Real-World Fuel Consumption of Passenger Cars

Norbert E. Ligterink and Arjan R.A. Eijk

Sustainable Transport and Logistics group, TNO, Delft, The Netherlands

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 (Ligterink, 2010 and Ligterink, 2013 and Ligterink, 2014). 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_2 emission itself, and the model year. (Ligterink 2009, Ligterink, 2012, Mock, 2013, Ntziachristos 2014) 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. 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_2 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_2 emission of 95 g/km.

Rather unexpectedly, as it did not occur in the data from 2004 till 2012, the real-world fuel consumption of vehicles for which last year fuelling data was already analysed decreased. 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 an newer data, yielding a smaller effect on average.

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.

Increase in fuel consumption with latest vehicle models

For each model year and each range of CO_2 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 (Ligterink, 2010 and Ligterink, 2013 and Ligterink, 2014), 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_2 emission of 90-99 g/km and, less pronounced, petrol cars in the 120-129 g/km CO_2 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_2. The diesel vehicle models of 2012 and 95 g/km of CO_2 are the exception to this rule. One vehicle model has a particularly large difference.

Table 1: The additional fuel consumption of petrol vehicles, for a given type-approval CO_2 and model year, based on the type-approval date.

CO_2 [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%

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_2.

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_2 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_2 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_2 and model year. The notable exception in the general trend is the 2012 group of 90-99 g/km.

CO_2 [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%	**57.5%**	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%	

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.

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. 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.

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.

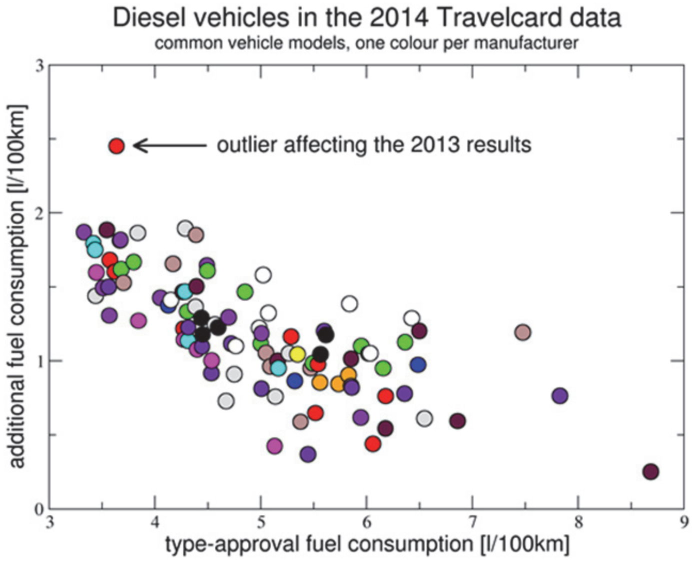

Figure 1: The common vehicle models of manufacturers with many models sold, throughout the years. The other red circles are in line with the general trend. Hence this manufacturer is not performing badly overall, except for this vehicle model.

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 be 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.

With a total distance of about 100 billion kilometres travelled with Dutch passenger cars the additional CO_2 emission with modern vehicles is about 4.5 million tonnes of CO_2. This is 12% of the total transport CO_2 emission, and 2.7% of the total CO_2 emission in the Netherlands in 2012. The gap between the expected reduction in CO_2 emission of transport and the actual CO_2 emission reduction is increasing year after year. As can be seen in Figure 2, the surplus CO_2 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_2 emission grew from 10% to 50%.

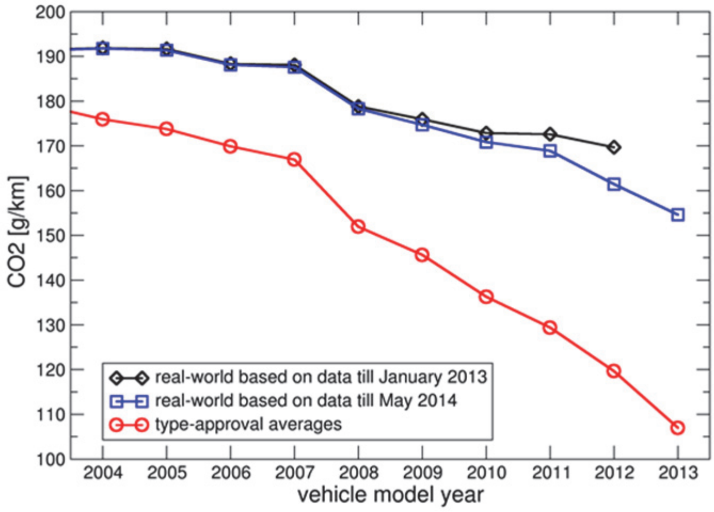

Figure 2: The type-approval and real-world fuel consumption of passenger cars. The analyses of 2013 and 2014 are shown separately. The current analysis shows a lower real-world fuel consumption (blue line) but with an increasing gap from 2012 to 2013. The average is based on 70% petrol and 30% diesel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

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 (see Fig. 3).

