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Discrepancies between type-approval and "real-world" fuel-consumption and CO_2 values

Assessment for 2001-2011 European passenger cars

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1. Executive Summary

Based upon analyses of more than 28,000 user entries of the German fuel consumption database spritmonitor.de and more than 1,200 vehicle models tested by Europe's largest automobile club ADAC, the ICCT found that the gap between type-approval and "real-world" fuel consumption / CO_2 values increased from about 8% in 2001 to 21% today, with a particularly strong increase since 2007. Potential reasons for this development include: (i) increasing use of existing tolerances and loopholes in the determination of road load, vehicle weight, laboratory test temperatures, and transmission shifting schedules for type-approval; (ii) inability of the current test cycle, the NEDC, to represent real-world driving conditions; and (iii) increasing market share of vehicles equipped with air conditioning systems. In order to eliminate existing discrepancies as much as possible and to ensure that future improvements in vehicle technology result in real-world reductions of CO_2 and fuel consumption, a number of changes to the existing test cycle, test procedure and compliance testing are recommended.

2. Introduction

In order to limit the negative effects of climate change and to reduce dependency on oil imports, the European Union (EU) needs to reduce its greenhouse gas (GHG) emissions by 80-95% below 1990 levels by 2050. A reduction of at least 60% by 2050 with respect to 1990 (70% with respect to 2008) is required from the transport sector, the only sector in which GHG emissions have increased since 2005 (+30% compared to -7% for all sectors) (EC, 2011a, 2011b).

For passenger cars, accounting for two thirds of the GHG emissions from the EU's transport sector, a voluntary self-commitment by the automotive industry to reduce the level of emissions for new vehicles was reached in 1998/99. However, the annual rate of reduction between 1998 and 2006, as measured by the New European Driving Cycle (NEDC), was only between 0.6% and 2.2% and the target of 140 grams of carbon dioxide (CO_2) per kilometer (g/km) for 2008 was missed (EC, 2010). In 2007 a decision was taken to introduce mandatory regulatory measures and in early 2009 the first mandatory CO_2 performance standards for passenger cars in the EU were adopted, setting a target of 130 g/km for 2015 and 95 g/km for 2020 (EU, 2009). In the course of setting mandatory standards, the annual rate of reduction of the average level of CO_2 emissions from new passenger cars has increased from a rate of 1.7% in 2007 to 5.1% in 2011 (ICCT, 2011c). The European average CO_2 emission level in 2011 was 140.3 g/km compared to 158.7 g/km in 2007 (EEA, 2011; T&E, 2011).

Given the success of the EU CO_2 performance standards for passenger cars it is evident that the existing 2015 and 2020 targets have to be affirmed and additional post-2020 targets have to be set in order to put the EU road transport on a pathway to meet the long-term (2050) target, while allowing manufacturers sufficient lead-time to develop the required technologies for meeting the targets. However, the performance standards only affect the type approval value for individual vehicles. Therefore, it is of great importance to ensure that reductions in the level of CO_2 emissions measured in the laboratory during the type approval test are also realized under real-world conditions.

From a consumer perspective, most drivers are aware that there exists a gap between the fuel consumption they experience during everyday driving and the corresponding values that are listed in information brochures they obtain from their local car dealer, the internet, or other media sources. As this gap increases, a part of the CO_2 and fuel consumption reductions achieved on paper do not pay back to consumers in fuel cost savings. This could lead to a situation where official type approval values provided by the vehicle manufacturers would lose credibility among consumers and where the willingness to invest into new vehicle technologies to reduce fuel consumption and CO_2 emissions is reduced.

This paper compares fuel consumption / CO_2 values of passenger cars from different sources and aims at quantifying the discrepancy between laboratory type-approval values and real-world values, including a retrospective analysis for the years 2001-2011 to determine if the gap between the two datasets has increased over time. Potential explanations for the discrepancies found are discussed and possible practical solutions for the future outlined.

3. Methodology

The analysis is based on three different data sources:

- Manufacturers' type-approval values, measured under laboratory conditions with certain flexibilities and making use of the NEDC, a standardized test cycle.
- Allgemeiner Deutscher Automobil-Club (ADAC) EcoTest values, measured under laboratory conditions that are supposedly more realistic, making use of the NEDC as well as an additional Motorway Cycle.
- spritmonitor.de values, as reported by thousands of consumers based on their everyday experiences, not making use of any standardized laboratory procedures.

Each of the data sources, their specific characteristics and the methodology for preparing and analyzing the data is described in detail below.

This paper focuses on new passenger cars in Germany, for two reasons: With about 3 million new passenger cars sold each year, Germany is not only the biggest market in Europe (20% market share) but also heavily exports to other countries (5.5 million passenger cars were exported in 2010) (VDA, 2011). Secondly, with the ADAC EcoTest and the spritmonitor.de database the availability of data for Germany is comparatively good. Yet, similar data sets may also exist in other EU member states[1].

For reasons of clarity, only CO_2 values are reported in the following analyses. CO_2 is an excellent proxy for fuel consumption. The conversion factors used are 2.43 kilogram (kg) CO_2 per liter of gasoline and 2.65 kg per liter of diesel fuel.

3.1 Manufacturers' type-approval values

Before being allowed to sell a new vehicle model on the market, a manufacturer needs to follow the so-called Type-Approval (TA) process. As part of this process the manufacturer determines the fuel consumption and CO_2 emission level of the vehicle on a chassis dynamometer, simulating the road load of the vehicle with the help of input factors that have been measured earlier on a road track. All tests follow procedures that are regulated in European Union and UNECE (United Nations Economic Commission for Europe) legal documents. A central document is regulation (EC) No. 715/2007.

The type approval test will normally take place at the premises of the manufacturer, under the authority of the technical service of the respective EU member state[2]. If the prescribed procedures have been followed, required tolerances are met and limits are not exceeded, type-approval will be granted by the national type approval authority. Within strictly specified conditions, type-approval for one vehicle model can also be extended to similar models of the same manufacturer. The advantage for the manufacturer is that in this case only one vehicle model has to be tested while type-approval is granted for several vehicle models at once. One of these conditions is that the CO_2 emission level measured by the technical service will not be more than 4% higher than the type approval value[3]. If a manufacturer does not foresee the need for any extensions, then there is a risk that this allowed tolerance will be abused to declare a 4% lower type approval CO_2 value than measured.

Applying a standardized test procedure that is the same for all vehicles in all EU member states (and beyond) has the advantage of repeatability and comparability of results. The driving cycle that is used to simulate the driving pattern of the tested vehicles, the NEDC, is always the same and therefore ensures that the CO_2 value of one vehicle is directly comparable to another vehicle. However, the current NEDC is not representative of real-life driving conditions but is rather a stylized driving speed pattern with low accelerations, constant speed cruises, and many idling events (Figure 3.1).

