Due to the variation in fuel consumption from one motorist to the next, the values are only significant for a sufficient amount of underlying data. Therefore, only cells with more than 100 vehicles are filled.

The tables show, as in previous studies, an increase of the difference between real-world and type-approval fuel consumption from the model year 2012 to the model year 2013. The notable exceptions are diesel cars with a type-approval CO<sub>2</sub> emission of 90-99 g/km and, less pronounced, petrol cars in the 120-129 g/km CO<sub>2</sub> emission range. The former was due to a few early vehicle models satisfying the 95 g/km limit of the Dutch road tax exemption, which makes a large effect. Generally, specific vehicle models follow the general trend for the same year and type-approval CO<sub>2</sub>. The diesel vehicle models of 2012 and 95 g/km of CO<sub>2</sub> are the exception to this rule. One vehicle model has a particularly large difference.

If instead of a percentage, the difference can be expressed as a constant different for petrol vehicles of about 45 g/km. For diesel vehicles the fuel-economic vehicles have an even higher value: close to 50 g/km. The less fuel efficient diesel vehicles seem to do slightly better, at 40 g/km additional emission of CO<sub>2</sub>.

Table 1: The additional fuel consumption of **petrol** vehicles, for a given type-approval CO<sub>2</sub> and model year, based on the type-approval date.

CO <sub>2</sub> [g/km]	2005	2006	2007	2008	2009	2010	2011	2012	2013
80-89					48.7%	46.8%	49.5%	49.8%	57.2%
90-99					44.3%	45.0%	53.4%	44.2%	46.4%
100-109	29.6%	26.2%	27.9%	31.3%	33.3%	32.9%	34.7%	42.6%	45.1%
110-119	39.4%	38.7%	30.4%	30.9%	34.6%	36.7%	36.6%	35.4%	42.4%
120-129	39.1%	24.7%	20.0%	26.6%	27.1%	31.1%	34.5%	35.6%	35.5%
130-139	16.8%	19.6%	24.1%	24.6%	27.1%	27.2%	28.8%	31.7%	34.4%
140-139	15.9%	19.2%	19.0%	22.9%	23.6%	25.4%	27.7%	28.9%	30.0%
150-159	13.7%	15.4%	15.6%	18.4%	19.4%	21.4%	24.7%	26.8%	29.0%
160-169	12.0%	12.3%	12.2%	16.3%	17.5%	18.8%	21.4%	21.8%	24.4%
170-179	10.4%	9.4%	10.2%	12.8%	16.4%	18.6%	20.8%	21.1%	23.0%
180-189	9.5%	8.2%	8.7%	11.2%	13.4%	18.4%	22.5%	22.6%	25.6%
190-199	9.0%	8.4%	10.0%	10.0%	12.6%	17.3%	24.6%	21.6%	22.6%
200-209	6.4%	7.2%	9.1%	6.3%	8.1%	16.5%	21.2%	16.8%	22.4%

In the Netherlands most new vehicles are sold in the 90-120 g/km range. In the past, i.e. until 2007, the average type-approval CO<sub>2</sub> was much higher, and the range was wider as well. Nowadays, only the first five rows in the tables are important for the average fuel consumption of new vehicles. Hence the lower

additional fuel consumption seen for diesel vehicles above 140 g/km hardly affects the national average. In terms of fuel consumption, in litres/100 km, the tables for petrol and diesel are less alike. In terms of CO<sub>2</sub> and also energy usage the additional fuel consumption for diesel and petrol is surprisingly similar.

Table 2: The additional fuel consumption of **diesel** vehicles, for a given type-approval CO<sub>2</sub> and model year. The notable exception in the general trend is the 2012 group of 90-99 g/km.

CO <sub>2</sub> [g/km]	2005	2006	2007	2008	2009	2010	2011	2012	2013
80-89						51.3%	52.6%	51.9%	60.2%
90-99				35.5%	34.3%	46.5%	47.3%	<b>57.5%</b>	47.4%
100-109	29.8%	25.9%	34.2%	37.8%	35.6%	37.2%	35.7%	34.7%	40.1%
110-119	23.1%	22.2%	24.5%	30.5%	28.6%	30.6%	33.6%	35.0%	37.4%
120-129	21.5%	21.7%	22.3%	22.9%	20.5%	23.4%	28.8%	29.5%	31.7%
130-139	16.7%	16.8%	18.4%	16.4%	17.2%	21.9%	24.6%	30.0%	32.0%
140-139	15.5%	15.0%	14.1%	17.1%	15.2%	17.0%	22.5%	23.3%	24.9%
150-159	11.5%	10.3%	11.8%	13.4%	13.2%	15.2%	20.5%	22.0%	25.0%
160-169	8.4%	8.6%	9.4%	11.8%	11.9%	12.7%	14.5%	24.4%	28.2%
170-179	6.5%	6.3%	9.1%	9.6%	8.4%	9.5%	16.4%	21.8%	25.5%
180-189	8.1%	4.8%	4.6%	5.3%	6.6%	5.9%	15.2%	22.5%	22.7%
190-199	2.3%	3.9%	6.5%	7.1%	4.5%	16.5%	25.5%	17.1%	
200-209	-0.2%	1.8%	1.4%	3.1%	9.9%	4.7%	6.5%	16.3%	

If the main vehicle models of the main manufacturers in the 2014 dataset of Travelcard Nederland BV are plotted (Figure 1), the notable exception clearly stands out from the general trend. For petrol vehicles the number of models on sale is even larger such that the amount of data per separate model is limited. However, generally the same trend is seen. There are basically no outliers, which means that in general all models of all manufacturers show real-world fuel consumption that is significantly higher than the type-approval value.

