Supporting Analysis regarding Test Procedure Flexibilities and Technology Deployment for Review of the Light Duty Vehicle CO_2 Regulations

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Executive Summary

Introduction

Context of the study

In December 2008 the European Parliament and Council reached an agreement through a co-decision procedure on the details of the CO_2 legislation for passenger cars, laid down in Regulation (EC) 443/2009. Besides the target of 130 g/km for 2015 and details of the way it is implemented, Regulation No 443/2009 also specifies a target for the new car fleet of 95 g/km for the year 2020. A similar regulation has been implemented for light commercial vehicles (Regulation (EU) 510/2011), setting a target of 175 g/km for 2017 and of 147 g/km for the year 2020. Both regulations are currently undergoing amendment in order to implement the 2020 targets. In July 2012 the European Commission published their proposals for the modalities for implementation of these targets for passenger cars (COM(2012) 393) and vans (COM(2012) 394). Implementation of new technologies and improvements of existing technologies are the main instruments for a manufacturer to achieve these CO_2 emission goals.

Scope and objectives

In this context the execution and interpretation of the applicable test procedures for determining CO_2 emissions of light duty vehicles deserve attention as these procedures contain flexibilities that could be exploited to achieve lower CO_2 emission values on the Type Approval test without applying technical improvements to the tested vehicle. By carefully selecting vehicle test conditions within, or possibly even outside, allowable bandwidths, manufacturers might be able to achieve reduced CO_2 emission levels on a given vehicle at homologation that do not correspond to an equivalent reduction in emissions for a given driving pattern on the road. In addition some relevant parameters are not or not sufficiently specified in the test procedure.

Over the last few years indications have accumulated that part of the reduction observed in the CO_2 emissions of new cars in Europe may not be attributable to the application of identifiable CO_2 reducing technologies. A preliminary evaluation in [TNO 2011] suggested that some 9 - 10% of the reductions observed in that period could not be attributed to additional technologies applied to the assessed vehicle models between 2002 and 2009. This report suggested that this difference might to some extent be attributed to the application of small technical improvements, including improved calibrations, but that a large share of the difference might be the result of the increased utilisation of flexibilities in the test procedure.

Obviously, reductions in type approval CO_2 emissions obtained in such a way not only affect the net impact of the regulation but also the costs of meeting the targets set for 2015 / 2017 and 2020. Due to a lack of hard evidence the possible effects of the increased utilisation of flexibilities could not be incorporated in the main cost assessment in [TNO 2011]. Instead the effect was included in a scenario variation. This sensitivity analysis indicated that a reduction in type approval emissions of 9 - 10% due to increased utilisation of flexibilities would lead to around € 600 lower costs per vehicle for meeting the passenger car target of 95 g/km in 2020, which is about one third of the costs estimated with cost curves based on application of headline technologies only.

This report presents results of an analysis of these test cycle flexibilities and their possible contribution to reduction of CO_2 emissions, as measured on the type approval test, compared to the estimated contribution from technology deployment in light duty vehicles. The study analyses observed reductions up to 2010. This study has been carried out within the Framework Contract on Vehicle Emissions (Reference ENV.C.3/FRA/2009/0043) by TNO, in association with consortium members Ricardo, AEA, and IHS Global Insight.

Structure of the work

The work, of which results are reported here, contained the following main steps:

- Review of available literature addressing flexibilities available under type approval procedures and their impact on measured emissions;

- Assessment of the vehicle emission legislation to understand the full range of flexibilities available under type approval procedures that impact on measured CO_2 emissions and their impact in terms of CO_2;
- Estimation of the degree to which these flexibilities would have been used by manufacturers in the past and identification of benefits in terms of pollutant emissions, administrative burden and cost;
- Interviews and research with type approval authorities and test houses to understand how the available flexibilities are used by manufacturers at present;
- Assessment of the level of technology deployment in the current new vehicle fleet and estimation of the achieved CO_2 reductions resulting from the deployed technologies;
- Comparison of the possible impacts of increased utilisation of flexibilities and of technology deployment with the net reduction in CO_2 emissions observed between 2002 and 2010 to assess the extent to which flexibilities may have contributed to the observed CO_2 reductions.

Indications obtained from a review of available literature

A total of 17 reports have been identified and reviewed, which directly and indirectly relate to the subject of flexibilities within current legislation, These reports covered different topics, including vehicle coast down assessment by independent organisations, NEDC test results by third party laboratories versus type approval test results, and estimations of the effect of the test process on cycle CO_2 results, including temperature effects. Several reports contained results of tests or simulations investigating the effect of variations of test parameters on the CO_2 emissions measured in the type approval test.

In the identified literature, a measureable difference is reported between type approval (TA) CO_2 values and independently measured CO_2 emissions of in-service vehicles. Not only are “real-world” emissions, measured on the road or in the lab on test cycles derived from real-world driving, higher than TA values, also independent vehicle tests on the NEDC generally result in CO_2 emissions above the TA values. Indications are found that the difference is increasing over time.

Key flexibilities identified in the literature review fall into two categories, firstly those that affect the coast down measurement test, secondly those that affect the type approval or NEDC test.

For the road load determination test (coast down measurement) the main identified issues are:

- wheel alignment, adjustment of brakes, transmission and driveline preparation
- ambient conditions – temperature, pressure, wind, humidity
- tyres - type, pressure, and wear
- test track – surface type and slope
- vehicle weight as tested
- vehicle body type

Test results described in several reports show differences between CO_2 emissions measured on the NEDC using independently determined road loads and those measured using type approval values ranging from 5 – 25%.

For the NEDC type approval test the main issues found are:

- inertia class
- factors affecting driving resistance on the dynamometer
- influence of the driver - using the tolerances in the driving cycle
- preparation of the test vehicle
- optimised measurement
- variation in gear shifting
- battery state of charge
- laboratory soak temperature

For most of the above NEDC test flexibilities the literature has provided quantitative indications of the impact of variation of test parameters on measured CO_2 emissions.

One report in particular concludes that CO_2 total reductions of the order of 20% may be possible by optimising all the factors relating to the NEDC test procedure. It also concludes that further reductions beyond 20% are expected when other factors are considered such as the coast down derivation test.

Identification of flexibilities in type approval procedures

Through a review of the procedures prescribed by legislation, in particular UNECE R101 on energy consumption and CO_2 emissions and the underlying UNECE R83 specifying various aspects of the type approval emission test procedure, a number of flexibilities to achieve a low drive cycle CO_2 result were identified within the type approval procedure. The potential impact of these flexibilities on CO_2 and other emissions was assessed for gasoline and diesel passenger cars and light commercial vehicles (LCVs). Using information obtained from literature (see above), engineering calculations and simulations carried out for the purpose of this project, and in-house expertise, estimates were made of the potential impacts of the identified flexibilities on the type approval CO_2 emission value.

As indicated in this assessment, it may be advantageous to make use of some of the flexibilities for several different reasons, for example to help meet legislated pollutant emissions limits, even if reduction of CO_2 emissions is not a priority. Also a proportion of the theoretically available flexibilities may not be practical to implement in every vehicle and whilst some reduce CO_2 they can have an adverse effect on other emissions (such as increasing NO_x). Thus it cannot be assumed that the full theoretical range of flexibilities is available in every case.

The analysis of a vehicle group (family) definitions demonstrates that in one family there can exist vehicles that strongly differ in the CO_2 emission values. In view of the CO_2 legislation, as well as of national fiscal stimulation measures for fuel efficient cars, it is disadvantageous for manufacturers to report only the reference vehicle with a relative high CO_2 emission. As a consequence the application of the vehicle group definition is not considered a flexibility, which is confirmed by the observation that generally all individual CO_2 results of all vehicle group members are reported in the type approval certificates.

A summary of the results per flexibility is presented in Table 1. This table should not be read in isolation as the comments in the detailed discussions in chapter 3 are needed to explain when each flexibility can be applied, and to what extent. The comments also discuss which flexibilities cannot be used in parallel, and hence cannot be added together to calculate a total CO_2 benefit. For the remaining flexibilities no structured experiments have been carried out to validate the extent to which the variations in CO_2 identified are additive. It is entirely possible that there will be complex interactions between the various factors and an experimental study would be necessary to verify these cumulative effects. The estimates presented in Table 1 relate to both passenger cars and light commercial vehicles unless stated otherwise.

As can be seen from Table 1, the estimated potential associated with utilising all flexibilities within allowable bandwidths relating to the coast down test is 4.5%. A recent report, included in the literature review described above, presents independent measurements on vehicles comparing CO_2 emissions measured using the type approval rollerbench settings as reported by the manufacturer and settings based on independently conducted coast down test. Observed differences are of the order of 10%. This seems to suggest that also flexibilities may be utilised which are outside allowable bandwidths or related to test conditions which are not or not clearly defined in the test procedure.

Some flexibilities were also identified that are specific to hybrid vehicles only, in contrast to conventional ‘internal combustion engine only’ vehicles. These flexibilities relate to the classification of hybrid electric vehicles, calculations required for determining the CO_2 emissions of hybrid and plug-in hybrid electric vehicles on the basis of performed tests, determination of the electric range of plug-in hybrids, regenerative braking on a two-wheel chassis dynamometer, and the gear shift schedule.

Table 1 Summary of all flexibilities identified and their potential effect on CO_2 and other emissions

	Fuel type	CO_2	NO_x	PM	CO	HC
Utilising all flexibilities relating to the coast down test	Gasoline	-4.5%	Down	Down	Up	Up
	Diesel	-4.5%	Down	Down	Up	Up
Reduction in vehicle mass of 110kg (one inertia class)	Gasoline	-2.5%	Down	Down	Up	Up
	Diesel	-2.5%	Down	Down	Up	Up
Optimising wheel and tyre specification to increase rolling radius by 5%	Gasoline	-2%	Up	Up	Similar	Similar
	Diesel	-2%	Up	Up	Similar	Similar
Reducing overall rolling resistance by 20%	Gasoline	-2.8%	Down	Down	Similar	Similar
	Diesel	-2.8%	Down	Down	Similar	Similar
Increasing the running-in distance from 3000km to 15000km (for cookbook method only)	Gasoline	-5%	Down	Down	Up	Up
	Diesel	-5%	Down	Down	Up	Up
Implementation of all laboratory instrumentation flexibilities, to the full extent	Gasoline	-4.7%	Similar	Similar	Similar	Similar
	Diesel	-4.7%	Similar	Similar	Similar	Similar
Testing at a soak temperature of 30°C compared to 20°C	Gasoline	-1.7%	Similar	Similar	Down	Down
	Diesel	-1.7%	Similar	Similar	Down	Down
Using cookbook load factors compared to coast down terms, (applies to light goods vehicles and all-terrain vehicles only)	Gasoline	-3%	Down	Down	Up	Up
	Diesel	-3%	Down	Down	Up	Up
Starting the test with a fully charged battery (due to external recharging throughout the soak period) compared to a partially discharged battery	Gasoline	-1%	Down	Down	Up	Up
	Diesel	-1%	Down	Down	Up	Up
Using a higher gear at each stage of the NEDC test, for example 2nd to 5th gear rather than 1st to 5th gear	Gasoline	-6%	Up	Similar	Similar	Similar
	Diesel	-6%	Up	Similar	Similar	Similar
Using driving technique to minimise acceleration rate and vehicle speed within the tolerance allowed, compared to a test driven exactly to the target cycle	Gasoline	-1.2%	Down	Down	Similar	Similar
	Diesel	-1.2%	Down	Down	Similar	Similar
Extending DPF regeneration interval from 50 NEDC tests, to 100 NEDC tests to reduce Ki factor	Gasoline	N/A	N/A	N/A	N/A	N/A
	Diesel	-0.3%	Down	Similar	Similar	Similar
Declaring for homologation a lower CO_2 value than has been achieved in testing: declared value is allowed to be up to 4% lower than the measured result	Gasoline	-4%	N/A	N/A	N/A	N/A
	Diesel	-4%	N/A	N/A	N/A	N/A

Possible flexibilities not related to bandwidths specified in the legislation

The analysis presented in this report mainly focusses on flexibilities related to allowable bandwidths specified in the legislation. From the consultation of test houses and TA authorities as well as through other channels indications have been obtained that other flexibilities exist which may be utilised.

In addition to the flexibilities identified from the regulations, consultations with type approval authorities and operators of test houses indicated that there are other aspects of collecting the coast down data that are not covered in the regulations, and very probably contribute to coast down road load factors being smaller than those collected from "standard" roads. Clear quantitative data are difficult to acquire, but it is estimated that these aspects contribute a further 3% reduction in CO_2 emissions.

Also some further flexibilities exist with respect to the R101 test. Application of additional flexibilities that are not related to bandwidths specified in the legislation is possible because formally they do not exist and relate to aspects of the test that do not need to be recorded or approved by the type approval authority.

These identified additional flexibilities are listed below. Except for the last item all additional flexibilities relate to the coast down test:

- Test track surface condition (concrete or asphalt)
- Prepared tyres (modified profile)
- Increased inertia of tyres (fluid or metal)
- Taping of body parts
- Optimized resistance of wheel bearings
- Optimized front cooling air inlet
- Optimized body position (height / ground clearance)
- Optimized wheel alignment
- Definition of a standard vehicle
- Slope of the test track
- Test modes

Due to lack of information on the potential impacts as well as levels of utilisation the overall impact of these additional flexibilities on measured CO_2 emissions could not be quantified.

Utilisation of flexibilities in the past

In the past decades test procedure flexibilities were applied on a restricted scale in view of meeting pollutant emission limits. Impacts on measured CO_2 emissions are expected to be relatively small. For petrol there was generally no need to use them due to the high effectiveness of applied emission control technologies. For diesels it is more likely that flexibilities have been used, as diesel vehicles generally had TA emission levels close to the limits. But flexibilities that reduce NO_x in diesel engines generally tend to increase CO_2.

Based on interviews with type approval authorities and test houses a number of flexibilities were identified that were used in the past. For these flexibilities the level of utilisation in 2002 was estimated as a starting point for estimating impacts of increased utilisation of test procedure flexibilities in the 2002 – 2010 period (see Table 2).