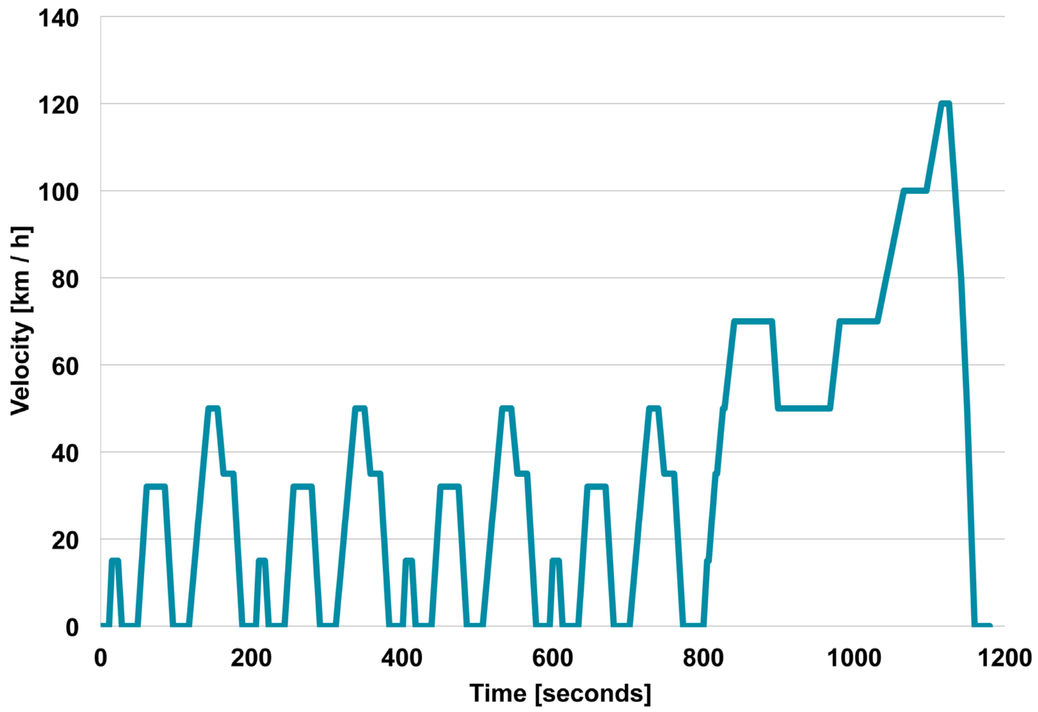
As a result, the CO_2 emissions measured over the NEDC will also not be representative for real-life driving. Furthermore, the fixed speeds, gear shift points and accelerations of the NEDC offer possibilities for manufacturers to optimize CO_2 and pollutant emissions specifically for the corresponding operating points of the engine in order to

1 For example HonestJohn.co.uk

2 For Germany, the technical service following the type-approval tests could for example be Technischer Überwachungsverein (TÜV)

3 See Regulation 692/2008 paragraph 3.5

Figure 3.1. Speed profile of New European Driving Cycle (NEDC)



achieve lower emission levels during type approval but not necessarily for real-world driving.

Another issue with the type-approval values is the flexibility allowed by the test procedures. One example is the ambient temperature during the test, which is regulated to be within 20-30°C. In a recent study it was found that an ambient temperature of 22°C instead of 28°C may lead to more than 4% higher CO_2 values (TÜV, 2010). This corresponds to approximately 6 g/km for an average new car.

Some flexibilities may have historical relevance but today seem like an anachronism. For example, instead of using the actual weight of a vehicle for the test, the vehicle is categorized into a discrete inertia class. This historically made sense with the use of mechanical dynamometers, which simulated vehicle weight by hanging inertia weights on the dynamometers. Nowadays, electronic dynamometers are used that can simulate any weight. The continued use of discrete inertia classes is technically not necessary and can result in CO_2 figures that are off by about 4-8 g/km CO_2 compared to the real values (ICCT, 2011a).

Finally, compliance testing and sanctions by the authorities in case of non-compliance are necessary to prevent manufacturers from putting a carefully prepared prototype vehicle up for type-approval, while actually producing a version of the car model that is different on crucial CO_2 related characteristics. To a certain extent this is covered by the Conformity of Production requirements and an obligatory In-Service Conformity program, both performed by the manufacturer and audited by the type approval authority. However, some differences and tolerances between prototype and production vehicles are still allowed and others, such as engine control unit (ECU) calibration and tire rolling resistance, are difficult to monitor. The EU legislative system is set up in such a way that once type-approval is granted it cannot be withdrawn, except for serious non-compliance cases.

Another problem with all of the allowed flexibilities is that while one manufacturer may make full use of the flexibilities to obtain as low CO_2 values as possible, another may choose to take a more conservative approach in the 'spirit' of the test procedure. Such conservative manufacturers, whose labeled CO_2 values are more reflective of real-world driving, may then run the risk of finding themselves at a competitive disadvantage. This can then lead to a situation in which test values from different manufacturers cannot be directly compared to each other anymore. Furthermore, depending on the pressure faced by the manufacturers to meet CO_2 emission targets, manufacturers may become more aggressive over time in the application of the flexibilities in testing, so that test values from a given year cannot be compared to values from other years anymore.

For the analysis in this paper, the type-approval values provided by manufacturers are used as the basis for all comparisons. This means the level of CO_2 emissions according to the type-approval process is set at 100% and the values provided by other sources are compared against it.

For the ADAC EcoTest the corresponding type-approval values are provided by ADAC, so that these can be used directly for a comparison. In contrast, spritmonitor.de does not provide type-approval values for comparison. In this case, type-approval values are obtained from an ICCT internal vehicle database that is based on data from various registration authorities as well as car manufacturers' and importers' associations (ICCT, 2011b). The CO_2 values used are sales-weighted. For example, if there exist two vehicle variants, one with and one without all-wheel drive, the average CO_2 emission to compare with the values provided by spritmonitor.de is calculated based on the sales of each vehicle variant in Germany in the respective year.

3.2 spritmonitor.de values

Spritmonitor.de[4] is an online database with more than 200,000 registered users that provides fuel consumption values for light-duty vehicles in Germany. The basic concept is very simple: Everyone can register for free, choose a vehicle model and exact configuration and then enter the fuel-consumption values that one observes in daily driving. The reported values are accessible to everyone, even non-registered users, either for each vehicle individually or aggregated to an average fuel consumption for a specific vehicle model configuration.

In contrast to other websites, spritmonitor.de does not ask the user to estimate the fuel-consumption for his/ her vehicle directly but instead asks to enter the amount of fuel refilled (in liters) and the kilometer reading after each refueling event. The resulting fuel-consumption is then calculated internally, thereby most likely providing more accurate fuel consumption values than if asking the user directly for an own estimate.

Within the scope of this analysis it was not possible to assess all the data included in spritmonitor.de. Instead, the following vehicle models were selected: Audi A3, A4, A6, A8, BMW 1-series, 3-series, 5-series, X5, Ford Ka, Focus, Mercedes-Benz C-class, E-class, ML-class, SLK-class, Opel Astra, Corsa, Renault Clio, Megane, Twingo, Toyota Aygo, VW Polo, Golf, Passat. Collectively, these models account for about 50 percent of annual sales in Germany. Each vehicle model is differentiated by type of fuel, transmission, engine power, and model year. In total, entries from 28,218 users were used for the analysis. Table 3.1 provides more details on the distribution of user entries per model year.