It should be noted that in the Table 1 and Table 2 each cell has a separate group of vehicles underlying the data. Each cell is an independent analysis. The global trend both with years as well as with type-approval value is solely based on the underlying data. No bias is introduced from assuming some generic cross-dependencies. For that reason, the visible trends are surprising. Moreover, there seems to be no end yet to the increasing gap between the official fuel consumption and the experiences of consumers. The decreasing fuel consumption with the same vehicle in the last year decreases the difference between real-world and type-approval fuel consumption somewhat. However, the increasing gap with more recent vehicle models is independent from this effect.

The disproportional effect of the 95 g/km diesel vehicle models of 2012 is shown in Figure 1. Currently, there are many vehicle models available below this type-approval value. Last year, only a few vehicle models were available. One of those models has an average fuel consumption of about 2.5 liters/100 km diesel extra. This value is indicated by the arrow. Consequently, the average real-world fuel consumption is higher than for the models sold in 2013.

In Figure 2 the analysis of last year as well as the current analysis are represented. There has been a change in fuel consumption for the vehicles which have been monitored before. Systematic effects, such as seasonal variations, have been excluded as underlying causes. In the next section the effect is further analysed. It affects all vehicle models for which new data is available by the fraction of the amount of the additional data. Therefore, it is clear this is an external influence affecting the fuel consumption, such as weather, congestion, fuel density, and a general attitude change for vehicle usage.

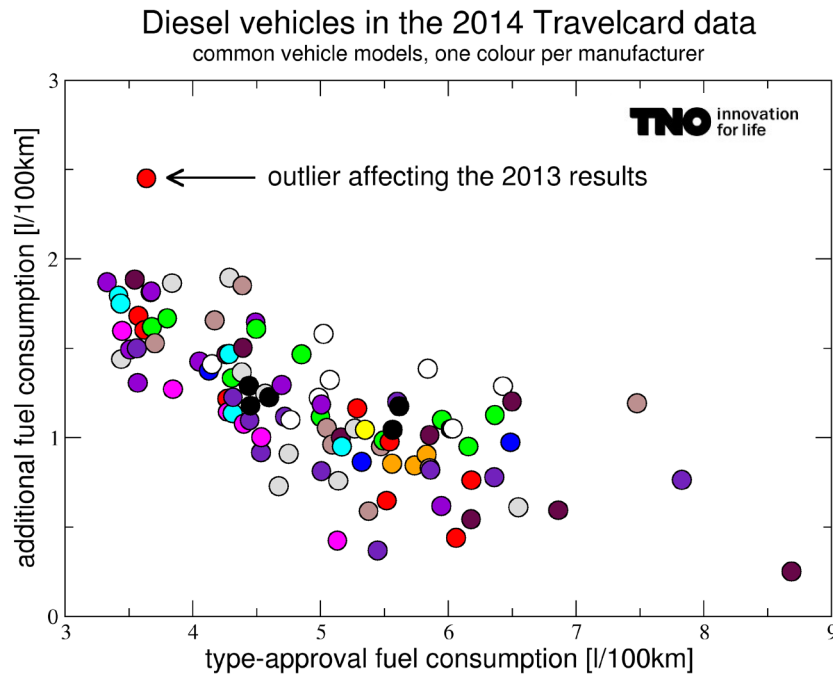


Figure 1: The common vehicle models of manufacturers with many models sold, throughout the years. The other red circles are in line with the general trend. Hence this manufacturer is not performing badly overall, except for this vehicle model.

With a total distance of about 100 billion kilometres travelled with Dutch passenger cars the additional CO<sub>2</sub> emission with modern vehicles is about 4.5 million tonnes of CO<sub>2</sub>. This is 12% of the total transport CO<sub>2</sub> emission, and 2.7% of the total CO<sub>2</sub> emission in the Netherlands in 2012. The gap between the expected reduction in CO<sub>2</sub> emission of transport and the actual CO<sub>2</sub> emission reduction is increasing year after year. As can be seen in Figure 2, the surplus CO<sub>2</sub> emission grew from about 15 g/km in 2004 and earlier to approximately 50 g/km in recent years. In other words: the gap has tripled. Relative to the type-approval value the increase appears even larger: the excess CO<sub>2</sub> emission grew from 10% to 50%.