Utilisation of flexibilities in the current type approval test practice

Since the introduction of European CO_2 legislation in 2008 the role of flexibilities has grown significantly. Besides the European CO_2 legislation, national tax regimes are a primary driver for marketing vehicles with lower CO_2 emissions. Especially specific fixed CO_2 emission thresholds (such as 95 or 110 g/km) force manufacturers to deliver vehicles which comply with these emission limits.

Based on consultation of type approval authorities and test houses an overview has been created of the flexibilities that are estimated to be currently used to lower CO_2 emissions as well as of their specific levels of utilisation in 2010. By subtracting estimated CO_2 effect resulting from past application (2002) from the value estimated for 2010, the impact of increased utilisation of flexibilities between 2002 and 2010 is estimated.

Table 2 Estimation of flexibilities applied in the last decade for passenger cars and LCVs

		Passenger cars		LCVs	
	Maximum possible CO_2 reduction	Current CO_2 reduction	Change since 2002	Current CO_2 reduction	Change since 2002
Coast down times (from chapter 2 and 3)	4.5%	2.5%	2.5%	0.5%	0.5%
Additional aspects of coast down times (identified from interviews)	4.0%	3.0%	3.0%	0.6%	0.6%
Reduction in vehicle mass	2.5%	0.25%	0.25%	0.0%	0.0%
Optimising wheel and tyre specifications	2.0%	0.0%	0.0%	0.0%	0.0%
Reducing rolling resistance by 20%	2.8%	0.0%	0.0%	0.0%	0.0%
Running in period of test vehicle	5.0%	0.5%	0.4%	0.5%	0.4%
Implementation of laboratory instrument flexibilities	4.7%	2.4%	1.7%	2.4%	1.7%
Soak temperature 30°C rather than 20°C	1.7%	0.9%	0.2%	0.9%	0.2%
Using cook book figures	3.0%	0.0%	0.0%	2.0%	0.0%
Using fully charged battery	1.0%	1.0%	1.0%	1.0%	1.0%
Using a higher gear throughout the NEDC	6.0%	0.0%	0.0%	0.0%	0.0%
Using driving technique	1.2%	0.7%	0.7%	0.7%	0.7%
Extending DPF	0.3%	0.05%	0.05%	0.1%	0.1%
Declaring lower CO_2 value	4.0%	2.0%	2.0%	2.0%	2.0%
TOTAL (from the product of individual contributions		**12.6%**	**11.2%**	**10.2%**	**7.0%**
Range for whole CO_2 emissions test			**6.2% - 16.0%**		**3.5% - 10.5%**

With respect to determining vehicle resistance factors it was found that coast down testing instead of “cook book values” is used for most passenger car models, but only for a minority of LCVs. Some aspects of the procedure are not specified, for example surface roughness. Most coast down data is collected using the Idiada track in Spain, which appears optimised for coast down data. Generally, the use of coast down data allows vehicle to vehicle comparison under controlled/repeatable conditions that take account of technical measures taken by the manufacturer to decrease rolling resistance and air drag. But it should be emphasized that the retarding resistances collected during coast down runs are not representative of retarding resistances for real road surfaces just as the NEDC is not representative of on the road driving.

Table 2 presents an overview of estimated impact of a range of individual flexibilities on the reduction in average CO_2 emissions between 2002 and 2010, as well as an estimate of their combined impact, specified separately for cars and for vans. From these numbers it can be concluded that application of flexibilities has strongly increased in the last decade leading to a reduction of registered type approval CO_2 emissions from passenger cars by around 11%. For vans a reduction of around 7% is estimated. The uncertainties around the "central" figures, indicated in the table above, were derived from a combination of the ranges available per flexibility, the positioning of the "actual change estimate" within this range, and information from the stakeholder interviews.

Some comments on the type approval process in Europe

The TA process differs between the US, Europe and Japan. Utilisation of test procedure flexibilities appears to be more wide-spread in the EU than elsewhere. The consultation of type approval authorities and test houses also provided some insights in the European type approval process that may have contributed to the use of test flexibilities as a means to reduce type approval CO_2 emissions of light duty vehicles:

- In Europe the type approval authority market is competitive. Manufacturers are clients of the test houses and type approval authorities, because they pay for services.
- The type approval process involves a degree of trust. Manufacturers do not want the TA authorities to think they are trying to operate outside the permitted limits.
- There are areas of subjective interpretation, and it would be wrong to assume that "the interpretation by all type approval authorities are the same".

Besides the actual type approval (TA) testing of more-or-less prototype vehicles, the European process also contains provisions to make sure that vehicles that are being produced and that are used on the road also comply with the type approval standards. Conformity Of Production (COP) testing is carried out to evaluate vehicles leaving the production line, while European Member States carry out In-Use Compliance (IUC) testing of vehicles.

Although one could imagine that especially COP testing could limit the use if flexibilities in the type approval procedure, it is found that this is not the case. COP test results are determined by:

- the specifications and properties of the test facilities,
- the specifications of the road load curves and test fuels, and
- the specifications and condition of the vehicles.

Except for the condition of a production vehicle all COP conditions can be chosen equal to the TA conditions. Therefore it is not expected that the COP procedure limits the use of flexibilities in the type approval procedure.

Deployment of new technologies in passenger cars and their impact on CO_2 reductions

Since 2002 various new technologies have been deployed in vehicles and these do contribute to reduced CO_2 emissions of new vehicles. Using historical light duty powertrain, production and sales databases for the EU27 an assessment has been made of the level of deployment of a range of CO_2 reducing technologies in passenger cars and vans sold in Europe. Combining the level of deployment (share of new vehicles equipped with a specific technology) with CO_2 reduction potentials, as determined in previous studies ([TNO 2006], [TNO 2011], and [TNO 2012b]) allows estimation of the contribution of various individual technologies to the observed reduction of average CO_2 emissions of new vehicles. Combining the impacts of individual technologies, together with an estimate of the potential impact of other, small technical improvements and optimisations in calibration, provides an estimate of the overall contribution of technology deployment to CO_2 emission reductions in cars and vans in the 2002-2010 period.

In this assessment account is taken of the impacts of observed increases in vehicle mass and power-to-weight ratios within the different vehicle segments. Both trends tend to increase the CO_2 emissions, and need to be counteracted by application of CO_2 reduction technologies in order to keep CO_2 emissions constant over time or to arrive at a net decrease. As a consequence these trends tend to reduce the net impact of the estimated levels of technology deployment on the CO_2 emission levels of new vehicles. In addition also the impacts of segment shifts, i.e. sales shifts between segments of small, medium-size and large vehicle and between petrol and diesel, have been quantified.

By comparing the observed 2010 CO_2 emission level for passenger cars with an estimated 2010 value based on the 2002 reference situation corrected for the net impacts of technology deployment, insight is provided in the extent to which the observed reductions can be fully attributed to technology or not. The results for passenger cars are presented in Figure 1 and Table 3.

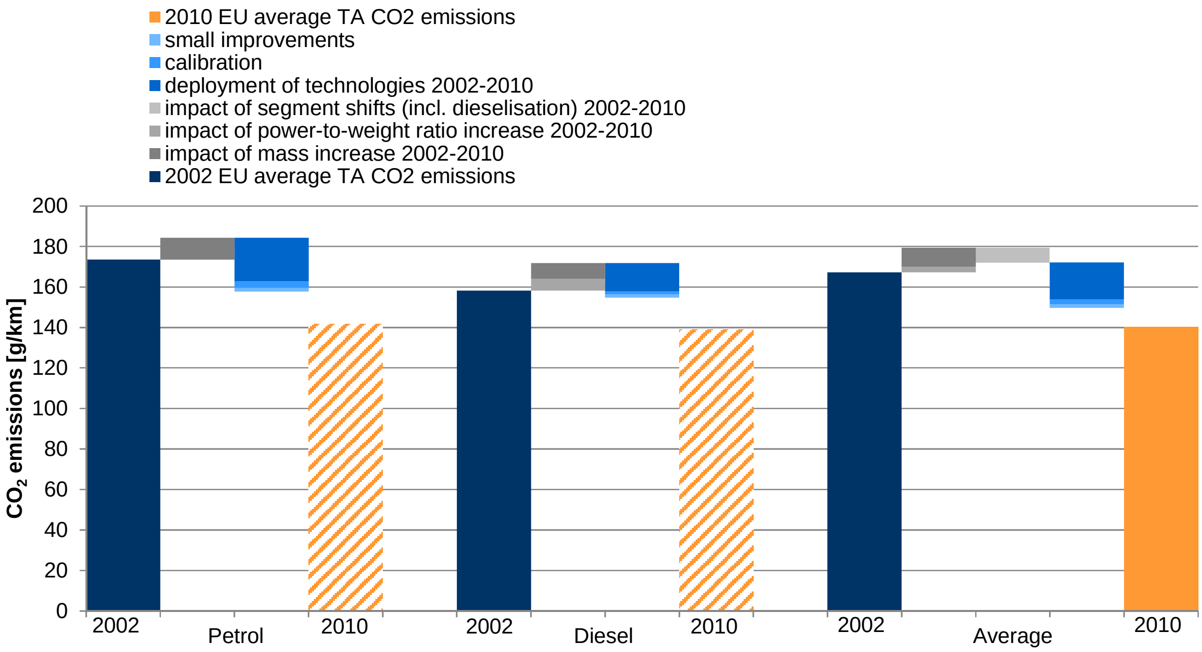

Figure 1 Estimation of the net CO_2 reduction resulting from technology deployment in passenger cars between 2002 and 2010.

Table 3 Overview of the estimated contributions from different factors to the net reduction of CO_2 emissions between 2002 and 2010 for passenger cars

Item	CO_2 [g/km]
2002 EU average TA CO_2 emissions	167.2
impact of mass increase 2002-2010	9.5
impact of power-to-weight ratio increase 2002-2010	2.5
impact of segment shifts (incl. dieselisation) 2002-2010	-7.4
deployment of technologies 2002-2010	-18.1
calibration	-2.6
small improvements	-1.7
estimated 2010 EU average TA CO_2 emissions	149.4
gap	9.1
actual 2010 EU average TA CO_2 emissions	140.4

From these numbers it can be concluded that it is likely that in the period 2002-2010 the registered CO_2 reduction of passenger cars has to a large extent been caused by implementation of technology, but also that the assessment made here reveals a gap of around 9 g/km that cannot be attributed to technology deployment.

Assessing the combined effect of flexibilities and technology deployment for passenger cars

A confrontation of the results of the "top-down" analysis of impacts of technology deployment relative to the 2002 baseline and a "bottom-up" estimate of what the 2010 value would have been without the assessed impact of increased utilisation of flexibilities is presented in Figure 2 and Table 4.

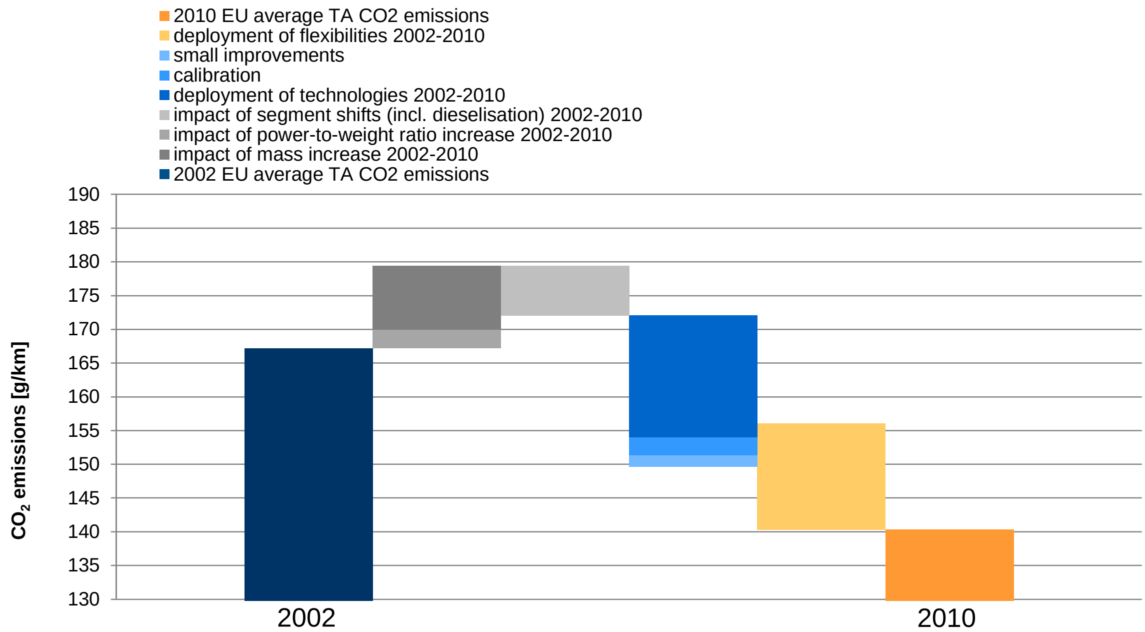

Figure 2 Graphical summary of the top-down and bottom-up analysis of the contributions of technology deployment resp. test cycle flexibilities to the reduction of passenger car CO_2 emissions observed between 2002-2010

Table 4 Summary of the top-down and bottom-up analysis for the contributions of technology deployment and test cycle flexibilities to the reduction of passenger car CO_2 emissions observed between 2002-2010

Item	CO_2 [g/km]
2002 TA average CO_2 emissions of passenger cars	167.2
impact of mass increase 2002-2010	9.5
impact of power-to-weight ratio increase 2002-2010	2.8
impact of segment shifts (incl. dieselisation) 2002-2010	-7.4
improved calibration	-2.6
small technical improvements	-1.7
deployment of technologies 2002-2010	-18.1
estimated 2010 EU average TA CO_2 based on 2002 value and impact of technology deployment and of changes in vehicle characteristics and sales between 2002 and 2010	149.7
overlap	6.4
estimated 2010 EU average TA CO_2 after correcting actual value for estimated impact of increased utilisation of flexibilities between 2002 and 2010	156.1
deployment of flexibilities 2002-2010	15.7
actual 2010 EU average TA CO_2 emissions of passenger cars	140.4

Combining the estimated impacts resulting from deploying CO_2 reduction technologies and increased utilisation of test flexibilities leads to an overlap in the sense that the sum of the two effects is somewhat larger than the net reduction that is to be accounted for. The fact that the two effects do not exactly match the observed reduction may be caused by uncertainties in various elements of the assessment:

- estimate of the impact of observed mass increase
- estimate of the impact of the observed power-to-weight ratio increase
- estimation of the average extent to which flexibilities are exploited and their actual impact on CO_2
- assessment of the average deployment level of technologies and their actual impact on CO_2

However, the overlap is limited compared to the estimated size of the effects of technology deployment and utilisation of test flexibilities. Also the size of overlap is of the same order of magnitude as the estimated uncertainty in the impact of test flexibilities (+/- 5%, or 7 g/km relative to the 2010 average of 140.4 g/km). The results therefore clearly indicate that neither technology deployment nor increased utilisation of test flexibilities can alone explain the observed reduction in CO_2 emissions of passenger cars between 2002 and 2010. This is a convincing indication that both factors have contributed to this reduction.