Naturally, the fuel consumption value reported by different users for the same vehicle configuration will vary, as their individual driving patterns and driving styles will be different. Also it will make a difference if one user reports fuel-consumption during summer with air conditioning often turned on or during the winter with the heating system on and the vehicle fitted with special winter tires. Figure 3.2 shows a typical distribution of fuel consumption values for one selected vehicle configuration in spritmonitor.de. As it can be seen, the individual values tend to differ from each other but at the same time follow a distribution pattern according to the law of large numbers, so that an average can be calculated. The approach for the analysis is as follows:

- For every vehicle configuration within the vehicle model range, the average fuel consumption is determined.
- The fuel consumption average is divided by the type-approval value for that vehicle configuration to obtain a relative value.
- The relative differences are weighted according to the respective sales number for the vehicle configuration in a given year, leading to an average weighted difference between spritmonitor.de data and type approval values.

In contrast to the type-approval values, fuel consumption reported in spritmonitor.de is not based on laboratory measurements and is not subject to any standardization or flexibilities, but reflects the fuel consumption consumers experience in use. For the analysis, the values obtained from spritmonitor.de are therefore considered to be the best representation of real-world CO_2 values.

Considering that the consumers reporting their experiences to spritmonitor.de are likely to pay more attention to the fuel consumption of their vehicles and to drive more fuel-efficient than other consumers, it is very possible that the difference between actual real-world CO_2 and type-approval values is actually higher than suggested by the spritmonitor.de analysis. However, even if there is a bias between the data reported to spirtmonitor.de and average in-use fuel consumption, any bias should be consistent over time and should not affect the observed trends in the relationship between the spritmonitor.de data and the type approval data.

3.3 ADAC EcoTest values

ADAC is Europe’s largest automobile club, with more than 17 million members. With its Landsberg technical center, ADAC has the necessary facilities to perform vehicle tests, similar to the ones that manufacturers carry out for the type-approval of a new vehicle. In 2002, ADAC started the EcoTest, a program “designed to provide a fair, reliable and objective assessment of the environmental performance of cars. Aimed at informing consumers, it provides an incentive for manufacturers and gives credit to those who make eco-friendly cars” (ADAC, 2009). The EcoTest is based on European vehicle emission and fuel consumption test procedures but extended by “procedures and parameters to cover a wide range of real-life driving scenarios in Europe” (ADAC, 2009).

The EcoTest consists of 3 tests[5]:

- NEDC cold: duplicating the EU type approval test, but at lower test cell temperature (22°C) and using the actual weight of the tested vehicle, instead of a usually lower test weight and discrete inertia classes
- NEDC hot: same as NEDC cold, but starting with a warm engine, and the air conditioner unit switched on (setpoint of 20°C)
- ADAC motorway: a dedicated cycle for driving on a motorway with speeds up to 130 km/h (Figure 3.3)

Calculation of the overall EcoTest result is done by first averaging the NEDC cold and NEDC hot. Then the result

4 See http://www.spritmonitor.de - The data used for this analysis was accessed in November / December 2011.

5 The ADAC EcoTest test procedure was changed on March 15, 2012 to include the new World Harmonized Light-duty vehicle Test Cycle (WLTC) and to better reflect up-to-date emission legislation. See for example: DIE ZEIT (2012): “ADAC-Test entlarvt die echten Emissionswerte”, March 15th 2012. Relevant for the data analyzed in the context of this paper is the methodology previously used by ADAC, which is described in the following section..

Figure 3.2. Example for a frequency distribution of a vehicle configuration in spritmonitor.de (Volkswagen Golf, 90 kW, gasoline, manual transmission, model year 2010)

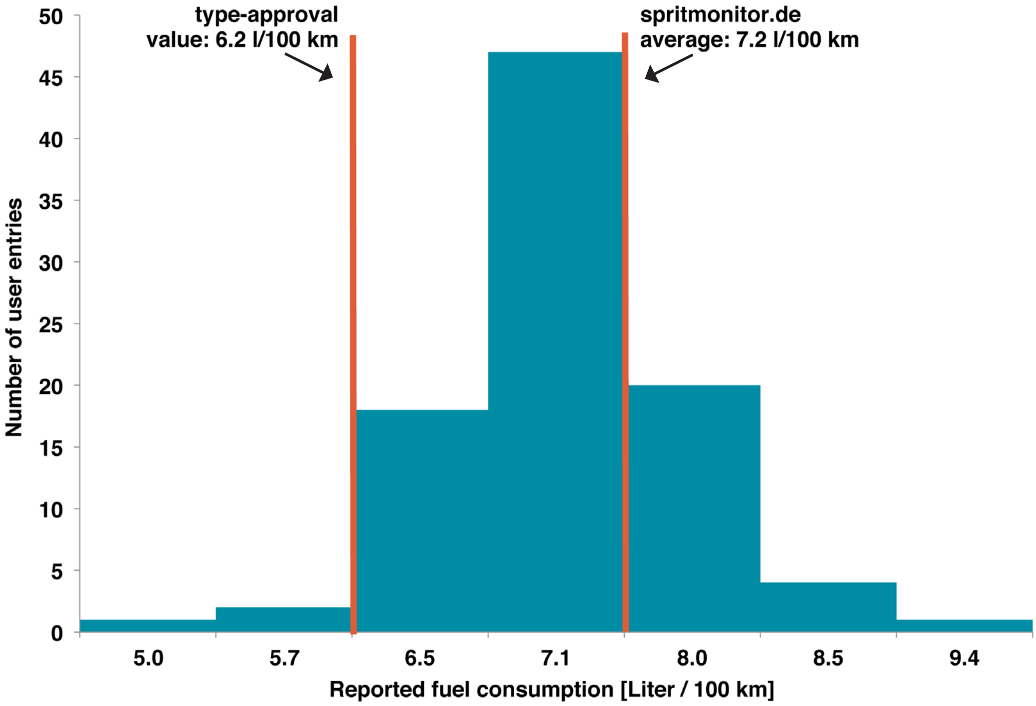
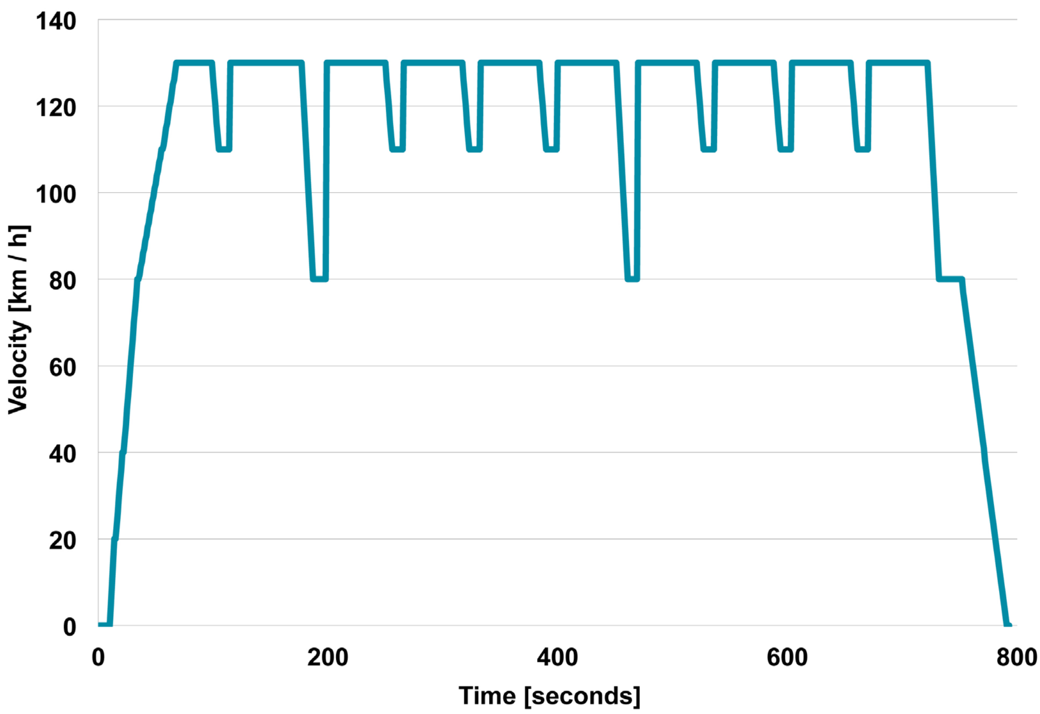