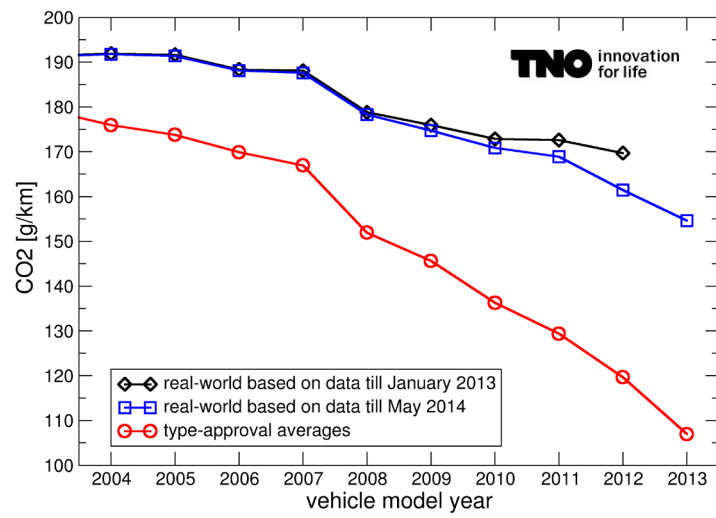


Figure 2: The type-approval and real-world fuel consumption of passenger cars. The analyses of 2013 and 2014 are shown separately. The current analysis shows a lower real-world fuel consumption (blue line) but with an increasing gap from 2012 to 2013. The average is based on 70% petrol and 30% diesel cars.

### 3 Lower fuel consumption with the same vehicle

The same analysis as in 2013, with new data till May 2014 added, yields lower fuel consumption for the same vehicles. Since the analyses started in 2008, this effect has never been encountered before. The vehicles for which a substantial amount of new fueling data became available were affected most: up to 4% lower fuel consumption for vehicle models from 2012. This effect was further analysed by following a group of vehicles over time. The vehicles from 2012 were followed over the last two years, which showed a downward trend, in correspondence with the difference between 2012 and 2013. This means the lower fuel consumption was not an artefact of the analysis, but a visible trend.

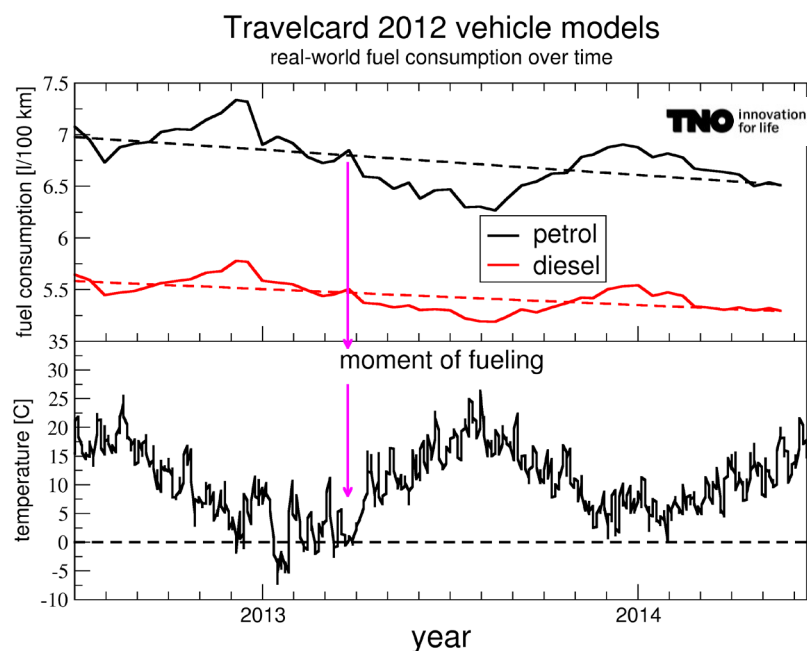


Figure 3: The fuel-consumption over time for the same sets of vehicles. On top of the annual variation, a downward trend is visible. This is in part related to the warmer weather in the second half of the two year period. The arrow indicates a colder period which is visible in the increase in fuel consumption [source temperature data: KNMI].

The mild weather may be in part responsible for this effect. However, lower congestion, and the dynamic speed limits, introduced in 2012-2013, in combination with extra lanes on the motorway in case of high traffic intensities could also have contributed to the effect. In general, 2013 has been a year with the lowest congestion for a long time, due to the economic crisis in combination with improved infrastructure. Another effect may be the high fuel prices and excise, and the attention in the media this has generated. Finally, the density of fuels can affect the volumetric energy density. With a lower density of fuel, as for example, in winter fuel, the volumetric fuel consumption increases. The density of fuel can vary a few percent. The specification of fuel densities are broad: 7% for petrol and 3% for diesel.

The underlying cause of the decreased fuel consumption is unexplained. However, as the effect is generic for petrol and diesel alike, the weather is the most likely cause. A colder period in the spring of 2013 is clearly visible as an increased fuel consumption for both diesel and petrol (indicated with the arrows). Given the typical vehicle usage of modern cars with about 50% of the distance on the motorway, about half of the total fuel consumption can be assigned to air drag. The air drag decreases with temperature and air density. Hence a 10 degrees higher temperature will lead to about a 2%-3% lower fuel consumption. This is only part of the annual fluctuation of the fuel consumption. Temperature also affects the additional fuel consumption due to the cold start, and the fuel density of summer and winter fuel.