The trend of decreasing real-world fuel consumption is investigated in more detail. A number of factors influencing real world fuel consumption are addressed and analysed. 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 cannot be fully distributed to the various factors. 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.

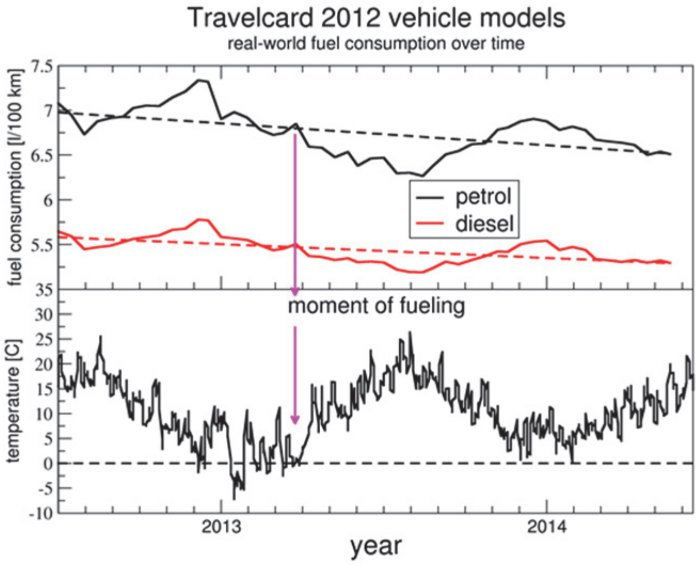

Figure 3: The fuel-consumption over time for the same sets of vehicles. On top of the annual variation, a downward trend is visible. This is in part related to the warmer weather in the second half of the two year period. The arrow indicates a colder period which is visible in the increase in fuel consumption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

Changing free-flow velocities on Dutch motorways causes a decrease of CO_2 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_2 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_2 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.

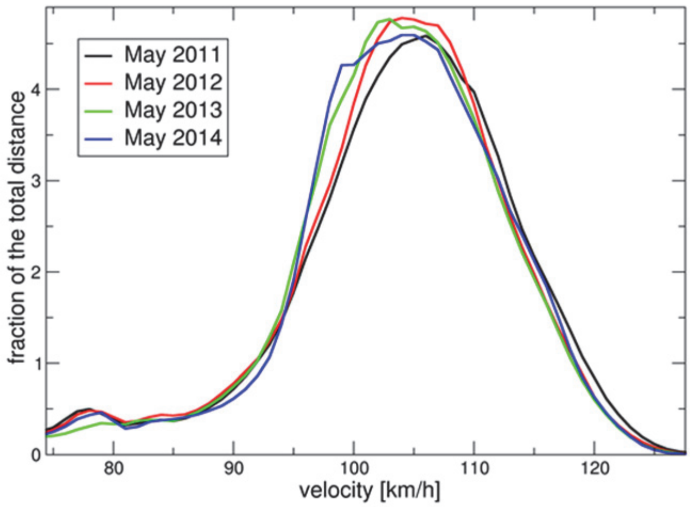

Figure 4: The distribution of velocities on the Dutch motorways. The shift towards lower velocities is clearly visible from 2011 to 2014.

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.

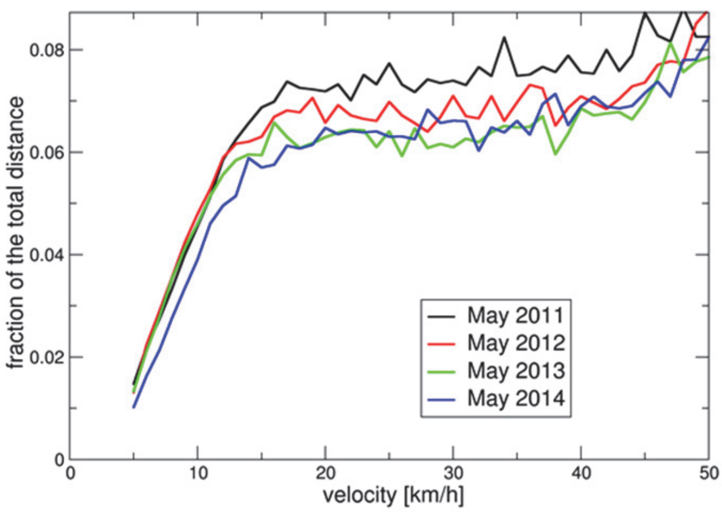

Figure 5: The distance driven at low velocities on the Dutch motorways has decreased from 2011 to 2014, from 3.1% to 2.6%.