Figure 3.3. Speed profile of ADAC Motorway Cycle



of the ADAC motorway cycle is added by a weight share of 70/30 respectively.

Testing at a lower cell temperature and using the actual weight of a vehicle instead of its inertia class is an improvement compared to the type-approval test procedures and will result in more realistic CO_2 emission values. Adding a motorway part to the NEDC and increasing the top speed for the driving cycle from 120 km/h to 130 km/h also improves the representability of the test.

However, 70% of the EcoTest is based on the NEDC driving cycle, which in itself cannot be seen as representative for real-life driving behavior. Therefore, even while the EcoTest was designed to deliver values that are closer to what consumers will generally experience as real-world fuel consumption, in practice it is expected to deliver results that rank somewhere between type-approval and spritmonitor.de data.

An important shortcoming of the EcoTest methodology is that it uses the same road load factors (to take into account rolling and air resistance of a vehicle) for the chassis dynamometer as applied by the manufacturer for the type-approval test procedure. There are indications that the current flexibilities in the road load determination procedure for type-approval may lead to road load values that are too low, effectively leading to lower fuel consumption and CO_2 emissions than found in real-world driving (TU Graz, 2009). Ideally, the ADAC EcoTest would correct for this by performing independent road load tests for the vehicles examined.

From 2002 until 2011 ADAC tested 1,284 vehicles in the course of the EcoTest measurement program (for details see table 3.1). A list of all vehicles, including the test results, is available online[6]. The EcoTest results also include the respective type-approval values for a vehicle, as reported by the manufacturer, for comparison.

For this analysis, the CO_2 values reported by ADAC EcoTest were aggregated by simple averaging instead of sales-weighted averaging. This is because ADAC tends to test state-of-the-art vehicles that often do not show high sales volumes until a year or two after the test. Linking the test values with a meaningful sales number was therefore not regarded as feasible within the scope of this analysis. As the ADAC EcoTest generally covers popular mainstream vehicle models and configurations, no significant effect of this simplification is expected for the analysis.

3.4 Comparison of data sources

Table 3.1 summarizes the number of data entries from spritmonitor.de and ADAC EcoTest used for the analysis. Spritmonitor.de values were available from 2001 to 2010 model years, covering 24 vehicle models totaling about 50% of annual sales in Germany, with about 2,500-3,500 user entries per year and 28,218 entries in total (one user entry represents one actual vehicle in use). 2011 values could not be included in the analysis as sales-weighted type-approval values were not yet available at the point in time of the analysis. ADAC EcoTest values were available from 2002 until 2011, with about 50-200 vehicle models per year, except for 2002, and 1,284 models in total.

Table 3.2 provides an overview of the differences in the characteristics of the data sources used for the analysis. Some of the details were explained in sections 3.1-3.3. Others will be examined in more detail in section 4.

4. Results and discussion

According to the EU CO_2 monitoring[7], emission levels for Germany have decreased from 179 g/km in 2001 to 152 g/km in 2010 (-15%) (EEA, 2011) (Figure 4.1). These values are based on the official type-approval procedures. As mentioned in section 3.2 for the analysis of spritmonitor.de not all data could be included but only a set of selected vehicle models. When plotting the sales-weighted type approval CO_2 emissions of these vehicles, they match almost exactly the official CO_2 monitoring data for Germany (Figure 4.1). This is seen as a strong indication for the fact that the selected vehicle models are representative of the German new vehicle fleet and provide a good basis for the following analysis. As there is no straightforward way to calculate a sales-weighted average for the ADAC test data, these are not included in Figure 4.1.

Table 3.1. Number of data entries for the sources used for the analysis

Year	spritmonitor.de (number of user entries selected)	ADAC EcoTest (number of vehicle models tested)
2001	2,283	---
2002	2,256	18
2003	2,389	86
2004	2,433	160
2005	2,786	103
2006	3,291	62
2007	3,691	193
2008	3,319	193
2009	3,289	178
2010	2,481	147
2011	---	144
All	**28,218**	**1,284**

For this representative set of vehicles, a comparison of the CO_2 emission levels as reported by spritmonitor.de users and the type-approval values reveals three findings:

- Real-world CO_2 values according to spritmonitor.de are higher than the corresponding type-approval CO_2 emissions as reflected in the official CO_2 monitoring. This implies that the real CO_2 emission level of new German passenger cars is higher than what is reported to consumers and policy makers.
- This difference between type-approval and real-world CO_2 levels is increasing over time. In particular since 2007 the gap has increased each year. In relative terms the increase is even larger, as the baseline of type-approval values is reduced over time (Figure 4.2). This finding is also confirmed by a recent analysis on behalf of the European Commission Joint Research Centre (JRC) (JRC, 2011).
- As a result, the decrease in CO_2 emissions for the new vehicle fleet according to spritmonitor.de data is only about half of what is reported based on the type-approval values.

In order to include the ADAC data into the comparison, the data is better represented as percentages of the type approval values instead of absolute CO_2 emission levels. Figure 4.3 illustrates the respective results, with the type-approval value for each year set at 100%.