It is very important to emphasize that the estimates presented are average impacts. Every manufacturer will have its own considerations for application of flexibilities and application of technologies. The estimated levels of utilisation of flexibilities and technology deployment are not representative for individual manufacturers.

Assessing the combined effect of flexibilities and technology deployment for light commercial vehicles

Due to a lack of information on the 2002 CO_2 emissions, a similar comparative exercise cannot be completed for light commercial vehicles. Nevertheless an assessment is made of the possible impacts of utilisation of flexibilities and technology deployment, both estimated relative to the average emissions of light commercial vehicles sold in 2010. The results are summarized in Figure 3 and Table 5, which also include the estimated impacts of changes in mass and power-to-weight ratio and of shifts in sales between segments.

Adding the CO_2 impacts of all assessed factors that may have influenced LCV CO_2 emissions between 2002 and 2010 leads to a “backcasted” estimate for the average 2002 LCV CO_2 emissions of 216.9 g/km. This is approximately 4% more than the 2002 reference value that was estimated in [AEA, 2009]. Despite the lack of reliable 2002 estimate it also for LCVS appears likely that both technology deployment and increased utilisation of flexibilities have influenced CO_2 emissions between 2002 and 2010, with absolute contributions from both being smaller than for passenger cars.

Table 5 Breakdown of factors that have affected the LCV CO_2 emissions between 2002 and 2010

Item	CO_2 [g/km]
2010 TA average CO_2 emissions of LCVs	181.4
deployment of flexibilities 2002-2010	12.5
impact of mass increase 2002-2010	-2.2
impact of segment shifts (incl. dieselisation) 2002-2010	8.6
calibration	4.0
small improvements	2.0
deployment of technologies 2002-2010	10.7
indicative estimate of 2002 emissions of LCVs	216.9

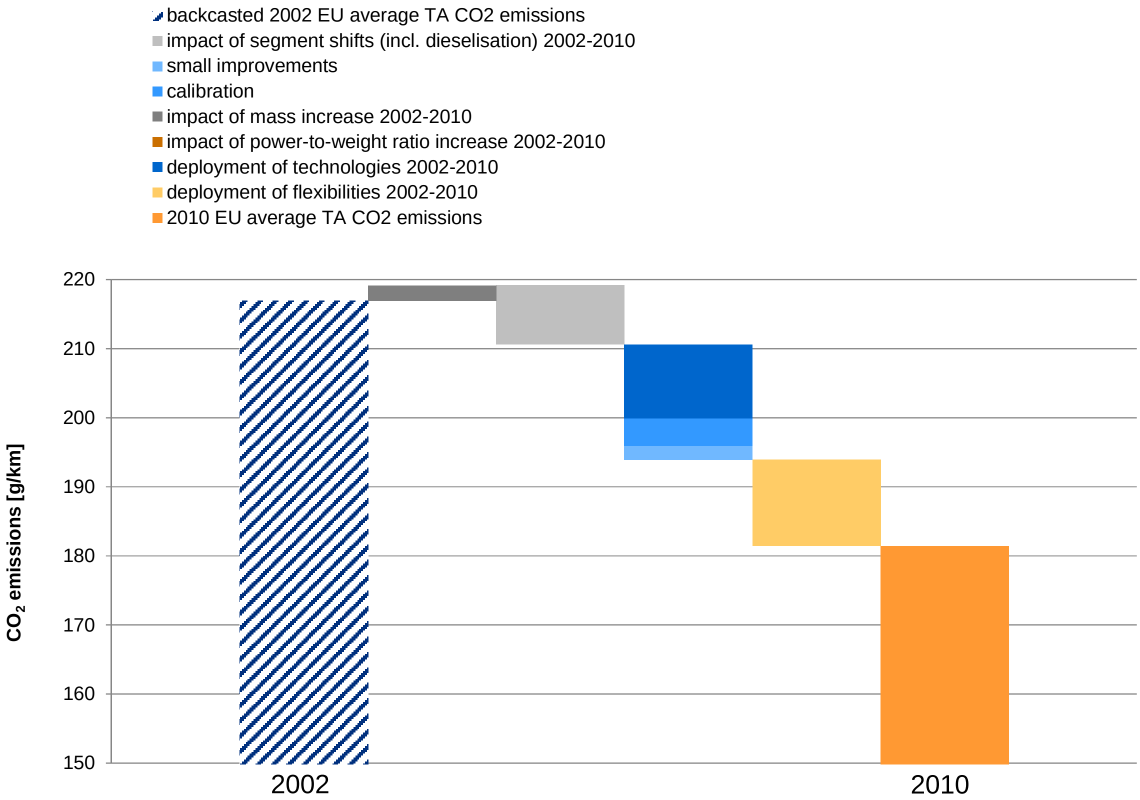

Figure 3 Contribution of various factors that have affected LCV CO_2 emissions between 2002 and 2010

Conclusions

The study identified a number of potential flexibilities allowable within the type approval procedure whose use may contribute to a reduction of CO_2 emissions as measured on the type approval test. From literature review and information from TA authorities and test houses it is clear that flexibilities are increasingly being used to lower CO_2 emissions of new vehicles on the TA test. For passenger cars it is estimated that the potential CO_2 reduction in 2010 due to additional use of flexibilities since 2002 is around 11% (bandwidth 6 - 16%). For LCV a value of around 7% (bandwidth 3.5 - 10.5%) is estimated.

With respect to the estimated impacts of increased utilisation of flexibilities the following remarks are made:

- There is uncertainty in the degree to which the flexibilities identified as potentially being utilised in 2010 may be used in combination. The CO_2 impacts are in general not simply additive. Without more detailed investigation into the interactions between factors the potential cumulative effect of combined flexibilities may only be quantified as a range.
- The utilisation of allowable flexibilities in the type approval procedure may vary from vehicle model to vehicle model and OEM to OEM and there is no clear picture of how they are implemented in specific cases.
- All estimates are for the current test procedures based on the NEDC. The adoption of the WLTP drive cycle and accompanying new test procedures may affect the number of available test flexibilities as well their impact on type approval CO_2 emissions. In the WLTP process attention is paid to reducing test cycle flexibilities, but available information indicates that also under WLTP flexibilities may still have a finite reduction potential.

The study also identified the level of deployment of CO_2 reducing technologies, their potential CO_2 benefit, as well as the impacts of improved calibration and took into account the effects on CO_2 emissions of changes in average vehicle mass and power-to-weight ratio for the period 2002 and 2010.

For passenger cars it is concluded that of the observed net reduction between 2002 and 2010 up to two thirds may have been achieved by the deployment of technologies, including small optimisations and improved calibration. However, the estimated reduction realised by technologies does not fully explain the difference between the 2002 and 2010 average CO_2 emissions. The estimate of the potential impact of test procedure flexibilities and their level of utilisation in the 2002-2010 period appears to explain the remaining gap.

For light commercial vehicles a confrontation of the combined effect of flexibilities and technology deployment with the net reduction over the 2002-2010 period was not possible due to lack of 2002 type approval CO_2 data for LCVs. Nevertheless also for this vehicle category it appears likely that both flexibilities and technology deployment have been used to reduce type approval CO_2 emissions. Also for LCVs the estimated impact of technology deployment on CO_2 reductions between 2002 and 2010 is larger than the estimated impact of increased utilisation of test flexibilities. Segment shifts may also have contributed significantly to reductions between 2002 and 2010.

The estimation of past and present use of flexibilities indicates that many of the identified flexibilities may not currently be utilised to their full potential. A further reduction of type approval CO_2 emissions due to a further increase in the utilisation of flexibilities beyond 2010 levels can therefore not be excluded. Taking account of the fact that the potentials of individual flexibilities are not fully additive and that there may be reasons why various flexibilities can or will not be utilised to their full potential, it seems possible that a further reduction potential of the order of 5 to 10 g/km could still be available between 2010 and 2020. This conclusion, however, is indicative and deserves further investigation.

In addition to the above, the utilisation of flexibilities outside allowable bandwidths, or related to test conditions which are not or not clearly defined in the test procedure, deserves more attention.

Overall the conclusion is that this study has generated convincingly strong indications that the reductions in CO_2 emissions of light duty vehicles, as observed over the last decade, can be attributed to a combination of deployment of CO_2 reducing technologies, increased utilisation of test flexibilities and a range of smaller factors, including changes in vehicle characteristics which affect CO_2 emissions and shifts in sales between different size classes.

Table of contents

1 Introduction

1.1 Background

The purpose of the current EU regulatory framework on CO_2 emissions from light duty road vehicles is to reduce greenhouse gas (GHG) emissions from passenger cars and light commercial vehicles as a contribution to the EU's overall strategy to reduce its climate impacts. The evolution of this legislation needs to be in line with the overall objectives set to achieve the EU high level objective of achieving an 80 to 95% reduction in economy-wide GHG emissions by 2050 compared to 1990 levels. The *Roadmap for moving to a competitive low-carbon economy in 2050* illustrates a number of scenarios for the necessary GHG emission reductions across the EU economy. The 2011 Transport White Paper (*Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system*) further elaborates on the transport-related aspects and specifies two targets for the transport sector as a whole: a 20% reduction of direct GHG emissions from 2008 levels by 2030 and a 60% reduction from 1990 levels by 2050.

1.1.1 *The current European regulatory framework*

Regulation (EC) 443/2009 regulates CO_2 emissions from new passenger cars while Regulation (EU) 510/2011 regulates CO_2 emissions from new vans. These Regulations set limits based on average tailpipe CO_2 emissions from new vehicle sales. For passenger cars the average CO_2 emissions have to be lowered to 130 g/km in 2015 and to 95 g/km in 2020. For LCVs, the targets are respectively 175 g/km in 2017 and 147 g/km in 2020. Various impacts of the 2020 targets for passenger cars [TNO 2011] and LCVs [TNO 2012], as well as of different modalities for implementing these targets, were analysed by the consortium responsible for this study.

Table 6 Development of average CO_2 emissions from new passenger cars in Europe (source: EEA, http://www.eea.europa.eu/publications/monitoring-co2-emissions-from-new/at_download/file)

Average CO_2 emissions from new passenger cars by fuel (EU-27 *)

gCO_2/km	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010 [a]	2011 [a, b]
All fuels	172.2	169.7	167.2	165.5	163.4	162.4	161.3	158.7	153.6	145.7	140.3	135.7
Petrol	177.4	175.3	173.5	171.7	170	168.1	164.9	161.6	156.6	147.6	142.5	137.7
Diesel	160.3	159.7	158.1	157.7	156.2	156.5	157.9	156.3	151.2	145.3	139.3	134.5
AFV	208	207.4	179.2	164.7	147.9	149.4	151.1	140	137	125.8	126.0	123.5

Note: * The geographical scope of the data changes over time from EU-15 to EU-25 and EU-27, see Annex 1 for details.

[a]: The calculation for the years 2010 and 2011 was done without considering IVAs, NSS and 'out of scope' vehicles.

[b]: For the calculation of the average CO_2 emissions of AFVs, electric bi-fuel vehicles were not considered, because not correctly reported by Member States. Note that 2011 data are provisional.

As a result of the (upcoming) regulation, as well as in response to other drivers such as fiscal incentives provided by various Member States to promote the purchase of fuel efficient vehicles (see section 1.1.3), the average type approval CO_2 emission of passenger cars in Europe has decreased from 172 g/km in 2000 to 136 g/km in 2011 (see Table 6).

1.1.2 *Indications of increased utilization of flexibilities*

However, over the last few years indications have accumulated that part of the CO_2 emission reduction observed in the Monitoring Mechanism may not be attributable to the application of identifiable CO_2 reducing technologies. A preliminary evaluation in [TNO 2011] of 6 petrol and 6 diesel vehicle models sold in 2002 and 2009 suggested that some 9 - 10% of the reductions observed in that period could not be attributed to additional technologies applied to the assessed vehicle models between 2002 and 2009. [TNO 2011] suggested that this difference might to some extent be attributed to the application of small technical improvements, including improved calibrations, but that a large share of the difference might be the result of the increased utilisation of flexibilities in the test procedure. With utilisation of flexibilities in the test procedure we mean that by carefully selecting vehicle test conditions within, or possibly even outside, allowable bandwidths, manufacturers might be able to achieve reduced CO_2 emission levels on a given vehicle.

Obviously, reductions in type approval CO_2 emissions obtained in such a way not only affect the net impact of the regulation but also the costs of meeting the targets set for 2015 / 2017 and 2020. Due to a lack of hard evidence the possible effects of the increased utilisation of flexibilities could not be incorporated in the main cost assessment in [TNO 2011]. Instead the effect was included in a scenario variation labelled the scenario a) cost curves (see Figure 4). The scenario a) cost curves were found to lead to around € 600 lower costs per vehicle for meeting the passenger car target of 95 g/km in 2020, which is about one third of the costs estimated with cost curves based on application of headline technologies only.