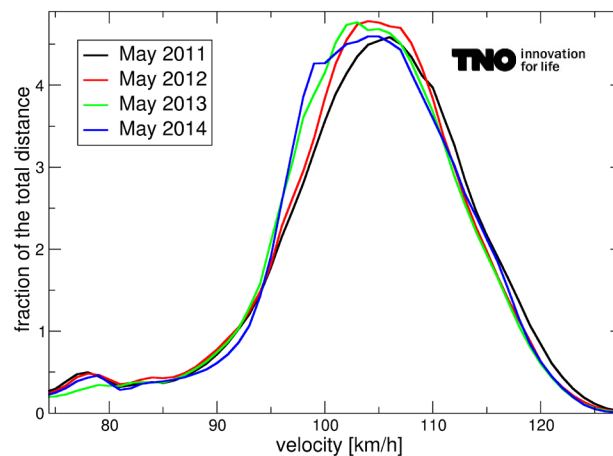


Figure 4: The distribution of velocities on the Dutch motorways. The shift towards lower velocities is clearly visible from 2011 to 2014.

### 3.1 Changing free-flow velocities on Dutch motorways causes a decrease of CO<sub>2</sub> emissions

The RWS (Dutch road authority) has made 15-minute average data available of the intensity and velocity of the majority of the Dutch motorways. From this data the driving dynamics and behaviour of individual drivers cannot be deduced. However, the global trend over time can be determined. With a simple model of the CO<sub>2</sub> emission for a given velocity, combined with the distribution of velocities, and weighed with the total distance, can be translated in a month-by-month CO<sub>2</sub> emission over the period January 2011 till May 2014. However, this analysis is complicated by driving at intermediate velocities. Based on the velocity, driving at 70 km/h would yield a low fuel consumption, i.e., constant driving. However, driving at 70 km/h on the motorway is due either to mild congestion on the whole road section, or heavy congestion in part of the time or on part of the road section. Hence this is associated with high dynamics.

From the data it is clear that not only the amount of heavy congestion decreased, but also the average velocity in free-flow conditions has gone down. A number of Dutch motorways have a so-called "spitsstrook": vehicles are allowed to drive on the hard shoulder, combined with a reduced maximal velocity on the section of the

motorway. Given a reference month May, the distribution of velocities changes from year to year. See Figure 4. Likewise, the distance driven in congestion has decreased in the same months. See Figure 5.

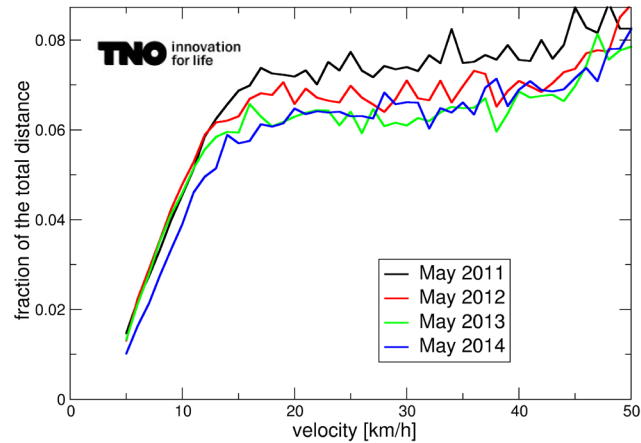


Figure 5: The distance driven at low velocities on the Dutch motorways has decreased from 2011 to 2014, from 3.1% to 2.6%.

To avoid the inclusion of congestion, the velocities in the band typical of free-flow are selected for the determination of the effect of changing velocities on CO<sub>2</sub> emissions. The effect of the velocity in free-flow situations are partly covered by simulating the CO<sub>2</sub> for free-flow driving, between 85 km/h and 130 km/h. This yields a reduction of a 1%-2% percent of CO<sub>2</sub> from 2011 to 2014. See Figure 6.

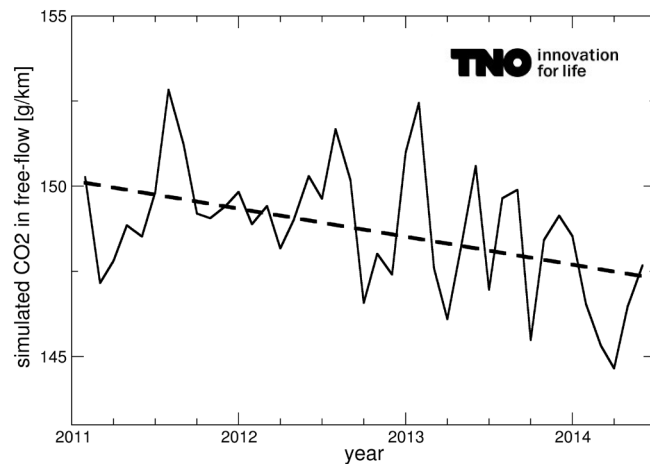


Figure 6: A simple simulation based on average free-flow velocities (85 -130 km/h) on the motorway. In the summer period the velocities and the CO<sub>2</sub> emissions are higher. A downward trend is clearly visible, yet difficult to quantify.

The congestion has also decreased. Again velocity, without dynamics, complicates the determination of the effect. Typically, the distance at high congestion will yield double CO<sub>2</sub> emissions.