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_2 emissions. The effect of the velocity in free-flow situations are partly covered by simulating the CO_2 for free-flow driving, between 85 km/h and 130 km/h. This yields a reduction of a 1%-2% percent of CO2 from 2011 to 2014. See Figure 6.

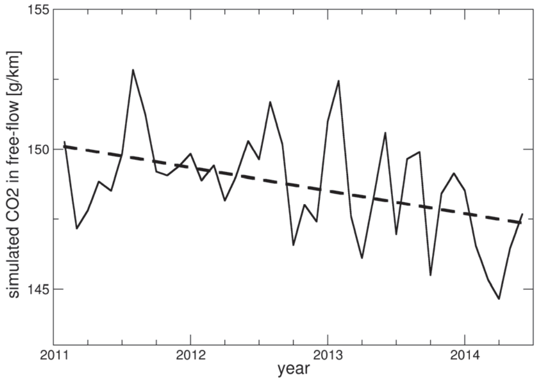

Figure 6: A simple simulation based on average free-flow velocities (85 -130 km/h) on the motor-way. In the summer period the velocities and the CO_2 emissions are higher. A downward trend is clearly visible, yet difficult to quantify.

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_2 emissions. Consequently, the percentage difference of distance driven in congestion results in a similar difference in CO_2 emissions. The estimated reduction in CO_2 emissions is 0.5%, due to the reduction of the congestion. See Figure 7.

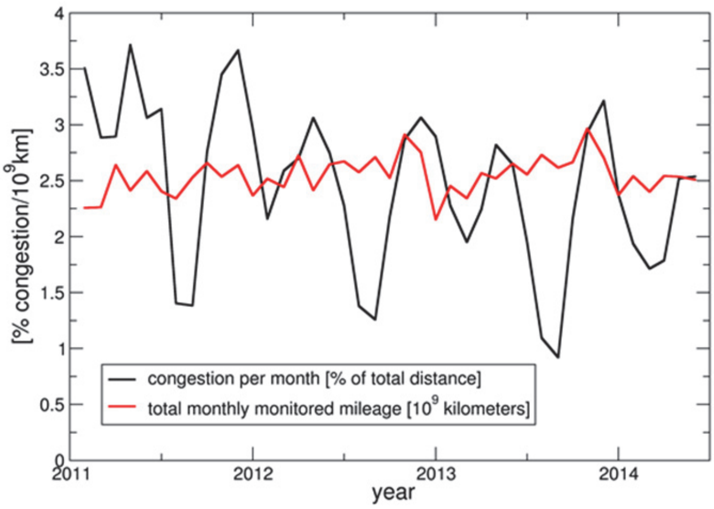

Figure 7: The percentage distance driven in congestion is shown by the black line. The large variation is due to holiday periods and weather. A downward trend of about 0.5% is visible. A similar reduction can be expected on the fuel consumption. The total distance, shown by the red line, increases slightly.

The reductions of CO_2 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_2 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_2 reduction for the group of business users examined in this study can be expected to be larger.

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_2 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.

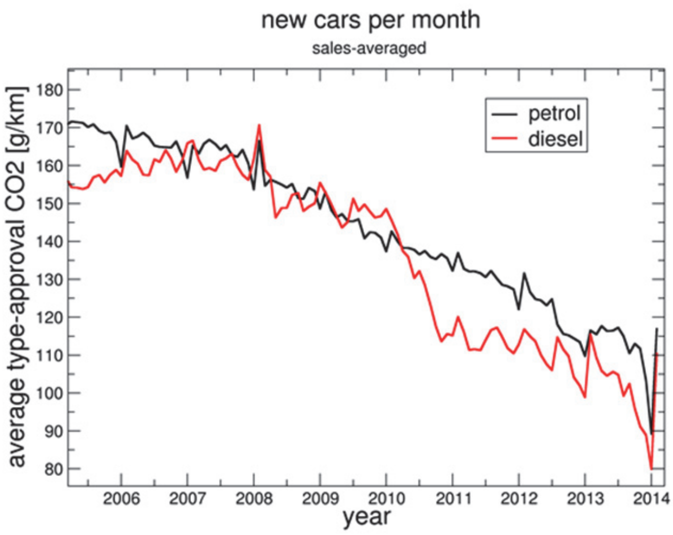

Figure 8: The Dutch average type-approval values of the new vehicles, derived from sales data. The dip at the end of December 2013 is due to the sales of plug-in vehicles.