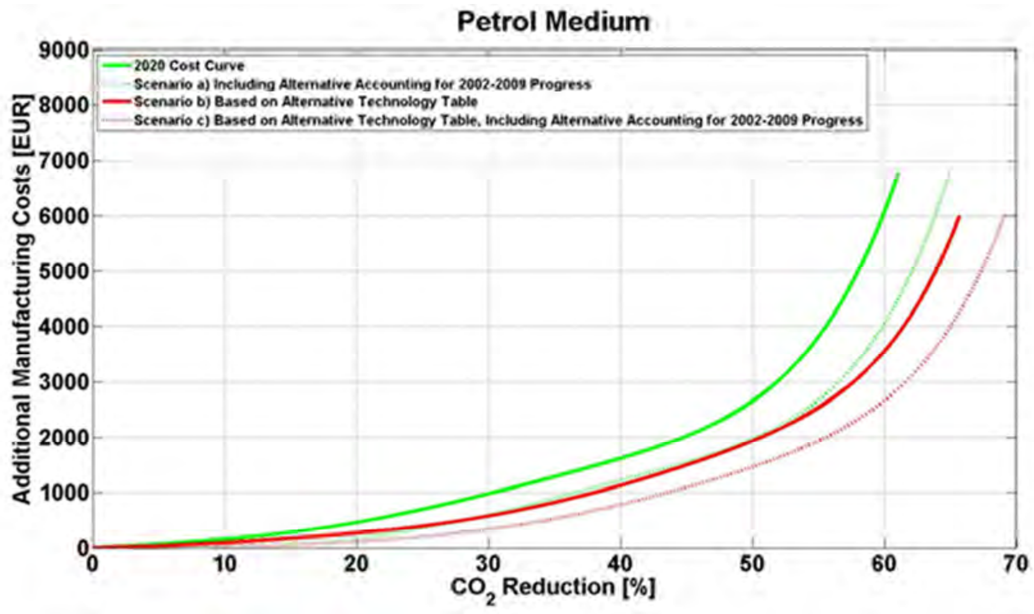

Figure 4 Example of the main cost curves and scenario variants used in the assessment of the impacts of the 2020 target for passenger cars in [TNO 2011].

The possible impact of increased utilisation of flexibilities is not only relevant from a regulatory point of view. Reductions on the type approval test that are not resulting from technological improvements to vehicles do not result in reduction of the fuel consumption in real-world driving. This means that vehicles do not deliver end-users the promised fuel cost reductions, leading to consumer misinformation. Consumer disappointment with real-world fuel consumption figures may ultimately lead to reduced support for the European CO_2 reduction policy as well as to fiscal and other stimulation policies in Member States. Also, varying levels of utilisation of flexibilities by different manufacturers may lead to unfair competition. Getting a clearer picture of this subject is therefore not only in the interest of the European Commission, but also in the interest of consumers, car manufacturers and Member State governments.

1.1.3 *The role of fiscal measures in Member States*

The role of fiscal stimulation measures by Member States in promoting increased utilisation of test flexibilities should not be underestimated and is even believed to be stronger at this point in time than the impact of legislative targets to be met by 2015 or 2017. Many Member States have fiscal stimulation measures to promote the purchase of fuel efficient cars. National taxation plays a major role in market dynamics and it is well known that manufacturers produce special vehicles for special markets. Many countries have included some form of CO_2 differentiation of registration and/or circulation taxes. National CO_2 labelling methodologies can be part of the incentive methodology.

ACEA[1] publishes overviews of national CO_2 taxation policies on their website. The incentives range from a CO_2-based component in the registration tax or annual circulation tax, a bonus or malus tax dependent on CO_2 emission or an additional fuel consumption tax. The tax regime can be linear or progressive.

Most incentives which are based on CO_2 emissions according to ECE-R101 create a certain tendency to apply flexibilities. Especially in case of a fixed parameter threshold levels (i.e. CO_2 < 50, 95 or 110 g/km) in combination with a fixed amount of reduced tax or subsidy manufacturers will do their very best to optimize vehicles because consumers are very sensitive to pricing and manufacturers to maintaining or increasing their market share. In some countries private use of a company car has been charged by a fictive raise of income and as a consequence more income tax must be paid. If the CO_2 emission is a parameter for this calculation it stimulates the use of flexibilities[2].

National tax regimes can thus be considered a strong incentive for marketing low CO_2 vehicles. Especially specific fixed CO_2 emission thresholds (such as 95 or 110 g/km) force manufacturers to deliver vehicles with type approval CO_2 emission values just below these limits.

1.1.4 *Purpose of this study*

The purpose of this study is to provide a more in depth assessment of the utilisation of test procedure flexibilities and its possible impacts and to analyse to what extent increased utilisation of flexibilities may have contributed to the observed reductions in CO_2 emissions of new cars sold in Europe.

1.2 Flexibilities

Test cycle flexibilities are multiple parameters, related to the tested vehicle and conditions under which it is tested, that can be adapted during the type approval test, leading to changes in reported light duty vehicle CO_2 emissions. Different types of flexibilities can be distinguished, i.e.:

- Variations within bandwidths indicated in the test procedure;
- Variations with respect to test conditions and parameters not or not clearly specified in the test procedures (“it does not say that it is not allowed…”);
- Variations outside allowed bandwidths.

The legislation allows manufacturers some leeway in preparing vehicles and carrying out tests, which has been utilised to a different extent by different manufacturers over time. The mere existence of flexibilities does not mean that they will all be fully deployed. There may be reasons why it is unattractive or impractical to use the full range.

1.3 Objectives of the work

The objective of this project has been to provide assistance to the European Commission in understanding how flexibilities in the regulatory test procedure may be utilised to reduce type approval CO_2 emissions of new vehicles and of the extent to which utilisation of flexibilities may have contributed to the reduction of light duty vehicle CO_2 emissions as observed until now.

Potential impact of test cycle flexibilities

The legislation allows manufacturers some leeway in preparing vehicles and carrying out tests. It is desirable to catalogue all of these flexibilities based on an analysis of the relevant rules and procedures accompanied by interviews with vehicle testing laboratories, organisations and experts.

Utilisation of test cycle flexibilities

The mere existence of flexibilities does not mean that they will all be fully deployed. There may be reasons why it is unattractive or impractical to use the full range. It is therefore desirable to assess

[1] http://www.acea.be/images/uploads/files/20110330_CO2_tax_overview.pdf
[2] http://cccfcalculator.hmrc.gov.uk/CCF0.aspx

the extent to which flexibilities have been and are being utilised and which aspects or proportions of the available flexibilities are unlikely to be used.

Assessment of level of technology deployment in current new vehicle fleet

The deployment of technologies is analysed in this study to provide a total overview of the factors that may have contributed to the average CO_2 reductions between 2002 and 2010. The deployment of identifiable CO_2 reducing technologies is expected to have contributed significantly to this reduction.

1.4 Scope and methodology

This project addresses the question of whether part of the observed reductions in CO_2 emissions of new light duty vehicles between 2002 and 2010, as measured on the type approval test, is to be attributed to other causes than the application of CO_2 reducing technologies. Specific focus is on flexibilities in the type approval test procedure that can be utilized to achieve lower measured CO_2 values.

The possible utilisation of flexibilities in the test procedure is one of the issues that may have contributed to the observed increase in the discrepancy between CO_2 emissions as measured on the type approval test and those measured under real-world driving conditions. This project, however, does not specifically deal with the question of whether and to which extent reductions in CO_2 emissions observed on the type approval test correspond to actual reductions in real-world CO_2 emissions. The results with respect to utilisation of flexibilities, however, are relevant to the discussion of real-world fuel consumption and CO_2 emissions.

The main scope of this study is the period between 2002 and 2010. It should be noted that since 2010, more CO_2 reducing technologies and flexibilities may have been applied by manufacturers. Since the majority of the study focusses the average deployment of flexibilities, not analysing the amount of flexibilities applied by individual manufacturers or the effect of flexibilities on specific vehicle models, it is important to notice that:

- some manufacturers may reduce more from their type approval CO_2 emissions by applying flexibilities than others, and that
- there may be a large difference between the average level of utilisation of flexibilities and the associated impacts on type approval CO_2 values and the more extreme figures that are found in testing of individual cars.

The overall hypothesis is that observed reduction in the type approval CO_2 value of new vehicles between 2002 and 2010 can be considered to be a combination of the following possible contributions:

- Effects of **application of technical measures** including:
  - CO_2 reduction due to application of identifiable technologies such as those included in the technology table underlying the cost curves developed in [TNO 2011].
    - Assessment of this potential is part of chapter 6.
  - CO_2 reduction due to small technical improvements that are not mentioned in technical specifications of vehicles and are not included in cost curve of [TNO 2011].
  - Effects of optimising the powertrain calibration by improving trade-offs against other parameters.
- The possible **utilization of flexibilities** in the test procedure:
  - Theoretical possibilities for this are identified in chapter 3. Evidence of actual utilisation is collected in chapters 4 and 5 (through consultation of experts at Type Approval Authorities and Technical Services) and may also be found within chapter 2 (literature search).

In this project an indication of the extent to which utilization of flexibilities in the test procedure may have contributed to the observed reduction in type approval CO_2 values between 2002 and 2010 is obtained through combining two different approaches:

- A **bottom-up approach** consisting of three steps:
  - Identification of all possible flexibilities in the specification of the test procedure and estimation of the possible impact that utilising individual flexibilities may have on measured CO_2 emissions;
  - Obtaining evidence or indications from existing studies and relevant experts on the extent to which various flexibilities may have been utilised;
  - Combination of the above into a bandwidth indicating, based on available information, the extent to which utilisation of flexibilities may have contributed to observed reductions of type approval CO_2 values between 2002 and 2010;
- A **top-down approach** in which possible contributions from applied technical measures, as indicated above, are subtracted from the observed CO_2 emission reductions. This gives an indication of the gap that could be explained by the possible use of flexibilities in the test procedure.

Given the uncertainties in estimating all possible contributions to the observed CO_2 reduction it is expected that the results of the two approaches will not give an accurate match. Figure 5 shows two examples of possible outcomes.

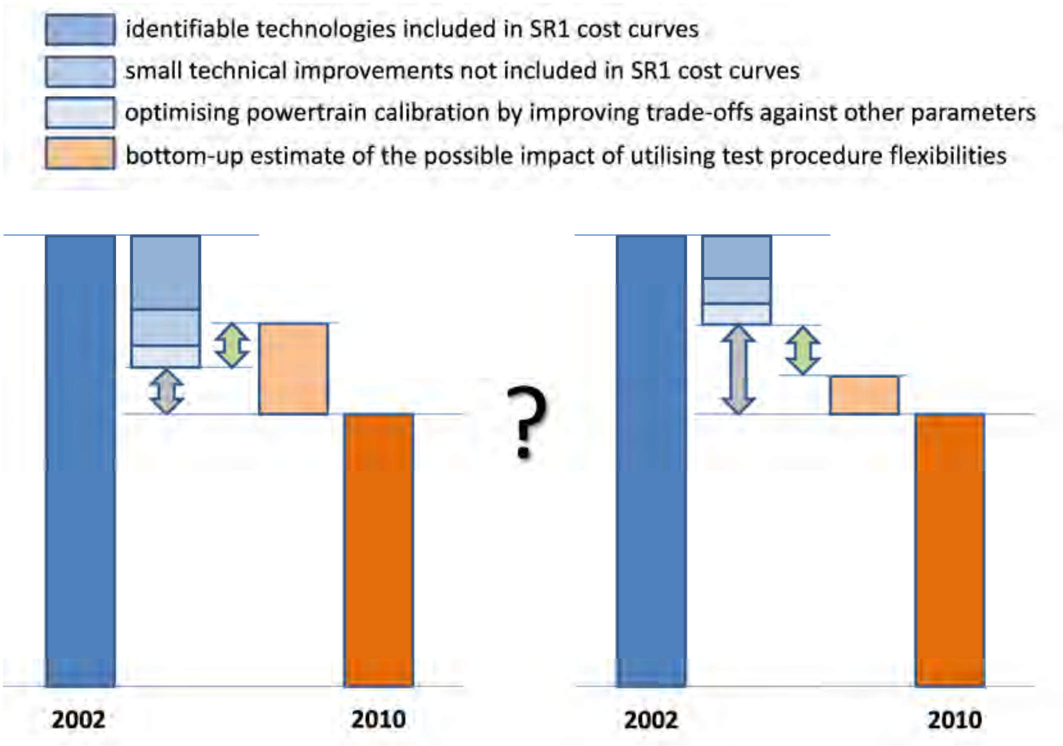

Figure 5 Schematic illustration of the approach for assessing the combined contribution of utilisation of test flexibilities and deployment of technical measures to the CO_2 emission reduction observed between 2002 and 2010

All results obtained in this project will be related to the observed changes in and possible effects on the average CO_2 emissions of the new light duty vehicle fleet and of different aggregate segments within the new vehicle fleet. The approach as outlined above is neither suitable nor intended to deliver OEM-specific indications of the possible utilisation of test procedure flexibilities.

1.5 Structure of the report

In view of the above the project has been structured into different tasks carried out by different (combinations of) consortium members. Table 7 indicates the chapters in which the results of the various tasks are reported and the partners involved in each of them.

Table 7 Structure of the report, indicating where results of different tasks are reported and the division of partners over tasks

Chapter	Description	PARTNERS
1	Introduction	
2	Literature review of publications addressing flexibilities available under type approval procedures and their impact on measured emissions	Ricardo TNO
3	Assessment of the legislation to understand the full range of flexibilities available under type approval procedures that impact on measured CO_2 emissions and their impact in terms of CO_2	Ricardo TNO AEA
4	Assessment of the degree to which these flexibilities would have been used by manufacturers in the past – e.g. to obtain benefit in terms of pollutant emissions, administrative burden, or cost	TNO AEA
5	Consultation of type approval authorities and test houses to understand how and to what extent the available flexibilities are used by manufacturers at present	AEA TNO
6	Assessment of the level of technology deployment in current new passenger car fleet	IHS Ricardo TNO
7	Breakdown of observed CO2 reductions between 2002 and 2010 for passenger cars into possible contributions from increased utilisation of flexibilities, technology deployment and other causes	TNO Ricardo AEA
8	Assessment of the combined effect of flexibilities and technology deployment for LCVs	IHS Ricardo TNO
9	Discussion and conclusion	

2 Literature review

2.1 Introduction

The vehicle type approval procedure includes testing of a vehicle on a chassis dynamometer, to assess compliance with standards for exhaust emissions, and obtain a measure of fuel consumption and carbon dioxide (CO_2) emissions. With the emergence of new legislation requiring compliance with fleet-average CO_2 emission targets, this CO_2 measurement has become important. Type approval figures and sales numbers of all cars sold in the EU are to be collected and reported by Member States under the Monitoring Mechanism, to be aggregated for assessment of each manufacturer's fleet-average CO_2 and check of its compliance with the manufacturer specific targets set under the CO_2 legislation.