Consequently, the percentage difference of distance driven in congestion results in a similar difference in CO<sub>2</sub> emissions. The estimated reduction in CO<sub>2</sub> emissions is 0.5%, due to the reduction of the congestion. See Figure 7.

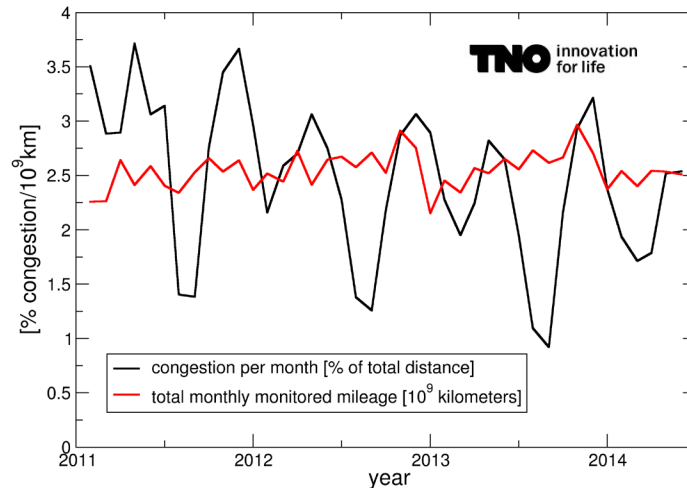


Figure 7: The percentage distance driven in congestion is shown by the black line. The large variation is due to holiday periods and weather. A downward trend of about 0.5% is visible. A similar reduction can be expected on the fuel consumption. The total distance, shown by the red line, increases slightly.

The reductions of CO<sub>2</sub> emissions 1%-2% due to a lower average free-flow velocity and 0.5% due to a reduction in congestion, are estimates on the basis of the average velocities alone. A major effect: the reduction of dynamics is not covered by this analysis. It can be expected that a lower free-flow velocity is also associated with a lower dynamics, and therefore an additional reduction in CO<sub>2</sub> emissions is to be expected.

The estimates are more likely to be too small, because vehicles in business use are more likely to encounter congestion, in the morning and evening rush hours, than other vehicles. Furthermore, from the data it is clear that, despite the 130 km/h speed limits are implemented on a part of Dutch motorways, few people drive at 125 km/h and higher velocities. However, it is more likely that drivers whose fuel bill is paid for, drive at a higher velocity and reduce their velocity more if a 100 km/h speed limit is enforced. Consequently, the CO<sub>2</sub> reduction for the group of business users examined in this study can be expected to be larger.



## 4 Real-world fuel consumption of plug-in hybrids

Plug-in vehicles have become very popular due to the recent incentives and road-tax exemptions. In total about 26,000 plug-ins were sold till the first quarter of 2014. The Volvo V60 and the Mitsubishi Outlander have a majority share in the sales. The absolute top was the sales of 8000 new Mitsubishi Outlander PHEV at the end of 2013, about one-fifth of the total vehicle sales in that period. The Volvo V60 plug-in hybrid similarly affected the end of year sales of diesel vehicles. The average type-approval CO<sub>2</sub> emission of all vehicles sold in December 2013 was at an all-time low with average values below 100 g/km for both petrol and diesel.

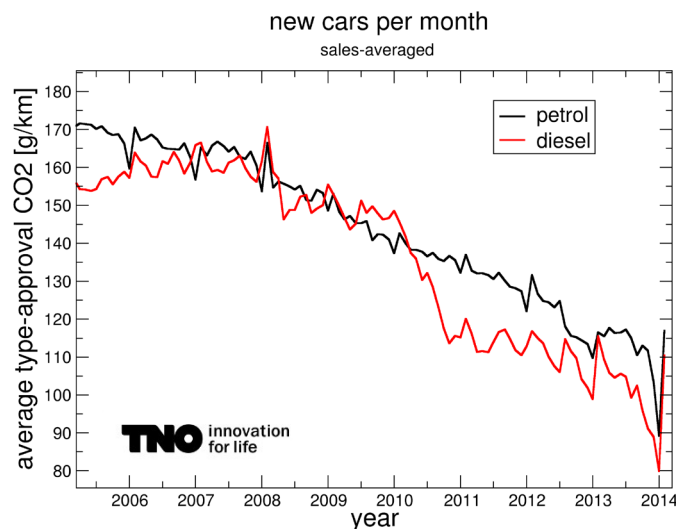


Figure 8: The average type-approval values of the new vehicles, derived from sales data. The dip at the end of December 2013 is due to the sales of plug-in vehicles.

### 4.1 Market share plug-in vehicles and the average type-approval CO<sub>2</sub>

The average type-approval CO<sub>2</sub> emission of new cars sold in 2013 is 107.9 g/km. However, if plug-in vehicles were excluded, the average type-approval value would come to 114.5 g/km. Hence, even over the whole of 2013, plug-ins are responsible for a substantial, *theoretical*, reduction of CO<sub>2</sub> emissions. In practice, they are responsible for an increasing gap between type-approval values and real-world fuel consumption.