6 http://www.adac.de/infotestrat/tests/eco-test

7 “The Regulation (EC) No 443/2009 requires Member States to record information for each new passenger car registered in its territory. Every year, each Member State shall submit to the Commission all the information related to their new registration.” (EEA, 2011)

Table 3.2. Table with comparison of testing characteristics

	Type-approval values	ADAC EcoTest	spritmonitor.de
Type of test	chassis dynamometer in laboratory	chassis dynamometer in laboratory	on-road
Test cycle	NEDC (cold)	NEDC (cold) (35%) NEDC (hot) (35%) ADAC motorway (30%)	no standardized test cycle; individual for each user
Maximum speed	120 km/h (only for 10 seconds)	130 km/h (for >500 seconds during ADAC motorway)	individual for each user
Driving behavior	strict driving pattern according to NEDC (reproducible)	strict driving pattern according to NEDC (reproducible)	driving pattern dependent of user driving style, weather and traffic conditions
Max. acceleration	1.04 m/s^2	1.04 m/s^2 (NEDC) Full throttle acceleration (ADAC motorway)	individual for each user
Idling	25% (about 300 seconds out of 1180 seconds)	25% (NEDC) <2% (ADAC motorway)	individual for each user
Vehicle weight	empty vehicle + 100 kg + 90% fuel + fluids/tool kit + spare wheel; no optional equipment; use of discrete inertia classes	vehicle incl. driver, optional equipment, fuel and tools/spare wheel (actual load depending on specific test vehicle), but no passengers and no luggage; no discrete classes	vehicle incl. driver, passengers, luggage, optional equipment, fuel and tools/spare wheel (actual load depending on user); no discrete classes
Road load values (driving resistance)	possibility to optimize road load by exploiting flexibilities of the test procedure	same as for type-approval values	actual vehicle road load
Ambient temperature	20-30 °C	22 °C (± 2 °C)	middle European ambient temperatures (about 9 °C on average for Germany)
Air conditioning	off	on (only for NEDC hot and ADAC motorway); target temperature: 20 °C	individual for each user; 96% of new cars in Germany equipped with A/C in 2008 (UBA, 2010)
Transmission shift schedule	fixed gear-shift points for vehicle with manual transmission; following suggested shift-points provided by manufacturer for vehicles with automatic transmission	same as for type-approval values; vehicles with manual transmission and gear-shift indicator: following suggested shift-points provided by manufacturer	individual for each user
State of charge starter battery	100% at start of test	starter battery not recharged after conditioning tests, i.e. <100% at start of test	normal operating value
State of charge (SOC) for battery (for hybrid-electric vehicles)	CO_2 = (Electric range x CO_2 100% SOC + 25 km x CO_2 minimum SOC)/(Electric range + 25 km)	CO_2 measurement when on-board display shows 60-70% SOC	individual for each user
Additional influences	none	none	user related influences, e.g. tire pressure, maintenance condition, use of electrical equipment, etc.
Other provisions	4% deviation of CO_2 allowed for type-approval for extension to other vehicles (see 3.1)	no such provision	no such provision

To help understand the results, Table 4.1 summarizes the main CO_2 related characteristics for the underlying datasets. These characteristics focus specifically on aspects that are different between type approval values and real-life data. Differences between CO_2 results of the datasets can be attributed to the differences in dataset characteristics.

ADAC EcoTest (NEDC cold)

As shown in Figure 4.3 the difference between type-approval CO_2 values and the ADAC EcoTest (NEDC cold) is the smallest. In this case, the only differences in characteristics between the EcoTest and the type-approval procedure are:

- a more realistic vehicle weight,
- a lower ambient temperature,
- a more realistic starter battery SOC, and
- a more realistic battery SOC for hybrid-electric vehicles.

The influence of the last argument can be significant for individual HEV CO_2 emissions, but since the market

Figure 4.1. Comparison of annual CO_2 emission levels according to manufacturers' type approval values (weighted by number of user entries in spritmonitor.de), values reported by spritmonitor.de users (same weighting as for manufacturers' values) and official CO_2 monitoring data

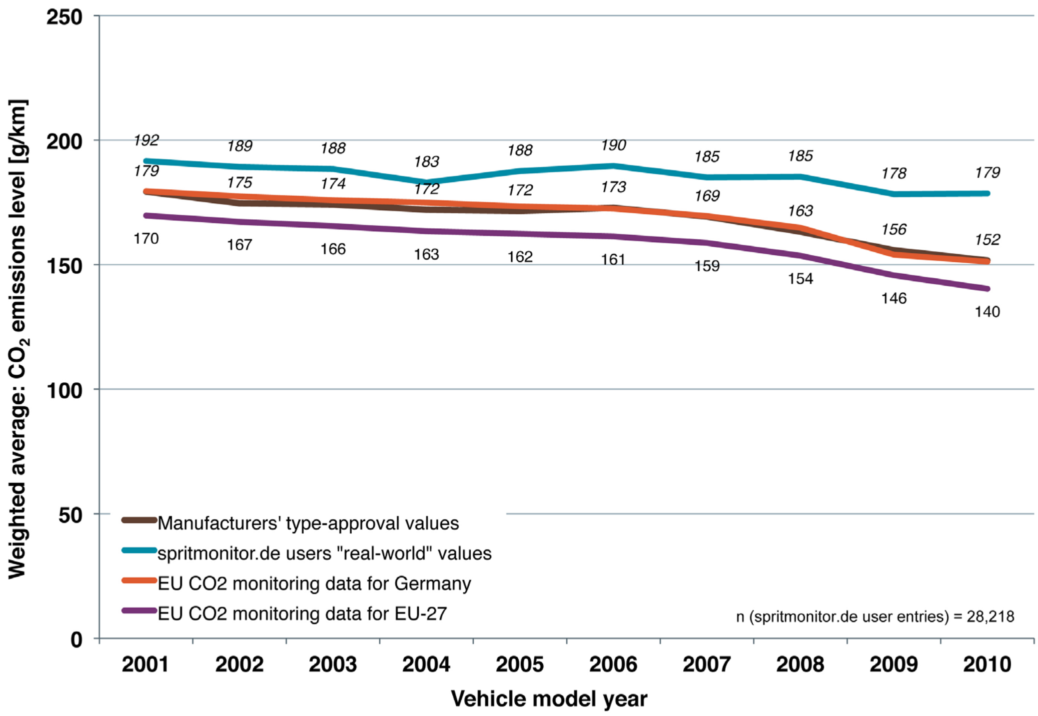


Figure 4.2. Percentage reduction in the average CO_2 emission value of new passenger cars in Germany since 2001 according to different data sources: manufacturers' type approval values (weighted by number of user entries in spritmonitor.de), values reported by spritmonitor.de users (same weighting as for manufacturers' values) and official CO_2 monitoring data