The vehicle type approval procedure is intended to represent a typical vehicle and driving conditions. Because this part of the procedure is performed on a single vehicle, there is a need to allow manufacturers some flexibilities in preparing vehicles and carrying out the tests to determine light duty vehicle CO_2 emissions. The procedure hence requires that the test represents a real vehicle to within specified tolerances (flexibilities).

With increasing pressure on manufacturers, it is hypothetically possible that these flexibilities could be exploited to obtain an advantageous result, for example by preparing a vehicle such that its characteristics remained within allowed tolerances but were advantageous with respect to achieving a low CO_2 emission measurement, or by conducting the test in such a way that test parameters were within allowed tolerances, but advantageous.

This chapter reports results of a literature review which has been conducted with the aim of identifying flexibilities, such as drag, vehicle warm-up, which have been reported in the public domain and to establish scientifically what the effect of variation within those tolerances may be on measured CO_2 emissions. Literature sources have also been scanned for potential indications regarding the actual utilisation of test procedure flexibilities.

In addition to this literature review chapter 3 reports results of a hypothetical exploration of a best case interpretation of the legislative procedure with an express intent to get a low CO_2 number has been conducted. This has been performed via a review of the legislation by experts including those who are regularly involved in the testing of light duty vehicles. The CO_2 impact of applying these flexibilities has then been calculated using a robust methodology versus a baseline vehicle.

These parts of the study are intended to highlight potential flexibilities available under the current type approval procedure.

2.2 Objectives

The objective of this section is to conduct a literature review to identify public domain reports characterising the flexibilities available under type approval procedures and their impact on measured CO_2 emissions. Of interest were results of tests performed over the NEDC for the purpose of new vehicle type approval and their impact on light duty vehicle CO_2 emissions. The review also attempted to identify literature covering independent test attempts to replicate manufacturer reported CO_2 values and to catalogue the magnitude of these reported discrepancies. The activities within the task reported in this section were:

- Desk research to identify relevant literature in the public domain;
- Contact and consult experts from type approval bodies for advice on available public domain literature;
- Review identified literature and summarise key findings regarding:
  - Identification of flexibilities and impact on light duty vehicle CO_2 emissions as measured on the type approval test;
  - Identification of any discrepancies between reported test cycle values and independent tests to replicate manufacturer reported CO_2 values on the NEDC.

2.3 Methodology

The type approval procedure allows manufacturers some flexibilities in preparing vehicles and carrying out the tests to determine light duty vehicle CO_2 emissions. The procedure requires that the test represents a real vehicle to within specified tolerances. The literature review aims to identify reported flexibilities, such as related to drag or vehicle warm-up, to establish scientifically what the effect of variation within those tolerances may be on measured CO_2 emissions.

The following sources were used to identify relevant publications in the public domain which either identify flexibilities within the type approval procedure, report on the effect that variation on tolerances has on measured CO_2 emissions or report on independent test attempts to replicate manufacturer reported CO_2 values:

- Ricardo PowerLink database: an on-line database which contains a comprehensive collection of powertrain-related material which references technical journals (250 titles), books and conference proceedings, published technical papers, patents and standards, official legislative publications and manufacturers' literature;
- UK Department for Transport reports;
- Type approval body reports – UTAC, EMPA, TUV, VCA;
- Reports of the European Commission – JRC;
- Journals and papers from SAE and JSAE;
- University research departments;
- Companies involved in vehicle emissions development or testing;
- Non-governmental organisations such as pressure groups.

2.4 Publications identified

As anticipated, the literature review confirmed that very few public domain publications cover the subject of flexibilities within the legislation. For this reason the list of relevant titles is limited, despite extensive research. Some publications however, do contain results that are relevant to the subject.

The following publications were identified as relevant, either detailing the flexibilities available, or in terms of quantifying the effect these flexibilities may have on cycle CO_2 and emissions:

1. Light Goods Vehicle – CO_2 Emissions Study - Final report, [AEA 2010]

2. In-Service Vehicle Testing Programme 2010-11, [Millbrook 2011]

3. In-Service Vehicle Testing Programme 2009-10, [Millbrook 2010]

4. Effect of ambient temperature (15 °C-28 °C) on CO_2 emissions from LDV over NEDC, [JRC 2009]

5. CO_2 and emission reduction by means of heat storage in the powertrain, [Burgin 2011]

6. Customer related CO_2-reduction by selective heat supply during vehicle warm-up, [BMW 2007]

7. Technical Guidelines for the preparation of applications for the approval of innovative technologies pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council (version: 11 July 2011), [JRC 2011]

8. Fuel consumption and emissions of modern passenger cars, [TU Graz 2010]

9. Pilotprojekt zur Relevantanalyse von Einflussfaktoren bei der Ermittlung der CO_2- Emissionen und des Kraftstoffverbrauchs im Rahmen der Typgenehmigung von Pkw, [TÜV Nord 2010a]

10. Future development of the EU Directive for measuring the CO_2 emissions of passenger cars – investigation of the influence of different parameters and the improvement of measurement accuracy, [TÜV Nord 2010b]

11. Road Load Determination – Vehicle Preparation, [STA/T&E 2011]

12. Development of a Worldwide Harmonized Light Vehicles Test Procedure (WLTP) ICCT contribution No. 3 (focus on inertia classes), [ICCT 2011]

13. Parameterisation of fuel consumption and CO_2 emissions of passenger cars and light commercial vehicles for modelling purposes, [LAT 2011

14. Use of a vehicle-modelling tool for predicting CO_2 emissions in the framework of European regulations for light goods vehicles, [LAT/TNO 2007]

15. On the way to 130g CO_2/km — Estimating the future characteristics of the average European passenger car, [LAT 2010]

16. Development of the World Harmonized light duty Test Procedure (WHTP), [WLTP 2012]

17. Road load determination of passenger cars, [TNO 2012b]

2.5 Results

The literature reviewed contains information that falls into the following sub categories:

- Vehicle coast down assessment by independent organisations;
- NEDC test results by third party laboratories versus type approval test results;
- Estimating the effect of variations in test conditions and execution on cycle CO_2 result, including temperature effects.

Each source is reviewed individually, with relevant quotations included, and conclusions from all sources are summarised together at the end of this chapter.

Light Goods Vehicle – CO_2 Emissions Study – Final report

[AEA 2010]

Summary
This report contains data that quantifies the relationship between vehicle mass and cycle CO_2. This is in the context of testing light goods vehicles at different levels of loading. This data is relevant as it helps quantify how reduction in type approved vehicle mass, due to potential flexibilities in the legislation, might affect the measured CO_2.

Using models derived from the test data, the report also goes on to assess the effect of drag coefficient, independently of rolling resistance.

“To illustrate how the CO_2 emissions vary with aerodynamic drag, Ricardo carried out a study where each of the three vans were simulated over the NEDC (regulatory cycle) using five different values of drag coefficient (Cd) ranging from 0.26 (low) to 0.50 (very high). This range extends above and below the drag coefficient for the standard panel van models.” Results for the Peugeot Partner are shown in Figure 6.

Figure 6 clearly shows the relatively low sensitivity of the CO_2 emissions for the low average speed ECE (or UDC) portion of the regulatory drive cycle to Cd (the red line), and, in contrast, the much higher sensitivity of the CO_2 emissions for the EUDC portion of the regulatory drive cycle (where speeds reach 120 km/h) to Cd (the yellow line). This is intuitively logical (aerodynamics are more important at higher speeds) but also quantifies how poor aerodynamic modification, increasing the drag factor from 0.33 to 0.50, would lead to around a 21% increase in CO_2 emissions for a Peugeot Partner, if its principal role were to travel longer distances at higher speeds, but only around a 3% increase in CO_2 emissions for vans undertaking urban deliveries.

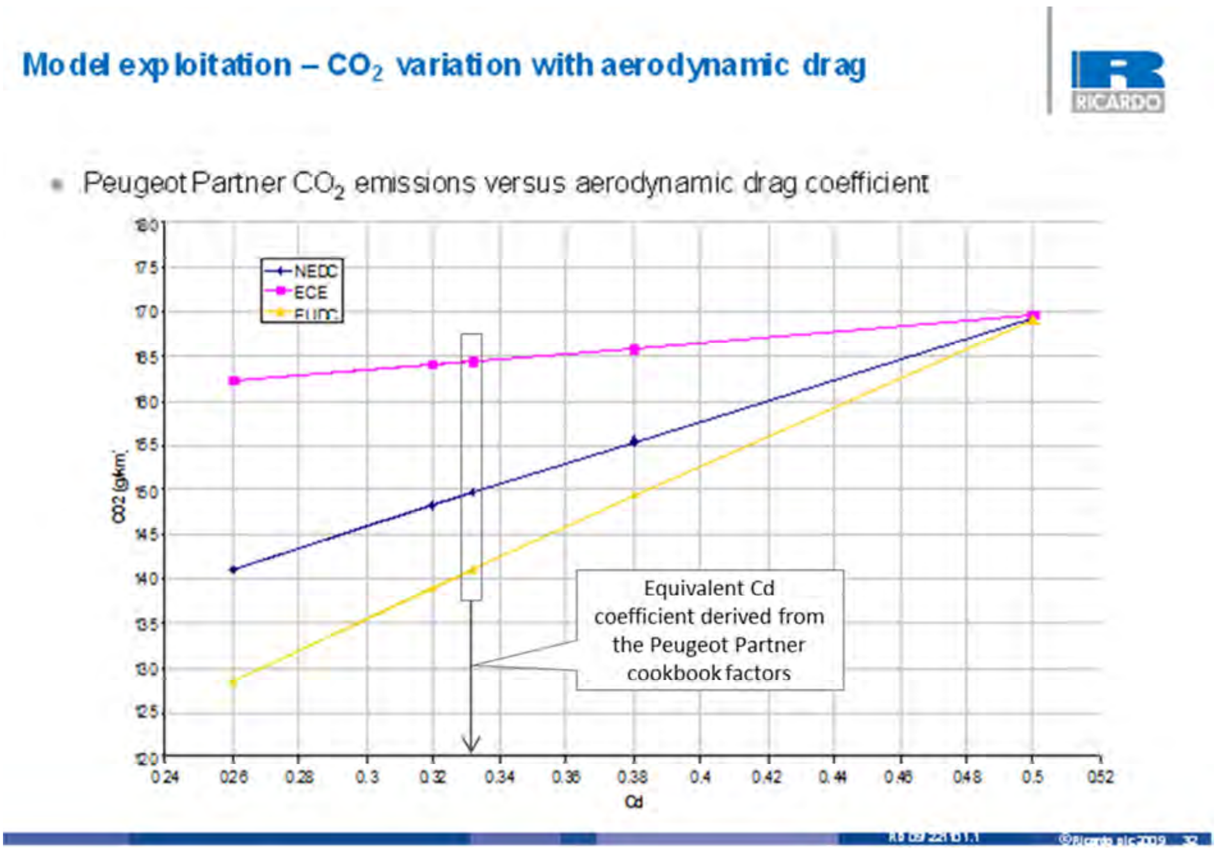

Figure 6 Variation in CO_2 emissions with drag coefficient over the NEDC for the Peugeot Partner

The study also included an analysis of the effect of vehicle weight on cycle CO_2. This was also modelled based on the test data. Some summary comments from the report are shown below:

- "The van measurement programme studied the effect of loading and drive cycles on CO_2 emissions for a small, medium and large van. The emissions from different drive cycles did follow the pattern expected from the drive cycles average speed, and the knowledge within the recently published speed related CO_2 emission factors. However, the effect of load was smaller than might have been expected. It was found that on average a fully loaded van will weigh 50% more than an empty van, however its CO_2 emissions would only increase by 7.8% (+/-1.8%)."
- "Over the regulatory NEDC the three vans tested had CO_2 emissions of approximately 150, 190 and 245 g/km. This simulation shows that for motorway driving the CO_2 emissions are virtually load independent (because it is the aerodynamics of the van that dominate CO_2 emissions rather than overcoming inertia, as during stop/start driving)."

The report goes on to investigate the effect of coast down times on cycle CO_2. It specifically compares reference dataset coast downs (so-called "cookbook" values as specified in the test procedure, see also section 3.2), versus independently measured coast downs. The CO_2 differences between these tests are expressed as an average of NEDC and some 'real world' drive cycles:

- "Finally, for one van, the Ford Transit, its CO_2 emissions were compared for when the dynamometer resistance was set up according to the industry standard coefficients reference data, and by matching the dynamometer to the vehicles' coast down data, measured by the Millbrook team. This study was to investigate the influence of test variables on CO_2 emissions in the context that the vast majority of van data are collected using these reference datasets. It was found that the coast down (van specific) settings led to higher CO_2 emissions for three of the four drive cycles with the average increase being 2.7%, but the spread of the change being high (around 3% for the range of drive cycles used)."

Conclusions

This report looks at the effect of vehicle mass, coefficient of drag, and coast down time on CO_2 emissions. Regarding the effect of coefficient of drag, on different phases of the NEDC cycle, it concludes the following: “increasing the drag factor from 0.33 to 0.50, would lead to around a 21% increase in CO_2 emissions for a Peugeot Partner whose principal role is to travel at higher speeds, but only around a 3% increase in CO_2 emissions for vans undertaking urban deliveries.” This statement helps to quantify the effect of aerodynamic drag on cycle CO_2.

It concludes the following regarding vehicle mass: “It was found that on average a fully loaded van will weigh 50% more than an empty van, however its CO_2 emissions would only increase by 7.8% (+/-1.8%).” This statement helps to quantify the effect of vehicle mass on cycle CO_2 for light commercial vehicles.

Regarding coast down times it concludes that on a range of cycles the CO_2 increased by an average of 2.7% when using independently measured coast downs. This data gives an indication of the difference in cycle CO_2 between using independently measured coast downs, compared to cookbook resistance factors for a light commercial vehicle.