Until mid-2013 only the Opel Ampera, Chevrolet Volt, and the Toyota Prius plug-in were the available plug-in hybrid models. Recently, the Mitsubishi Outlander PHEV and the Volvo V60 diesel plug-in hybrid joined the ranks of plug-in vehicles, with substantial sales numbers in the Netherlands. Both are larger, heavier vehicles, with, consequently, a higher fuel consumption. The real-world fuel consumption of plug-ins particularly bears little relation with the type-approval values, as the latter are based on a large amount of electric driving, which is not seen in practice. The type-approval fuel consumption is based on mainly electric driving on the fully charged battery, combined with an additional 25 kilometres on fuel. Only a very small portion of the plug-in vehicles reach values close to the type-approval value.

Table 3 shows an overview of the total sales and the corresponding type-approval CO<sub>2</sub> values. Both LPG and CNG yield a reduction in CO<sub>2</sub>, despite these are typically not the smallest and most fuel efficient cars. The fuels have a lower CO<sub>2</sub> emission for the same energy content. The difference between petrol and diesel has been decreasing over the years, with the exception of 2010-2012, when fuel-efficient diesel vehicles entered the market a few years after fuel-efficient petrol vehicles did so since 2007.

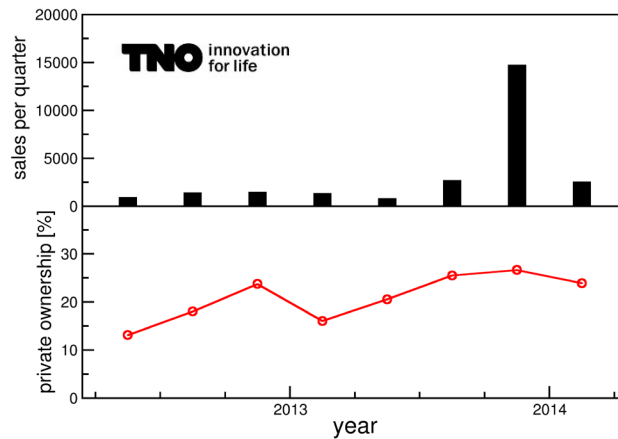


Figure 9: The quarterly sales of the five plug-in models studied in this report in the top graph, in the lower graph the fraction private ownership of these vehicles, which has increased but remains at about a quarter of the total ownership.

Table 3: The sales figures and corresponding CO<sub>2</sub> values for new vehicles in 2013. Diesel and petrol are the major shares, however, plug-in vehicles make a large contribution, unlike other technologies and fuels. Plug-in are defined here as “electricity” available as a second fuel. This category includes a number of normal hybrids in the database [source: RDW].

Fuel (1 <sup>st</sup> fuel)	"2 <sup>nd</sup> Fuel"	Sold in 2013	Average type-approval CO <sub>2</sub> [g/km]
Diesel		101632	106.0
Petrol		266452	117.7
Diesel	Electricity	10942	41.6
Petrol	Electricity	32135	63.9
CNG	Petrol	208	102.7
CNG		273	100.0
Alcohol	Petrol	17	153.7
LPG	Petrol	1939	112.5
Electricity		2600	0.0
Average (excluding E as 1 <sup>st</sup> )		416198	107.9
Average (excluding E as 1 <sup>st</sup> and 2 <sup>nd</sup> )		370521	114.5

From the alternative fuels, for new vehicles, LPG has the largest contribution. Although the sales are not significant, it signals a possible transition with the increasing attention for CO<sub>2</sub> emission in fiscal schemes.

## 4.2 Real-world fuel consumption of common plug-in vehicle models

For the separate vehicle models of plug-in vehicles we find the following fuel consumption numbers. All vehicle models have substantial numbers related to them, in the range of 300 – 800 individual vehicles per model.

Petrol:

- AMPERA/VOLT: 4.44 l/100km (type-approval: 1.2 l/100 km)
- PRIUS PLUG-IN: 4.59 l/100km (type-approval: 2.1 l/100 km)
- OUTLANDER PHEV: 6.56 l/100km (type-approval: 1.9 l/100 km)

Diesel:

- VOLVO V60: 5.32 l/100km (type-approval: 1.8 l/100 km)

Apart from the average fuel consumption per vehicle model, the variation in fuel consumption is also an interesting aspect. The variation in fuel consumption for each individual driver of a plug-in hybrid car is typically larger than with conventional vehicles. Traditionally, the variation of fuel consumption is the order of 30%-40%, between best and worst. For plug-in vehicles this variation is in the order of 100%. In this case of a larger electric range, i.e., a larger battery, the different between best and worst is also larger. For example, the Prius Plug-in has a small range, with a smaller difference between best and worst. The Ampera, on the other end, is of the spectrum with a wide range as can be seen in Figure 10.