Market share plug-in vehicles and the average type-approval CO_2

The average type-approval CO_2 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_2 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_2 values. Both LPG and CNG yield a reduction in CO_2, despite these are typically not the smallest and most fuel efficient cars. The fuels have a lower CO_2 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.

Table 3: The sales figures and corresponding CO_2 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 (1st fuel)	"2nd fuel"	sold in 2013	average type-approval CO_2 [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 1st)		416198	107.9
average (excluding E as 1st and 2nd)		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 CO2 emission in fiscal schemes.

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.

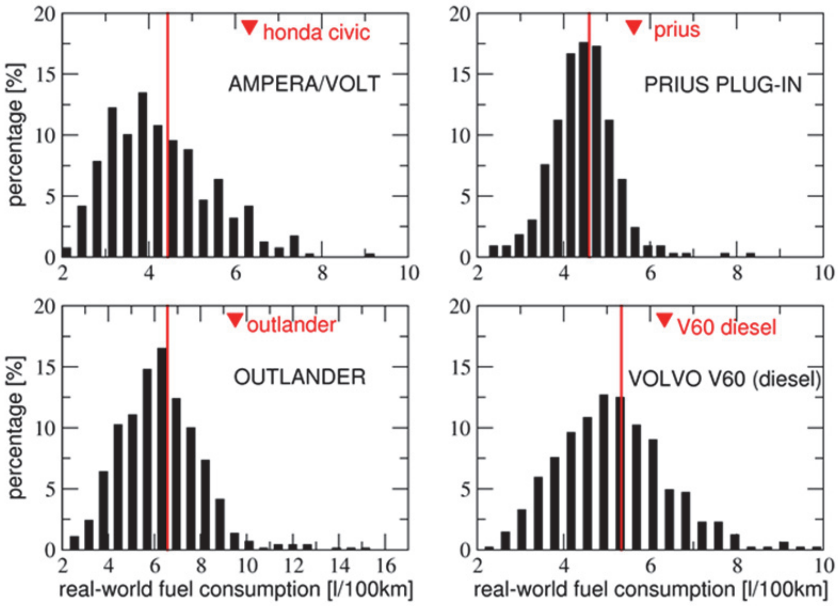

Figure 10: The distribution of fuel consumption for the different vehicles. The triangles represent a similar vehicle without a plug. From comparing the fuel consumption of both, one can conclude from the reduced fuel consumption that the electric mileage is between 15% and 30% of the total mileage on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

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_2 emission and fuel consumption. With a value of 8 l/ 100 km as reference would yield an electric distance of 17%.

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

	Type-approval CO_2	**Empty battery CO_2**	**Type-approval range**	**Type-approval electric distance**	**Real-world electric distance**
Model	*[g/km]*	*[g/km]*	*[km]*	*[%]*	*[%]*
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 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_2 emission benefits on paper and the actual reductions.

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_2 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.

Acknowledgement

The authors would like to thank the Dutch ministry of Infrastructure and the Environment for their support and financial contribution to the project.

References

Ligterink, N.E. & Bos, B., CO_2 uitstoot in norm en in praktijk – analyse van zakelijke rijders rapport TNO-MON-2010-00114

Ligterink, N.E. and Smokers R.S.M, Praktijkverbruik van zakelijke auto's en plug-in auto's, TNO report 2013 R10703.

Ligterink, N.E and Eijk, A.R.A. Update analysis of real-world fuel consumption of business passenger cars based on Travelcard Nederland fuelpass data, rapport TNO 2014 R11063.

Ligterink (Norbert E.), Richard T.M. Smokers and Mark Bolech, Fuel-electricity mix and efficiency in Dutch plug-in and range-extender vehicles on the road, EVS27, 2013.

Ligterink, N.E., De Lange, R, & Passier, G.L.M., Trends in real-world CO2 emissions of passenger cars, proceedings of the ETTAP09, Toulouse, June 2009

Ligterink, N.E. & Bos, B., CO2 uitstoot in norm en in praktijk – analyse van zakelijke rijders TNO-MON-2010-00114.

Ligterink, N.E., Kraan, T.C., & Eijk, A.R.A., Dependence on technology, drivers, roads, and congestion of real-world vehicle fuel consumption, Sustainable Vehicle Technologies: Driving the Green Agenda, 14-15 November 2012 2012, Gaydon, Warwickshire.

Mock (Peter), John German, Anup Bandivadekar, Iddo Riemersma, Norbert Ligterink, Udo Lambrecht, From laboratory to road: a comparison of official and 'real-world' fuel consumption and CO_2 values for cars in Europe and the United States, ICCT white paper 2013.

Ntziachristos L.D. et al., In-use vs. type-approval fuel consumption of current passenger cars in Europe, *Energy Policy* 67 (2014) 403–411.