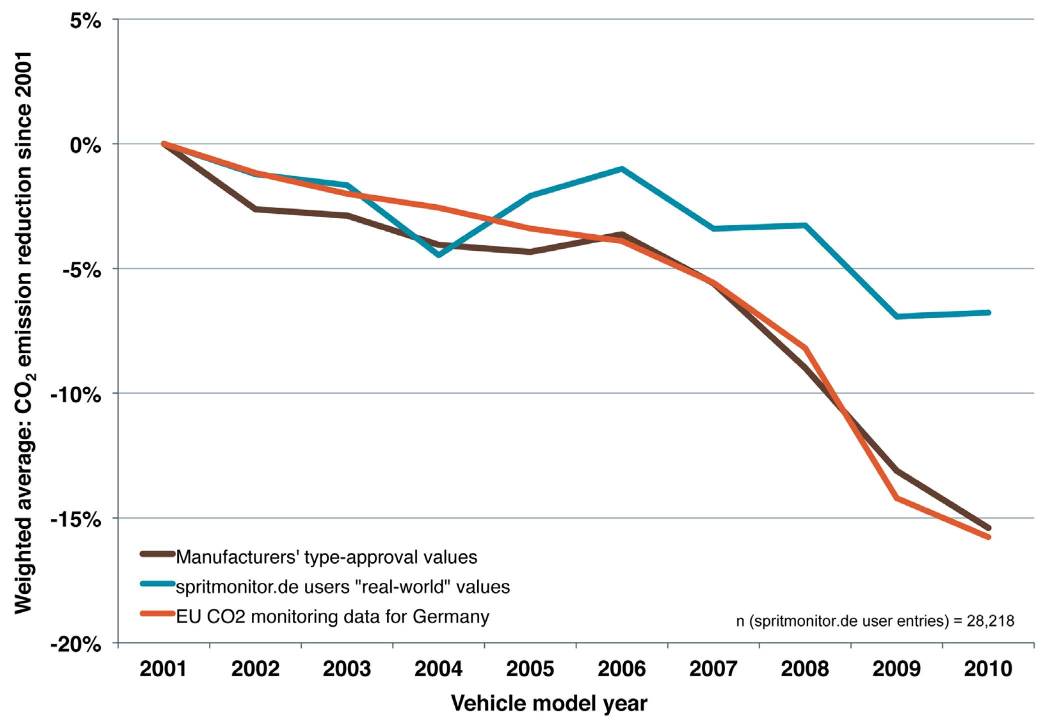


Figure 4.3. Differences in the level of CO_2 emissions according to type-approval values (set at 100%) and other data sources (compared against type-approval values) over time. Note that ADAC EcoTest (NEDC hot) includes the effect of the air conditioning system turned on, while ADAC EcoTest (NEDC cold) does not.

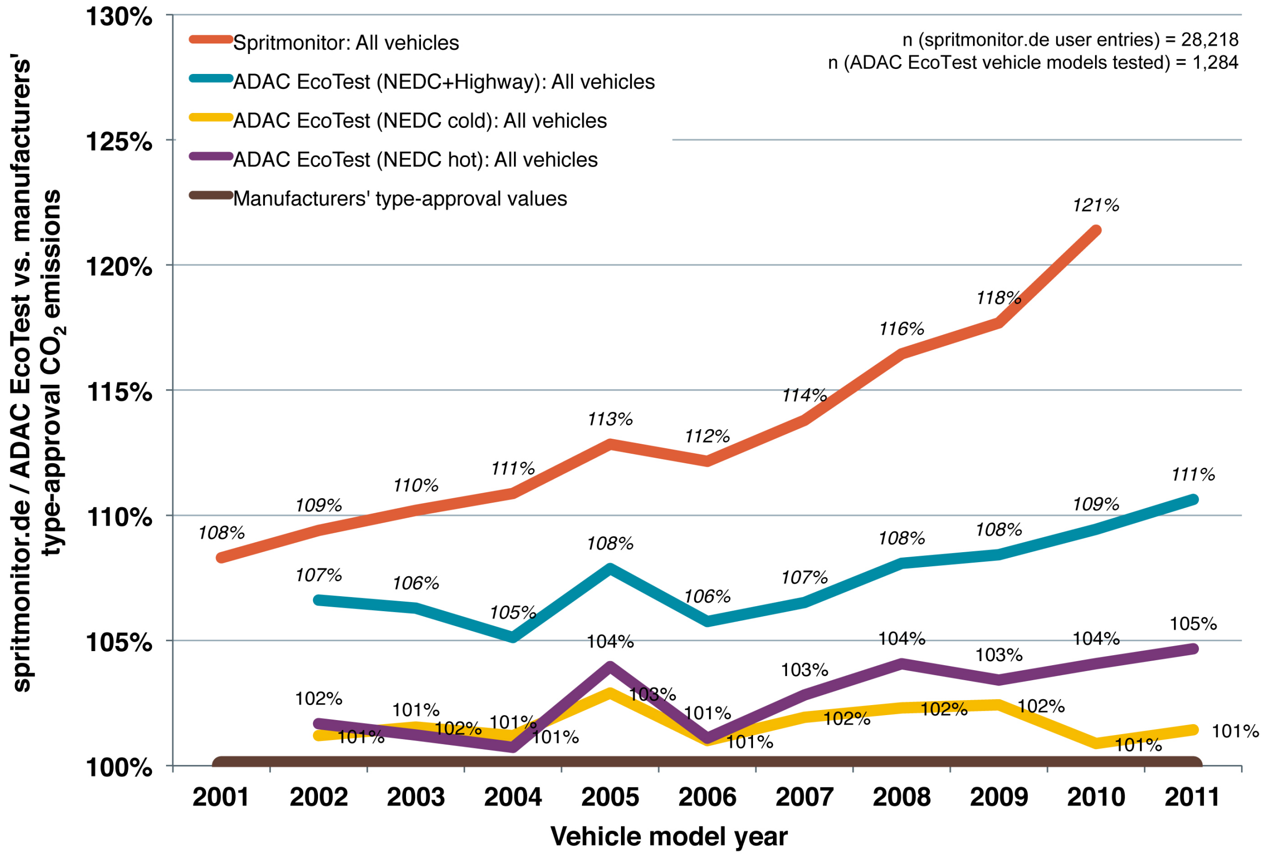


Table 4.1. Main distinguishing CO_2 related characteristics of underlying datasets

- Same as type-approval; o Not the same as real-world, but more realistic than type-approval; + real-world

	Type-approval values	ADAC EcoTest (NEDC cold only)	ADAC EcoTest (NEDC hot only)	ADAC EcoTest (ADAC cycle + NEDC motorway	spritmonitor.de
Realistic vehicle weight	-	o	o	o	+
Realistic ambient temperature	-	o	o	o	+
Realistic SOC of starter battery	-	o	o	o	+
Realistic manual transmission shifting pattern	-	-	-	-	+
Realistic road-load values	-	-	-	-	+
Air conditioning turned on	-	-	o	o	+
Real-world driving pattern including motorway	-	-	-	o	+

penetration of such vehicles is very low it will not show in national fleet figures.

Based on Figure 4.3 the combined effects of vehicle weight and ambient temperature add up to about 1-2% difference in CO_2 for most years[8].

A recent study by the German TÜV on a limited number of passenger cars revealed the following influences on CO_2 (TÜV, 2010):

- The effect of increasing vehicle test weight by two inertia classes (about 220 kg) can increase CO_2 emissions by up to about 9%.
- Testing a vehicle at 22°C instead of 28°C can increase CO_2 emissions by up to about 4%.