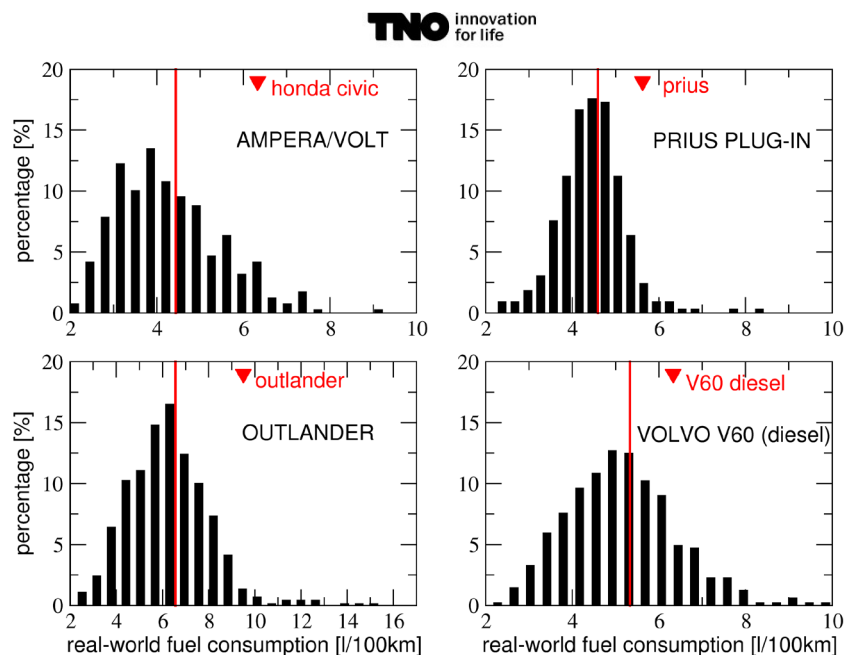


Figure 10: The distribution of fuel consumption for the different vehicles. The triangles represent a similar vehicle without a plug. From comparing the fuel consumption of both, one can conclude from the reduced fuel consumption that the electric mileage is between 15% and 30% of the total mileage on average.

Comparing the fuel consumption of the plug-in hybrids with that of similar vehicles without the possibility of electric charging, the share of electric driving can be estimated from the reduction in fuel consumption.

For the Ampera and Volt there are no natural candidates for a vehicle without charging capabilities. The Honda Civic has a similar size and hybrid driveline, and is therefore chosen as reference.

Table 4: The type-approval values of the common plug-ins, compared to the real-world findings.

	Type-approval CO <sub>2</sub>	Empty battery CO <sub>2</sub>	Type-approval range	Type-approval electric distance	Real-world electric distance
<i>Model</i>	<i>[g/km]</i>	<i>[g/km]</i>	<i>[km]</i>	<i>[%]</i>	<i>[%]</i>
BMW I3	13	103	170	87%	-
Opel Ampera	27	116-119	83-87	77%	30%
Chevrolet Volt	27	116-119	83-87	77%	30%
Toyota Prius Plug-in	49	98	25	50%	18%
Volvo V60 plug-in hybrid	48	143	50	66%	16%
Mitsubishi Outlander PHEV	44	136	52	68%	31%

The electric distance lies in the order of 15%-30% of the total distance. Likely, the number is smaller than estimated, because plug-in vehicles are hybrids, which are typically more fuel efficient. This is not related to the charging capabilities or electric range, as shown in Table 4. The comparison seems favourable for the Mitsubishi Outlander PHEV. However, this may be due to the reference vehicle: a conventional Outlander, with a fuel consumption of 9.5 l/100 km. A hybrid SUV probably has a lower CO<sub>2</sub> emission and fuel consumption. With a value of 8 l/100 km as reference would yield an electric distance of 17%.

The popularity of the Mitsubishi Outlander and Volvo V60 is partially due to the fact that they are in a different market segment than earlier plug-in vehicles. These vehicles are even less likely to remain in the Netherlands after the age of four years. In business use, currently, the fiscal benefits of having a, seemingly, fuel efficient car are larger than privately owned. On the other hand, in business use, the attention for fuel consumption is less than would be if the driver pays the fuel bill out of pocket. Both aspects drive the gap between the CO<sub>2</sub> emission benefits on paper and the actual reductions.

## 5 Conclusions

The comparison of conventional vehicle models of 2012 and 2013 shows the gap between type-approval and real-world fuel consumption has increased with approximately 2%. If plug-in vehicles are included the gap is even bigger. This is mainly due to the very low type-approval fuel consumption values of plug-in vehicles, which are established on the basis of the official type approval test. This test contains a large share of electric driving that is generally not encountered in everyday operation. Prevailing legislation, as well as the proposed new legislation, assumes an electric driving distance of 50% to 80%, depending on the battery capacity. In the real world, the electric distance varies from 15% to 30%.

Observing the global trend from 2012 to 2013 is somewhat complicated by the change in external circumstances. This causes the same vehicles to be slightly more fuel efficient in the study of 2013 than in 2014 study.

Generally, all manufacturers and all vehicle models follow the same trend with model year and with type-approval CO<sub>2</sub> value. The notable exceptions always have been SUV's, which have a higher real-world fuel consumption compared to other vehicles in the same group. One particular vehicle model has joined its ranks. It had large sales in 2012, due to it being an early mid-segment model which satisfied the tax exemption of 95 g/km for diesel vehicles. This made it possible to have sufficient data, such that it had a significant deviation from other vehicles in the same group.