In-Service Vehicle Testing Programme 2010-11

[Millbrook 2011]

Summary
This report contains test data and analysis from a programme carried out by Millbrook, an independent emissions testing laboratory, for the UK Department for Transport. The objectives included in-service testing of a range of vehicles to compare independently tested cycle emissions with the type approval values for each vehicle.

It should be noted that the vehicles tested were Euro 4 customer vehicles, and preference was given to vehicles with higher mileages (in the range of 15,000 to 100,000 kilometres). It should also be noted that the coast down terms used for these tests were provided by the manufacturers at the start of the tests, rather than being determined independently.

In summary Table 8 the column for CO_2 shows the actual tested cycle CO_2 as a percentage of the type approval value[3]. Summary Table 9 shows the percentage of vehicles tested by fuel type which were either over 100% of the type approved value (worse) or below 100% of the type approved value (better).

Table 8 Emission decisions (pass relating to meeting pollutant emission limits) and CO_2 emissions summary by vehicle model

		Emissions Decision	CO_2
Petrol Euro 4	Chevrolet Matiz	Pass	100.1%
	Fiat 500	Pass	100.4%
	Hyundai i10	Pass	105.8%
	Smart Fortwo	Pass	99.3%
Diesel Euro 4	Ford Mondeo	Pass	98.6%
	Honda FR-V	Pass	102.8%
	Jaguar X-Type	Test More	100.7%
	Kia Rio	Pass	111.6%
	Vauxhall Corsa	Test More	96.1%
	Vauxhall Vectra	Pass	94.0%

[3] Note that Emissions Decision results “Pass” and “Test More” refer to criteria emissions, not CO_2 emissions. Yellow in the CO_2 column means more than 104% of the type approval value (i.e. the 4% production / family tolerance).

Table 9 Summary of CO_2 results by fuel type

	% of Type Approval	CO_2
Petrol Euro 4	Under 100%	16.7%
	Over 100%	83.3%
Diesel Euro 4	Under 100%	62.5%
	Over 100%	37.5%

Conclusions
This report looks at in service measured CO_2 on the NEDC versus type approval values, using dynamometer settings as specified by the manufacturer for the type approval test. It shows a relatively close match between the independently measured values and the type approval figures, with some results being over, some under, and many close to 100% of the type approval value. For gasoline vehicles 16.7% were under, and 83.3% were over the type approval CO_2. For diesel vehicles 62.5% were below and 37.5% were above the type approval CO_2.

The report states that coast down curve data was provided by the manufacturers for these tests. Therefore it could be concluded that even though the testing was carried out by an independent laboratory, some flexibilities may have already been utilised in the measurement of this coast down data.

However, the mixed picture presented by Table 10, together with the fact that the CO_2 results in Table 9 are on average not significantly higher than 100% of the homologated values, indicates that for Euro 4 vehicles the use of flexibilities to minimise CO_2 emissions for homologation was not widespread, at least as far as flexibilities related to the Type I test procedure are concerned. The utilisation of flexibilities related to the coast down test does not become apparent in this report due to the use of manufacturer values for the rollerbench settings.

In-Service Vehicle Testing Programme 2009-10

[Millbrook 2010]

Summary
This report is very similar to “In-service vehicle testing programme 2010-11”. It contains test results for a similar objective and the same test processes were used. A summary of the results obtained are shown in Table 10.

Table 10 Emissions and CO_2 decisions summary by vehicle model

		Emissions Decision	CO_2
Petrol Euro 4	VW Touran	Pass	98.9%
	Ford Focus ST	Pass	107.4%
	Citroen C3	Pass	102.7%
	Honda Civic Hybrid	Pass	108.3%
Diesel Euro 4	Skoda Octavia	Pass	107.1%
	Jaguar X-Type	Test More	100.0%
	Volkswagen Golf	Pass	99.2%
	Toyota Yaris	Pass	102.1%
	Kia Rio	Test More	112.9%
	Honda FR-V	Test More	102.8%

Conclusions
The test data presented shows on average that diesel vehicles were 4% higher in CO_2 than their type approval values. The gasoline vehicles were on average 4.3% higher than their type approval values. A key statement in the report is that coast down curve data was provided by the manufacturers for these tests. Therefore it could be concluded that, even though the testing was carried out by an

independent laboratory, some flexibilities may have already been utilised in the measurement of this coast down data.

Effect of ambient temperature (15 °C - 28 °C) on CO_2 emissions from LDV over NEDC

[JRC 2009]

Summary

This is a report on the effect of ambient temperature on CO_2 measured over the NEDC test cycle. The following comments from the report state the limitations of the testing in that the same coast down settings were used for each ambient temperature test. Table 11 shows a matrix of the vehicles tested.

- "If the vehicle coast down data at different temperatures are not available, a pragmatic approach is to carry out the tests (between 15 °C and 28 °C) keeping constant the CD (Coast Down) settings used at 22 °C. A test at 15 °C will thus be characterized by a slightly higher resistance to progress than at 22 °C (due to the increased internal friction of the CD), which in part compensates for the lower coast down times of the vehicle at 15 °C compared to 22 °C. At 25 °C there is the opposite effect."

This statement infers that there is an effect on coast down terms (therefore cycle CO_2) of temperature due to increased rolling resistance.

Table 11 Vehicle test matrix

			No. of tests			
			15 °C	22 °C	25 °C	28 °C
Vehicle 1	M1-Gasoline 1200 cm3	Euro 4	2	2	2	
Vehicle 2	M1-FFV(G-E) DI 2000 cm3	Euro 5A	3	5		
Vehicle 3	M1-Gasoline 1368 cm3	Euro 5A	6	4	4	4
Vehicle 4	M1-Diesel 1248 cm3	Euro 5A	2	3	2	
Vehicle 5	N1-Diesel 2179 cm3	Euro 3	2	2	2	

Figure 7 shows the relationship derived from these tests to correlate ambient temperature (including 12 hour soak time) to a change in cycle CO_2.

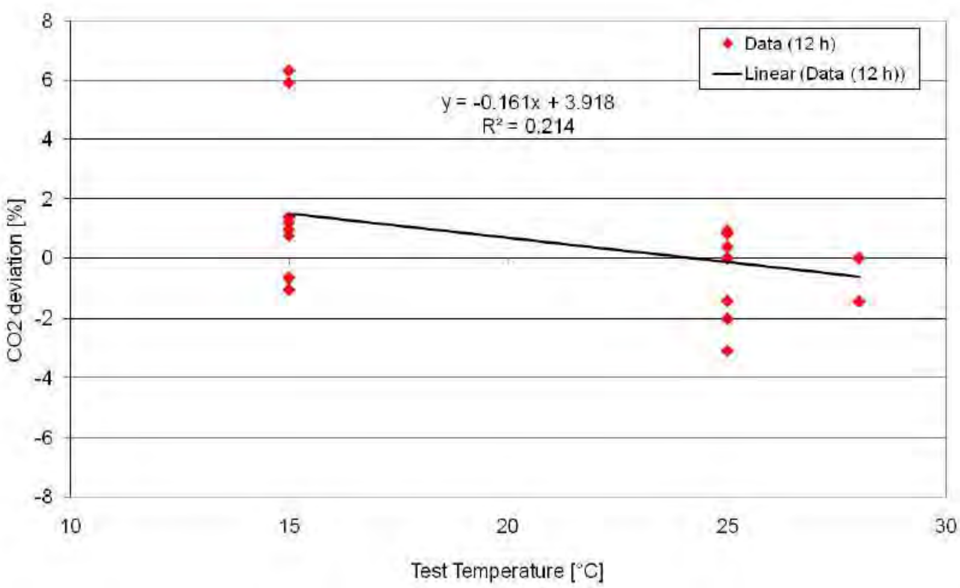

Figure 7 NEDC CO_2 deviation from test carried out at 22°C

Conclusions
The effect of soak temperature on CO_2 was investigated by testing a range of gasoline and diesel passenger cars and light goods vehicles, of engine size 1.2 – 2.2 litres, at different soak temperatures. An average relationship was found for the vehicles tested: 1°C rise in soak temperature = 0.161% reduction in CO_2 over the NEDC.

CO_2 and emission reduction by means of heat storage in the powertrain

[Burgin 2011]

Summary
This report investigates the effect of engine encapsulation on CO_2 emissions. The report concludes as follows:

- "Approximately 7K (Kelvin) higher temperatures measured in the powertrain after 12 hours cooling down can be expected of such a concept. Main target of heat storage in the powertrain is to reduce CO_2 emissions during engine restart due to elevated oil and coolant starting temperatures. Estimations based on measurements and calculations done on a C-segment diesel car resulted in a CO_2 reduction of about 1.5 percent in the NEDC cycle after 9 hours cooling down."

This data may help quantify the effect of test process variation, in relation to engine temperature, on cycle CO_2.

Conclusions
The report considers the effect of vehicle temperature on cycle CO_2, however it approaches the subject from the point of view of engine encapsulation to store heat energy. The data presented is of interest but does not differentiate sufficiently between temperature effects, and soak time effects to draw relevant numerical conclusions.

Customer related CO_2-reduction by selective heat supply during vehicle warm-up

[BMW 2007]

Summary
This report covers the effect of heat flow in different areas of the vehicle and the relationship to NEDC fuel consumption. It is a model based analysis and looks at the benefit in optimum heat distribution between engine oil, engine coolant, gearbox oil, and rear axle drive oil. Its findings include the following statement:

- "Based on ID-network transient model and its validation. The optimum fuel consumption reduction effect in the NEDC has been found when the heat was distributed equally between the gearbox and the rear axle drive."

This information is relevant to the literature review in that it provides information relating to temperature effects on CO_2 emissions (based on fuel consumption). This information is specific to different areas of the vehicle, and therefore may help understanding of any test process variation that results in differing heat distribution throughout the vehicle.

Conclusions
This report looks at the effect of heat distribution throughout the drivetrain, rather than average vehicle temperature. This is of significance when reviewing legislation relating to vehicle soak conditions. If one part of a vehicle is allowed to cool more slowly than other areas during the soak period it may be advantageous to know which area yields the greatest benefit. Temperature measurements are taken from coolant and engine oil only, not gearbox and axle components. The report concludes that increasing the temperature evenly between the gearbox and the rear axle drive gave the best improvement in CO_2, rather than biasing the heat retention towards one area.

Technical Guidelines for the preparation of applications for the approval of innovative technologies pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council (version: 11 July 2011)

[JRC 2011]

Summary

This report explains the methodology required to demonstrate CO_2 reduction benefit by the use of technologies that may not show a benefit on the standard NEDC test cycle.

This information is applicable in the sense that it helps quantify the benefit of running at different coolant temperatures. The document states that the cooling behaviour of a vehicle's engine after cut-off can be described mathematically by the following equation:

$$\boxed{T(t) = (T_O - T_A) \cdot e^{(-dt)} + T_A}$$

with:

$T(t)$: temperature over time [°C]

T_O: temperature of the operating engine [°C]

T_A: ambient temperature [°C]

d: decay constant [1/h]

The plot in Figure 8 is included, showing cool-down time variation. In this case it is due to an 'eco-innovation' such as engine encapsulation, but the calculations may also be useful in assessing the effect of temperature due to NEDC test process variation.

Input data:

- temperature of the operating engine (coolant): $\mathbf{T_O = 95\ °C}$
- mean ambient temperature (Chap. 5.8): $\mathbf{T_A = 14\ °C}$
- decay constant of baseline vehicle: $\mathbf{d_B = 0.5\ /h}$
- decay constant of eco-innovation (EI) vehicle: $\mathbf{d_E = 0.3\ /h}$
- CO_2 reduction factor at increased temperature (Chap. 5.9): **RFT = 0.17 % / K**
- parking time distribution (share of vehicle stops): **SVS** - see Chap. 5.10
- CO_2 type approval value: $\mathbf{TA_{CO2} = 130\ g/km}$

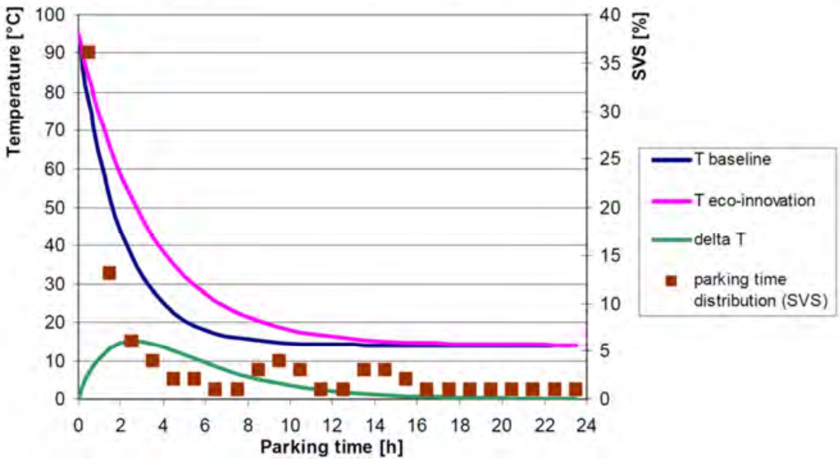

Figure 8 Cool down curves of baseline and eco-innovation technologies, temperature differences and parking time distribution

The relationship between starting temperature and CO_2 reduction is particularly useful:

- "The starting temperature of the engine influences the CO_2 emissions. A higher engine temperature reduces friction losses of the lubricant and moving parts. A percentage reduction factor of CO_2 emissions in relation to a temperature increase of the engine (temperature of coolant) can be given. This value refers to the NEDC including a cold start."

The value found is:

CO_2 reduction factor at increased temperature (RTF) [%/K] = 0.17

This value includes a security margin to cover differences between individual vehicle versions with different engine types and sizes and to cover accelerated cooling because of real-world wind effects. Although it has been determined for the engine temperature a similar effect is to be expected for CO_2 emissions as function of variations in the soak temperature.