The average difference in test weight between what is stated by ADAC EcoTest and type-approval is expected to be much smaller than two inertia classes, but it shows the relation between weight and CO_2. The definition of test weight in the test procedure is generally lower than a representative value (e.g. no passengers or luggage are included). The influence of the test cell temperature is found to be comparable to the temperature set-points of both tests. It can be concluded that the observed 1-2% difference in CO_2 emissions between ADAC EcoTest and type-approval values is well explained by these dissimilar test characteristics.

ADAC EcoTest (NEDC hot)

The difference between type-approval CO_2 values and the ADAC EcoTest (NEDC hot) was about 1% for 2002-2006 and since then increased to about 5%. In addition to the differences already mentioned for the ADAC EcoTest (NEDC cold), the differences in characteristics between the EcoTest (NEDC hot) and the type-approval procedure are:

- an engine oil temperature of approximately 90°C before starting the test procedure (instead of 20-30 °C), and
- the air conditioning system turned on.

A higher oil and engine temperature at the start of the test will result in lower fuel consumption and CO_2 emission levels[9]. Turning on the air conditioning system will lead to higher fuel consumption and CO_2 emissions due to the required power for the compressor. Having these two counteracting effects mixed together makes it difficult to draw conclusions about each factor individually. A positive difference indicates that the influence of the air conditioning system is higher than the hot start effect. The average annual extra fuel consumption of a (petrol) passenger car by using the air conditioner unit was recently quantified to about 5% (EMPA, 2010). The number of vehicles equipped with air conditioning systems has increased significantly over time, in Germany from about 25% of all new passenger cars in 1995 to about 96% in 2008 (UBA, 2010). In view of these numbers, it is to be expected that a large part of the increasing discrepancy between ADAC EcoTest (NEDC hot) and type-approval values is related to the increasing number of vehicles equipped with air conditioning systems.

ADAC EcoTest (NEDC cold + NEDC hot + ADAC motorway)

The ADAC EcoTest including an additional test cycle for motorway driving goes one step further. While the top speed in NEDC is limited to 120 km/h for only about 10 seconds, the ADAC EcoTest adds a cycle that has speeds up to 130 km/h for an extended period, with majority of time spent at speeds above 110 km/h. The weighting applied in the ADAC EcoTest is 70% NEDC and 30% motorway cycle results. Including this additional motorway cycle has a major effect on the results, as shown in Figure 4.3. The average gap between the ADAC EcoTest (NEDC cold + NEDC hot + motorway) results and the type-approval values is 5-7% for the years 2002-2007 and has since steadily increased to a level of 11% in 2011.

As shown in the previous paragraph, about 3% (average between ADAC EcoTest NEDC cold and NEDC hot) in 2011 can be attributed to the combined effects of the vehicle weight and test temperature, while the air conditioner on/off and hot/cold start effects are averaged. This means that the remaining 8% increase in CO_2 is associated to the much more demanding ADAC Motorway cycle. Calculations show that the air drag component for the ADAC motorway cycle is 4.5 times higher compared to the NEDC[10]. Applying the 70/30 weight share leads to the conclusion that the ADAC EcoTest is about twice as energy demanding (only considering the air drag). Taking the other road load components and engine efficiency into account, a difference of 8% more CO_2 due to the more demanding ADAC Motorway cycle is certainly explainable.

Spritmonitor.de

The difference between type-approval values and real-world values as reflected by spritmonitor.de shows a gap of about 8% in 2001, which increased to 12% in 2006 and since then progressively raised to 21% in 2010 (Figure 4.3).

The difference when compared to ADAC data (including the motorway cycle) in 2010 is about 12%, which according to Table 4.1 can in particular be attributed to the combined effects of the starter battery, actual road load, realistic temperatures, driving patterns and shifting strategies.

The influence of the starter battery state-of-charge (SOC) on the CO_2 emission was also part of the investigation by TÜV Nord (TÜV, 2010). They tested an extreme difference between a fully charged starter battery and an almost depleted one over the NEDC cycle. It was found that especially for small passenger cars the difference can amount up to 30%. During real-life situations the SOC of

8 It was also checked if the results are comparable for the type of fuel (diesel or gasoline). In general, the relative differences of CO_2 against the baseline are slightly larger for diesel cars, but not more than one percentage point overall. For gasoline it is the other way around. The same was found to be true for all trend lines examined for this paper.

9 Please note that the average trip length is related to the effect of the higher cold start fuel consumption: the effect is lower for longer average trips. As the average trip in Germany (14 km) is close to the NEDC length (11 km), the cold start effect in the datasets for real-life (spritmonitor.de) and type approval is expected to be similar.

10 The air drag is equivalent to the square of the vehicle speed. If the squared speed of each second over the whole of the ADAC motorway cycle is summed up, it is found that the sum is about 4.5 times higher than for the NEDC.

the battery will never be so low that it is almost depleted, so this result is illustrative at best. However, it shows that the battery SOC has a significant influence on the CO_2 emission. The road load of a vehicle is normally determined by a coast down test on a test track. A vehicle is accelerated to above 120 km/h and shifted into neutral gear. From the deceleration curve and the actual weight of the vehicle, the total resistance force curve is calculated as a function of the speed, referred to as the road load. Each time a vehicle is tested in a laboratory (also for the ADAC Ecotest), the chassis dynamometer is set in such a way that the same road load is simulated. Evidently, there is an incentive for manufacturers to exploit flexibilities in the road load test procedure to the full extent. For example, the road load value could be reduced by reducing the test mass, removing body parts that negatively impact aerodynamics, preparing the brakes to avoid parasitic losses, using an optimized wheel alignment, selecting low rolling resistance tires and overinflating the tires. All these measures are not strictly forbidden, they are the result of creatively making use of the allowed possibilities and tolerances. As a consequence, vehicles measured on a chassis dynamometer have a lower CO_2 emission than non-optimized, real-world vehicles on the road, if all other test parameters are identical.

The University of Graz (TU Graz) tested some passenger vehicles with actual road load and found that the difference in CO_2 emissions between type approval value and the measurement was 17% on average, ranging from 9 to 24% (TU Graz, 2009). This suggests that the difference between ADAC EcoTest and spritmonitor.de values could be explained primarily by only the road load effect. However, in reality the real-world driving pattern as well as other factors will also be responsible for a share of the 8% to 21% difference.

What is striking is the development of the discrepancy between ADAC EcoTest and spritmonitor.de values over time. The gap between both datasets has been increasing, in particular since 2007. An increasing market share of vehicles with air conditioning systems is already covered by the ADAC EcoTest, as is some of the temperature and weight effect. Also, a significant change in the driving or shifting patterns of consumers in Germany since 2007 seems unlikely, as well as a change in overall ambient temperatures. Therefore, the data suggests that the increasing discrepancy could be attributed to manufacturers increasingly exploiting existing flexibilities for road load determination, shifting strategies of automatic gear boxes, and by applying dedicated calibrations for the type-approval procedure. Some new driveline technologies might also be contributing to an increasing gap. For example the introduction of start/stop systems in recent model years[11] has contributed to lower CO_2 emissions in the NEDC. However, since the idling time in the NEDC is much higher than in real-life, the actual CO_2 reduction is expected to be lower.