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## 7 Signature

Delft, 21 July 2014

A handwritten signature in blue ink, consisting of a stylized 'G' followed by 'K' and a long horizontal stroke.

Gertjan Koornneef  
Projectleader

A handwritten signature in blue ink, consisting of a stylized 'N' followed by 'L' and a long horizontal stroke.

Norbert Ligterink  
Author

## A Methodology

### A.1 Data

The analysis of fuel consumption is possible because of sufficient data. However, even this large dataset has its limitations. Only a few vehicle models have sufficient underlying data to make significant conclusions. The need for a large set of data is the natural spread of fuel consumption with vehicle usage, such as average velocity, trip length, weather, etc.. The grouping of data, i.e., on the basis of fuel, type-approval value, and year is done on the basis of the smallest variation in the remainder. However, this variation is still large. In this section the grouping is explained and the variation is quantified.

Table 5: Number of vehicles (excluding plug-ins) included in current analysis per model year.

Year	Petrol vehicles	Diesel vehicles
2004	10513	15812
2005	11607	17535
2006	12265	16427
2007	9469	11435
2008	13887	13765
2009	12414	10037
2010	10827	8759
2011	13163	16061
2012	12047	18125
2013	7794	12588

### A.2 Type-approval date and model year

The fuel type and type-approval value as characterisation require little explanation. The "year" as variable does require further explanation, which is given here. Type-approval date registered by the road authority (RDW) is the first date this particular vehicle is allowed on the European roads. This date may be later than the first vehicle of this type is allowed on the road. The model type is defined as a unique type-approval code. It is not clear whether every type-approval code signifies a real change in the vehicle, but it is assumed as such. Tracing the type-approval code of newly sold vehicles in time, it is noted that the bulk of an unique type-approval code is sold over a period of three-quarter of a year. The latest vehicles are sold a year later, and the first a half year before. Popular vehicle models are typically sold under a few hundred different type-approval codes. Hence, using the type-approval date as the variable in the data analysis is appropriate, as most identical vehicles are sold within a period of a year. For example, a vehicle model mainly sold in the first half of 2011, may have its first few sales in autumn 2010 and 15% of the final sales in 2012.



### A.3 The rule of large numbers

The analysis of fuel consumption, in real-world use, is only possible because of the large amount of data available. This makes it possible to draw global conclusions, and some limited conclusion for parts of the full set, under the assumption the different motorists have similar vehicle usage. Based on the total mileage, and the homogeneity of the group, who change vehicle every couple of years, the trends over years, and the decreasing type-approval values are well established. Moreover, the half a million business-use passenger cars, of 8 million in the Netherlands, account for a substantial part of the total distance travelled with passenger cars. In this way, they affect the national averages as well.

In principle at least 500 vehicles are needed to make a significant claim on fuel consumption for a group of motorists. This is due to the fact that the variation in fuel consumption, not only over time, but also from one driver to the next varies significantly.

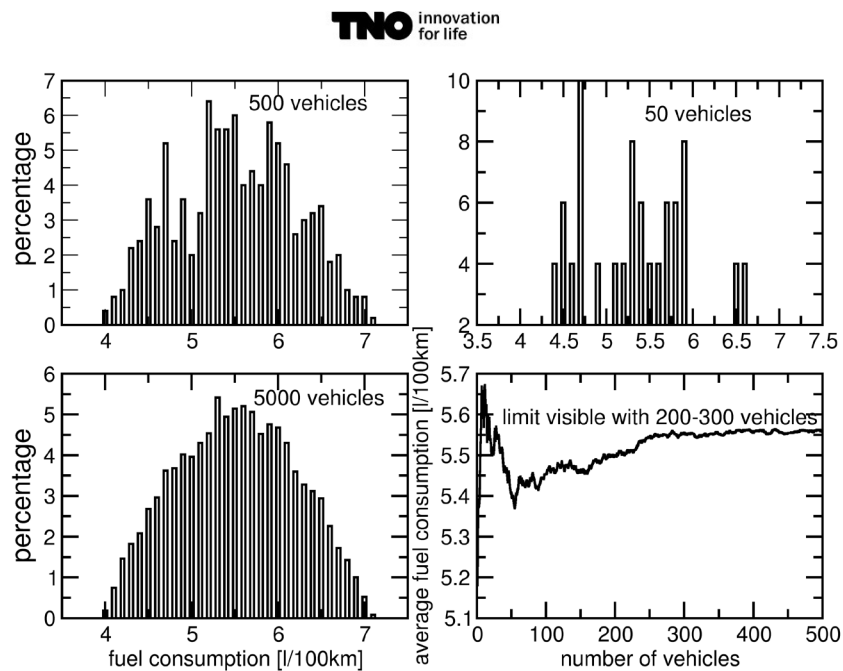


Figure 11: Only with 5000 vehicles or more, in a separate group to be analysed, the general shape of the distribution, and the variation between drivers, is clear. With such numbers effects of a few percent can be recovered. If one is only interested in an average number, at least a few hundred vehicles must be included. The effects of a few percent cannot be analysed with a few hundred vehicles as the variation between drivers and vehicle usage is too large. A simulation of a homogeneous group shows the effect of limited numbers.