Conclusions

This report gives a relationship to relate temperature increase to cycle CO_2 reduction. The relationship is needed because any technology that retains heat energy in an engine will not necessarily show a benefit on a standard NEDC test. This is due to the requirement that the engine must be within 2°C of the soak temperature at the start of the test. It is a not specific to any particular size or type of vehicle, it is a generic guideline. The relationship is: 1°C rise in temperature = 0.17% reduction in CO_2 over the NEDC

This relationship correlates well with the one described in the report: 'Effect of ambient temperature (15 °C-28 °C) on CO_2 emissions from LDV over NEDC'. It is a useful guideline to help assess the CO_2 benefit of any temperature related flexibilities in the legislation.

Fuel consumption and emissions of modern passenger cars

[TU Graz 2010]

Summary

This report looks at the variation over time in vehicle emissions, both on the NEDC test and under real world conditions. The report compares test results from vehicles tested on a variety of cycles, including the NEDC cycle, and compares measured results to type approval results. It also includes results that come from tests conducted with independently measured coast downs, rather than manufacturer specified coast down curves.

The report mentions one factor that may be contributing to the disparity in emissions reduction between type approval data, and real world data:

- "Due to a much lower spread for standard factory models in the emission behaviour the vehicles can be designed to be generally closer to the type approval limit values. Thus the fleet emissions in the NEDC were reduced to a smaller extent than the limit values."

This comment explains that although emissions limits have reduced over time, vehicle emissions have not reduced by the same factor, due to the manufacturing improvements that allow a smaller emissions margin to be used.

NEDC results are presented from seven diesel and two gasoline vehicles, using coast down terms measured as quoted below. Type approval numbers are quoted but measured results are presented as averages for the diesel / gasoline groups. Comparison of coast down data is not presented. Type approval values for the vehicles tested are shown in Table 12. Table 13 and Table 14 show averaged values for the same group of vehicles when tested independently using measured coast downs, split by fuel type.

Table 12 Type approval emission values of tested passenger cars

Marke	Fuel type	CO_2	CO	HC	NOx	HC+NOx	PM
		Type approval values [g/km]					
Audi A3 Sportback	Diesel	116	0.1808		0.1489	0.1729	0.0004
BMW 318d	Diesel	125	0.312		0.201	0.237	0.0001
Fiat Doblo 1.6l	Diesel	138	0.29		0.156	0.211	0.001
Opel Astra 1.7CDTI 59kW	Diesel	125	0.189		0.13	0.151	0.001
Peugeot 407 SW	Diesel	150	0.167		0.155	0.189	0.0002
VW Golf VI	Diesel	119	0.391		0.116	0.186	0.001
VW Passat Blue Motion	Diesel	129	0.236		0.123	0.151	0
Fiat Punto EVO	Gasoline	134	0.395	0.042	0.018		
Mazda 3 2.0i	Gasoline	159	0.433	0.048	0.01		0.002

Table 13 Average emission levels for tested diesel cars in the different test cycles

NEDC	HC	CO	NO_x	CO_2	FC	PM	PN
PreEURO 1	0.103	0.483	0.716	161.4	54.1	0.1163	
EURO 1	0.068	0.553	0.612	160.1	50.4	0.0747	
EURO 2	0.105	0.571	0.554	169.9	57.6	0.0483	
EURO 3	0.046	0.272	0.441	147.9	48.5	0.0256	
EURO 4	0.027	0.165	0.243	179.5	56.5	0.0082	
EURO 5	0.039	0.312	0.255	162.7	51.2	0.0018	1.459E+12

Table 14 Average emission levels for tested gasoline cars in the different test cycles

NEDC	HC	CO	NO_x	CO_2	FC	PM	PN
	[g/km]						[#/km]
PreEURO 1	0.798	5.316	1.312	170.1	62.2	0.116	
EURO 1	0.111	1.291	0.295	182.9	58.0	0.002	
EURO 2	0.179	1.093	0.209	190.5	59.7	0.003	
EURO 3	0.083	0.778	0.052	181.9	57.5	0.004	
EURO 4	0.050	0.421	0.028	182.0	56.7	0.001	
EURO 5	0.052	0.393	0.015	185.1	57.6	0.005	4.682E+12

Due to the averaging of the data in this report it is not possible to compare type approval values to independently tested values for individual vehicles. However, the following comments were made relating to this topic, referring to coast down terms in particular:

- “The cars were measured first in a coast down test. In a coast down test the driving resistance parameters, which have to be set later on the roller test bed, are measured by the deceleration of the vehicle from 120 km/h to 20 km/h. The tire inflation pressure was set according to manufacturer specifications. The tires were used as delivered by the dealer. All cars tested in this study had summer tires. The coast down tests were performed on a flat road in the north of Graz. The wind velocity was near to zero in all the tests, and the road condition was dry and clean. The driving resistance values measured should be representative of real world driving. However, the driving resistance values obtained most likely are higher than the values used in type approval due to the not optimized rolling resistance values of the tire-road surface combination.”
- “The driving resistance values were gained by coast down tests with the actual tires on a standard road for all EURO 5 cars while in the A300 db (ARTEMIS 300 database) most likely many vehicles were tested with type approval resistance values, which typically are clearly lower than the average resistance values on the road. Higher driving resistances increase also the NO_x emissions from diesel cars in the test cycle due to the higher engine work.”

The following comments were also made regarding the use of smaller engineering margins. Improvements in manufacturing reduce the spread of emissions results, allowing manufacturers to utilise smaller engineering margins, the end result being that a lower legal limit can be met, even in COP (Conformity of Production) testing, without reducing the emissions of the type approval test vehicle:

- "The distance to the limit values can be smaller for modern vehicles due to smaller spreads for standard factory models and thus less risk to exceed the limit values in the COP tests."

Conclusions
This report looks at vehicles tested using measured coast downs (rather than manufacturer provided coast downs) across the range of emissions levels from pre-Euro 1 to Euro 5. It provides some commentary on techniques used to measure the coast downs, and possible differences to manufacturers own measurements as follows:

- "Many vehicles were tested with type approval resistance values, which typically are clearly lower than the average resistance values on the road."
- "The driving resistance values measured should be representative of real world driving. However, the driving resistance values obtained most likely are higher than the values used in type approval due to the not optimized rolling resistance values of the tire-road surface combination."

It also comments on the use of smaller engineering margins to regulated emissions limits, due to improved manufacturing techniques.

Pilotprojekt zur Relevantanalyse von Einflussfaktoren bei der Ermittlung der CO_2-Emissionen und des Kraftstoffverbrauchs im Rahmen der Typgenehmigung von PKW

[TÜV Nord 2010a]

Summary
In this report an analysis is performed on the relevance of different factors and flexibilities that influence the CO_2 emissions and the fuel consumption during a type approval test. At the end different possibilities for minimizing the gap between type approval procedure and real world drive emissions are presented. In order to achieve the last referred output, which is relevant as an input for the on-going global discussion on WLTP, several type approval parameters and tolerances were evaluated.

Approach
The approach followed in this report considers initially the following formula for the fuel consumption:

$$B_e = \frac{\int b_e \cdot \frac{1}{\eta_{ü}} \left[m \cdot f \cdot g \cdot cos\alpha + \frac{\rho}{2} \cdot c_w \cdot A \cdot v^2 + m(a(t) + g \cdot sin\alpha) \right] \cdot v(t) \cdot dt}{\int v(t) \cdot dt}$$

where:

B_e	Consumption [g/m]	ρ	Specific weight $[kg/m^3]$
$\eta_{ü}$	Driveline efficiency	c_w	Air resistance factor
m	Vehicle weight [kg]	A	Front vehicle area $[m^2]$
f	Rolling resistance factor	$v(t)$	Velocity $[m/s]$
g	Gravitational acceleration [m/s^2]	a(t)	Acceleration $[m/s^2]$
α	Pitch angle [°]	t	Time $[s]$
b_e	Specific fuel consumption of the motor [g/kWh]		

Test cycle comparison
An initial comparison for three vehicles, each one with a different engine type and market segment, indicates non convergent fuel consumption values between the following test cycles:

- NEDC performed by OEM;
- NEDC / UDC / EUDC;
- CADC (Urban; Road; Motorway).

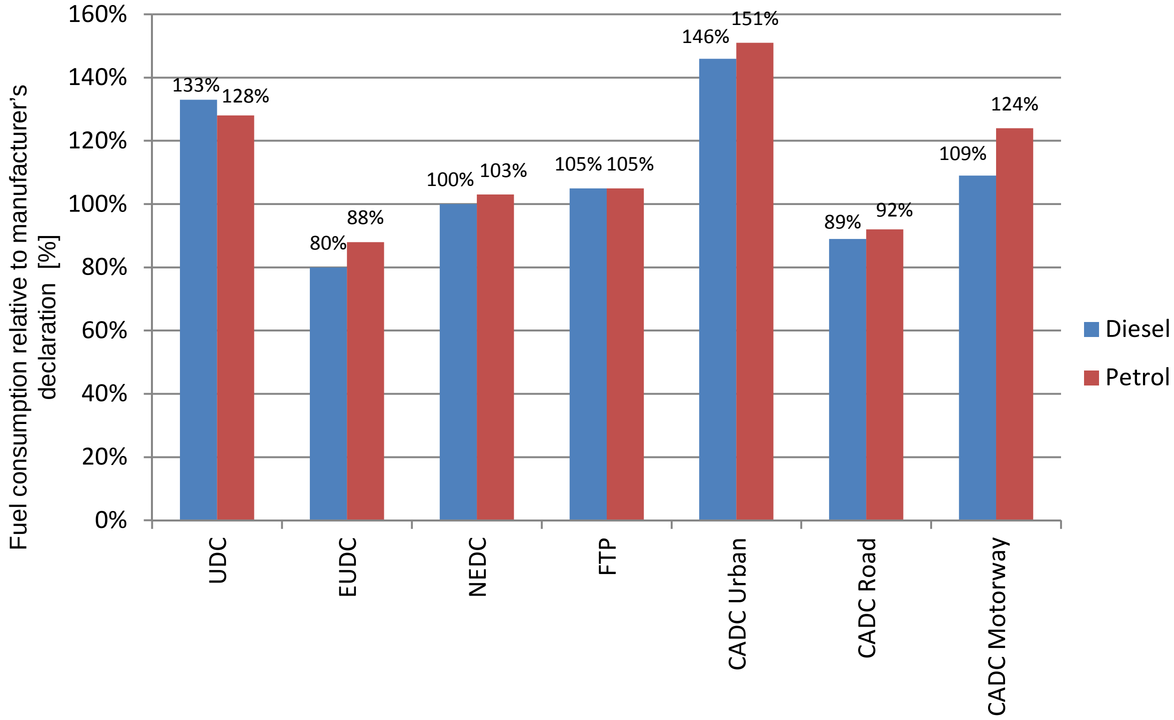

Figure 9 Variation of fuel consumption between different test cycles (UDC = Urban Drive Cycle - EUDC = Extra Urban Driving Cycle - NEDC = New European Driving Cycle – FTP = Federal Test Procedure - CADC = Common Artemis Driving Cycle

As is indicated on Figure 9 these values are contained in a range from -20% (EUDC ; petrol engine) to +50% (CADC Urban ; Diesel). It is difficult to fully reproduce the real driving behaviour in a test cycle but this investigation suggests that a broader coverage of the engine's operation points (dependent of the gear transmission factor for a given velocity) could be an important asset to minimize this difference. Another approach to achieve this objective is to introduce the cold start in other test cycle stretches (inner city, rural and motorway).

The vehicle speed tolerance range is introduced in the test cycle to meet different test driving situations. Vehicles have different dynamic response behaviours and therefore a standard test cycle must contain a certain band of tolerance. Actually this includes a difference of $\pm$ 2 km/h and $\pm$ 1 sec, which can influence CO_2 emissions for a maximum of 4%. Experienced test drivers are able to run the emission test within the band of tolerance with minimum CO_2 emissions.

Gear switching points

The power of a vehicle is dependent on torque and engine rotational speed. These two factors are dependent on the gear ratio and can so be optimized through this parameter. For automatic gears the manufacturer has the possibility to define the optimal working ratio. For manual gears, the table (included in council directive 70/220/EEC) indicating the gear change points (as function of vehicle speed) is out of date and doesn't reflect the new engine developments where lower rotational speeds provide a higher torque. The reduction in CO_2 emission measurements can reach up 20% in city driving and 10% in rural driving. The use of a new table where the gear switching points are presented in function of vehicle mass, power demand, nominal rotational speed and idling speed is a proposal in this publication. For the automatic gears the "default" driving mode should be used or, if this mode doesn't exist, the measurements should be made using the highest and lower emission modes.

The choice of a vehicle inside the various types of a model family follows the worst-case criteria (aerodynamics, moment inertia and weight). In fact the actual weight criteria excludes the additional weight of some auxiliary equipment that imply higher CO_2 emissions and fuel consumption. This way the test should include the worse CO_2 emission and fuel consumption equipment combination (worst case scenario) and there should be a possibility for the manufacturers to indicate for each auxiliary equipment the imbedded consequence in fuel consumption and CO_2 emission.

Vehicle driving resistance
The vehicle driving resistance can be influenced by the friction between wheels and rolls and in the powertrain. Here this report indicates through two examples that the real rolling resistance is much higher in comparison with the one ideally used for a given vehicle. The use of larger tires can represent an increase of 25% in driving resistance (at 20 km/h), and in the NEDC can lead to a CO_2 emission increase of 6%. Also inside the same tire class, the choice of flat tires or winter tires can represent an increase of 12.9% in CO_2 emissions (at 120 km/h) and 1.4% in the NEDC. The increase of tire pressure from 2.2 bar to 3.3 bar can also include (at 120 km/h) a reduction of 12.7% in air resistance and a 3.1% CO_2 emission reduction on the NEDC. Globally, the investigation indicates that the total driving resistance can be reduced by 12.7%, resulting in 1.4% CO_2 emission reduction (NEDC approach), if the tire pressure is increased from 2.2 to 3.6 bar. The wheel alignment have a tolerance of 10', which can represent an increase of 0.2% in the total driving resistance. Here the actual regulations only consider a 10' angle change in the front axis wheels, instead of considering the four vehicle wheels. As for the angle change, the other parameters should consider a worst case scenario: tire dimension, tire pressure, road friction and rolling periods in a cycle. In total these tolerances can represent a variation of $\pm$ 20% in the CO_2 emissions.