The timing of the discrepancy increase also coincides with development of mandatory CO_2 emission targets at the EU level. Reducing type-approval CO_2 emission values by exploiting existing flexibilities in the test procedures is cheaper than applying technical measures to reduce CO_2 emissions, so that these “soft” measures are likely to be used before any technical changes to the vehicles. The downside of this development includes type-approval values becoming less meaningful to consumers over time, lower than anticipated reductions in CO_2 emissions, and a misleading guideline for policymakers when discussing future emission targets.

5. Conclusion and Outlook

Vehicle use and driving patterns vary from driver to driver, and it is certainly a challenge to define what constitutes real-world driving. However, by looking at in-use fuel consumption / CO_2 data points for thousands of drivers, it is possible to derive clear trends over time:

- The difference between type-approval and real-world CO_2 emission levels of new passenger cars in Germany has increased from about 8% in 2001 to about 21% in 2010. The widening of the gap is especially noticeable since 2007 when mandatory CO_2 emission standards for the EU were under development.
- The analysis confirms that there was a decrease in the level of CO_2 emissions of new passenger cars in Germany since 2001. However, the magnitude of reduction in reality appears to be only about half of what is suggested by the type-approval values (about 7% instead of 15% since 2001).

These developments lead to two key concerns:

a) From a policy maker perspective, to ensure that regulatory CO_2 emission reductions result in similar ambient air emission reductions in order to achieve future greenhouse gas emission targets,

b) From a consumers’ perspective, to avoid disappointment due to higher than expected fuel consumption, which could have negative implications for the willingness of consumers to invest into fuel efficient (and low-CO_2 emission) cars in the future.

Analysis of the differences and the trends of the datasets that are available for this study helps to understand why there is a gap between real-life and type-approval CO_2 emissions, and why it increased after 2007 when CO_2 legislation was developed.

The gap between type-approval and real-world emissions can likely be explained to a large extent by the following factors:

- Many characteristics of the NEDC test cycle are not representative for real-life driving behavior (low accelerations, low maximum speed, high idling time, constant speeds instead of transients, favorable shifting points, etc.)
- Cold start testing is performed at ambient temperatures close to 30 °C, while real life temperatures are lower, leading to higher fuel consumption.
- The allowed tolerances and flexibilities in the road load test procedure cause the road load of type-

11 According to ICCT internal data the market share of new passenger cars with start/stop technology has increased from zero in 2001 to about 5% in 2010.

approval vehicles to be lower than that of production vehicles.

- At the type approval test the battery is charged to 100% capacity.
- The type approval test weight is lower than the real-life average.
- Vehicles are type-approved without the air conditioning system turned on (or any other power consuming equipment)
- Other flexibilities and tolerances in the type approval test procedure are exploited to positively influence the test results (e.g. tolerance allowed to follow the NEDC speed trace, allowed 4% tolerance between measured and declared CO_2 value, etc.)

The *increase* of the gap is possibly accelerated by the following factors:

- Potentially increasing exploitation of existing tolerances and flexibilities in the road load determination test procedure and the type approval test procedure.
- An increasing market share of vehicles being equipped with an air conditioning system, while the negative impact on fuel consumption is not covered by the type approval test.
- The introduction of start/stop systems in recent model years, whose positive influence is likely more visible in the type approval than in real-life

For the future, a number of recommendations can be derived from the analysis:

- From a policy perspective, there exists a fundamental dilemma due to the fact that policy makers interested in reducing real-world CO_2 emission levels currently can only address type-approval emission levels by legislation. As shown, a reduction of the type approval value does not necessarily translate in the same amount of reduction of real-life CO_2 emissions. It is expected that this dilemma cannot be solved in the short term. Nevertheless, it is important to monitor real-world emission reductions on a regular basis –preferably by independent research- in order to reveal and address gaps between type-approval and real-world emission levels in a timely and effective way. Some member states run in-service conformity programs for that purpose[12].
- The limited representativeness of the NEDC is generally recognized and a revised driving cycle is under development at the United Nations level. This World Harmonized Light-duty vehicle Test Procedure (WLTP) is expected to apply to the EU type-approval from after 2015. To be useful for policy makers and also to be accepted by consumers, it is important to ensure that the WLTP cycle is as representative for EU real-world driving as possible.
- As the analysis demonstrated, the key is to improve not only the test cycle, but also the test procedures. This is also part of the WLTP discussions and some improvements are expected for the future. Several feasible proposals are currently on the table to address existing loopholes for some of the key factors, for example:
    - Road load determination procedure: At present, road load factors measured by vehicle manufacturers and used during the type-approval procedure are not published in the EU, unlike in the US where this information is publicly available. For the future, it is important make this data available for verification by independent bodies (e.g. for the mentioned in-service conformity checking). Furthermore, it is strongly recommended to improve the road load determination procedure in order to arrive at more realistic road load and CO_2 emission values (WLTP, 2011).
    - Vehicle test weight: Making use of the current vehicle weight definition and distinct inertia classes leads to a systematic underestimation of vehicle weight and limits the incentive for manufacturers to provide realistic weight values. Revisiting the definition of vehicle test weight and switching to a step-less approach is expected to result in more realistic CO_2 emission values (ICCT, 2011a).
    - Air conditioning systems: Nearly all new passenger cars in the EU are equipped with an air conditioning system. These systems have a significant effect on the CO_2 level of a vehicle but are currently not reflected at all in type-approval procedures. The EU is currently working on developing a test procedure for air conditioning systems (TU Graz, LAT, & TNO, 2012). It is important that this procedure be as realistic as possible and that the efficiency of air conditioning units be taken into account for future CO_2 emission legislation.
- In addition to the test cycle and test procedures, attention needs to be paid to compliance testing to ensure that prototype / early-production vehicles used for type-approval are representative of the mass-production vehicles that are delivered to customers later on. To a certain extent this is covered by the Conformity of Production requirements, and an obligatory In-Service Conformity program. Yet, some differences and tolerances between prototype and production vehicles are still allowed and only pollutant emissions are covered. In addition, the EU legislative system is set up in such a way that once type-approval is granted it cannot be withdrawn, except for serious non-compliance cases. A better approach is used in the US, where manufacturers have to provide all relevant information for each model year of their production vehicles, all equipment on test vehicles must be representative of the highest selling variation, and manufacturers must perform their own compliance activities under the In-Use Verification Program (IUVP). Also, new data must be submitted each year unless the manufacturer demonstrates that the previous data is still representative of the highest selling variation.

12 See http://www.eurisec.eu

While more research is needed to quantify the effects of key parameters, the results of the current analysis clearly demonstrate that a focus on real-world vehicle emissions, not only for pollutant emissions[13] but also for CO_2, is needed. For the future, more data sources are planned to be added to the underlying analysis of this paper. If available, data from EU member states other than Germany will be added, and an extended version of this paper will be published.

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