Chassis dynamometer vehicle inertia setting
The current level setting for the inertia moment criteria selects a given vehicle in ranges of 110 – 120 kg for the reference weight. This report indicates an average increase of 5% in the CO_2 emissions, 3.2 g/km for diesel and 3.4 g/km for petrol, and a fuel consumption increase of 0.12 l/100 km (diesel) and 0.15 l/100 km (petrol) in the NEDC, for each higher inertia class. Currently it is technically possible to reduce the interval (study proposal: 125 lbs / 56,7 kg), allowing a more realistic approach. The inertia moment interval doesn't consider higher weight vehicles (from an empty weight of 2355 kg), allowing high differences (not quantified in this report) between test cycle emissions and real drive emissions for very heavy vehicles.

Chassis dynamometer vehicle resistance setting
The current tolerance for the driving resistance during the type approval test is set at $\pm$ 5% for upper vehicle speeds (120 km/h – 40 km/h) and $\pm$ 10% for lower speeds (under 20 km/h). The friction of the inertias of the powertrain is not considered in the resistance force calculation. In the US and Japan this issue is considered and a supplementary factor in the vehicle weight is introduced (USA + 3%; Japan + 3.5 %). This study compares the results for the driving resistance force with the theoretical values where it finds a high difference that could be corrected by reducing the existing tolerance margin.

Vehicle soak and room temperature chassis dynamometer
The surrounding temperature tolerance is situated between 20°C and 30°C, which can correspond to a 4% margin of CO_2 emissions. In order to introduce a more realistic approach this investigation suggests a conditioning time of 6 hours before the start of the test and an oil and water temperature of 22°C with a tolerance of +3°C to -2°C. This report also suggest that vehicles of class Euro5 are less sensitive to temperature changes, due to recent optimization in frictional losses and less sensitivity of oil towards temperature changes.

Chassis dynamometer wind simulator
The report also indicates that there isn't any influence on the CO_2 emissions or fuel consumption related to the assumed wind speed. Investigation performed in the context of this report showed that a wind speed that is proportional to the vehicle speed or a constant value of 21.6 km/h result in the same CO_2 emissions and fuel consumption.

Administrative band of tolerance
As an improvement of existing regulation, this publication suggests that the 4% tolerance that can be used by OEM should be reduced so that the type approval value is the same as the measured value by the OEM.

Auxiliaries
The use of auxiliary equipment can also have an effect on a vehicle's CO_2 emissions and fuel consumption. The biggest consumer can be the air conditioning equipment which alone can lead to an increase between +5 and +50% in CO_2 emissions and fuel consumption (NEDC). Also for the use of other equipment such as radio, day driving lights or electrical heating devices an increase of vehicle CO_2 emissions and fuel consumption was measured. The publication suggests the inclusion of permanently switched on devices (example: day driving lights) during test measurements but advises against the inclusion of equipment that is manually switched on (due to the reproducibility criteria). It also indicates that OEMs should present to the clients the effect in fuel consumption and CO_2 emissions related to the use of each of these auxiliary devices.

Battery state of charge of a vehicle with combustion engine
This report also indicates that selective charging of the starter battery during the NEDC test may result in a decrease of 2,4% in vehicle CO_2 emissions and fuel consumption (NEDC). This way it suggests that battery should be fully loaded before the start of the measurements. The eventual charge balance of the battery during the test should then be incorporated in the final CO_2 emissions and fuel consumption (or electrical in the case of hybrid vehicles).

Conclusions
The investigation conducted by TÜV Nord evaluated a range of parameters that are present in a type approval test procedure. The conclusions of this report are an important asset for the understanding of the existing difference between the OEM indicated values and the field measurement (i.e. independent NEDC testing) results of CO_2 emissions and fuel consumption. As can be verified in Figure 10, this difference has increased for the Euro 5 vehicles. This way the identification of the existing flexibilities and the quantification of its impact was performed in this report.

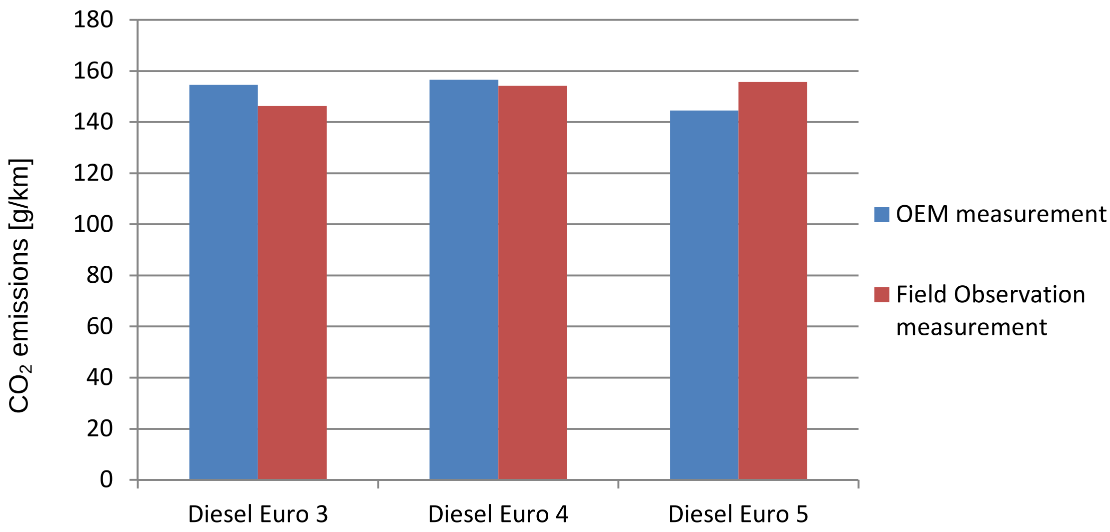

Figure 10 Average CO_2 emissions of Diesel vehicles (Type Approval value versus independent testing)

In this report the different parameters are analysed and their impact on CO_2 emissions and fuel consumption is measured. These impacts and main conclusions of the report are summarised in Table 15.

It should be noted that the magnitudes of some of the tested variations are greater than the allowable tolerances for the type approval procedure. In these cases it is recognised that the measured variations in CO_2 emissions do not correspond to the anticipated magnitude of variations due to available test flexibilities. In the next chapter the correlations found in this study have been used as one of the inputs for assessing the impact of variations within allowable bandwidths.

Table 15 Impact of different parameters on CO_2 emissions.

Parameter	Conditions / Tolerances	Impact CO_2 emissions / fuel consumption	Suggestion
NEDC	Cycle construction conditions	[-20;50] % variation	- Broader coverage of the engine working points; - Cold start introduction in other test cycle stretches; - Review length of the rolling sections.
Tolerance range	Variation of ± 2 km/h and ± 1 sec from the nominal value curve	± 4%	Minimizing/eliminating tolerance
Gear switching	Gear switching point	-20% for city driving -10% for rural driving	- Manual gears: New table with gear switching point values that can include vehicle mass, power demand, nominal rotational speed and idling speed; - Automatic gears: Use of default mode or worst case mode (in fuel consumption and CO_2 emissions).
Test vehicle	- Worst case criteria; - Auxiliary equipment weight is not included.	Not defined	- Inclusion of the emissions and consumption impact of each of the auxiliary devices; - Auxiliary equipment weight should be considered in the worst case scenario approach.
Driving resistance	I. Tyres: pressure, type and size II. Wheels angle III. Road friction IV. Rolling periods inside the cycle V. Driving resistance force tolerance at the chassis dynamometer: ± 5% for upper vehicles speeds (120 km/h – 40 km/h) and ± 10% for lower speeds (under 20 km/h) VI. Friction of the rotational weights of the powertrain not considered.	I, II, III and IV: ± 20% V: +5% VI: not defined	- Follow the worst case scenario approach; - Reduce the tolerance at the chassis dynamometer; - Adapt the introduced vehicle weight, considering the friction of the rotational weights.
Inertia Moment weight	- Gradation of the vehicle reference weight for each 110 – 120 kg - Vehicles with an empty weight higher than 2355 kg aren't considered	± 5% between each gradation	- Reduction of the gradation to 56.7 kg; - Introduction of a gradation for vehicles with an empty weight higher than 2355 kg.
Temperature	25°C±5°C	± 2%	- Conditioning time of the vehicle for six hours before the start of the test; - Oil and water temperature at 22°C, with a tolerance of +3°C -2°C.

Parameter	Conditions / Tolerances	Impact CO_2 emissions / fuel consumption	Suggestion
OEM indication	Test value must not be 4% higher than the indicated by OEM.	Until 4%	Tolerance elimination
Auxiliary equipment	Utilization dependent on user (except, as an example, day driving lights that are permanently switched on)	Airco: +5 and +50% Other equipment has lower impact	- Inclusion of permanently switched on devices during test measurements; - Presentation to the clients of the effect on fuel consumption and CO_2 emissions of the use of each of these auxiliary devices.
Starter battery	Usually fully charged	Up to +30% when battery is charged during test	- Battery should be fully charged before the start of the measurements; - Change of battery state-of-charge during test should be incorporated in the final CO_2 emissions and fuel/electrical consumption figure.

The previously identified flexibilities provide us a broad image for the possible root-causes of the difference identified in Table 15. An analysis should not consider a mere sum of all the quantified impact parameters but an individual approach to the factors that are more closely related to real behaviour driving and worst case scenarios.

For the real driving emissions one can consider the cycle construction as one of the most broadly ranged variables, where its included tolerance should be eliminated. Also the flexibilities included in the driving resistance factors should be evaluated by introducing worst case scenarios and evaluating chassis dynamometers definitions.

The choice of a vehicle should obey to the worst case scenario inside a vehicle model family (including the selection of auxiliary equipment). Regarding the vehicle properties there is a need to review out of date assumptions like the manual gear switching points and the gradation range for the moment inertia weight. At the auxiliary equipment side, specific measurements should be introduced for assessing the impact of each of the devices, directly through energy use or indirectly through added weight, on the vehicle fuel consumption and CO_2 emissions.

On the side of the regulations, Table 15 indicates clearly that a reinforcement of monitoring of real world emissions is a need. It is also concluded that the pre-defined emission and consumption margin of 4% given to the OEM should be eliminated. Instead, the battery state-of-charge balance should be incorporated in the final consumption and emission balance.

Future development of the EU Directive for measuring the CO_2 emissions of passenger cars – investigation of the influence of different parameters and the improvement of measurement accuracy

[TÜV Nord 2010b]

Summary
This report investigates the effects of various different factors on vehicle CO_2 emissions, based on the type approval NEDC test cycle. The study includes test data from different vehicles, with adjustments made to each parameter under consideration. The parameters considered are the following:

- variation of the inertia mass
- variation of the driving resistance on the dynamometer
- influence of the driver, by using the tolerances in the driving cycle

- preparation of the test vehicle
- optimized measurement
- variation in gear shifting
- automatic start-stop function
- starting test with partially discharged starter battery (“low battery”)

A summary of test results is shown in Table 16 arranged by vehicle and adjustment parameter. The values in the table are percentage variations from a baseline test result CO_2 g/km in ‘as received’ form. I.e. the baseline test is performed with an in-use vehicle. The results are further split by phase as follows, NEDC - total drive cycle result, EUDC - extra urban portion of the cycle, UDC – urban portion of the cycle:

Table 16 Detailed vehicle test results presented as percentage CO_2 deviation from a baseline test

Measurement	Deviation of the CO_2 emissions from the basic measurement [%]																	
	Petrol vehicles									Diesel vehicles								
	1			2			3			4			5			6		
	UDC	EUDC	**NEDC**	UDC	EUDC	**NEDC**	UDC	EUDC	**NEDC**	UDC	EUDC	**NEDC**	UDC	EUDC	**NEDC**	UDC	EUDC	**NEDC**
Manufacturer's declared values	-8.1	-3.4	**-6.1**	-2.1	-1.1	**-1.7**	-18.0	-7.0	**-12.6**	+3.6	-4.4	**-0.9**	-16.8	-10.1	**-13.1**	-11.8	-7.3	**-9.9**
Increased inertia mass	-	-	**-**	-0.4	+0.9	**+0.4**	+0.6	+3.3	**+2.0**	+1.5	+3.9	**+2.8**	-1.6	+0.3	**-0.6**	+6.5	+11.7	**+9.3**
Reduced load	-	-	**-**	-1.9	-4.9	**-3.4**	-0.7	-3.3	**-2.0**	-5.1	-6.0	**-5.6**	-8.3	-13.1	**-10.8**	-2.5	-6.5	**-4.6**
Influence of the driver	-0.7	0.0	**-0.1**	+0.6	-0.6	**-0.5**	+0.9	-1.2	**-0.8**	-0.1	-1.8	**-1.5**	-0.1	-0.3	**-0.6**	+1.2	-3.0	**-1.6**
Conditioning to 28°C	+0.7	+0.8	**+0.7**	-9.3	+0.2	**-4.3**	-3.7	-1.8	**-2.7**	-3.8	-0.3	**-1.8**	-6.4	-2.4	**-4.3**	-1.1	-0.5	**-0.7**
Optimized measurement	-	-	**-**	-	-	**-**	-3.0	-2.6	**-3.5**	-2.4	-6.8	**-5.3**	-16.1	-16.0	**-16.5**	-5.5	-8.7	**-7.7**
Variation of gear shifting	23.9 *	11.2 *	**17.4 ***	-22.6	-3.6	**-12.7**	-23.6	-6.5	**-15.1**	-13.1	-1.4	**-6.6**	-17.4	-4.5	**-10.7**	-16.6	-2.5	**-9.3**
Start-stop system deactivated	-	-	**-**	-	-	**-**	+2.8	-1.1	**+0.9**	-	-	**-**	+6.6	+1.1	**+3.8**	-	-	**-**
Low battery	-	-	**-**	-	-	**-**	+35.1	+8.0	**+21.7**	+14.9	+3.6	**+8.6**	+46.7	+14.1	**+29.5**	+30.8	+4.8	**+17.0**

Conclusions also include recommendations for changes to the regulations to better control variation of these parameters.

Additional points to note are the wide variation between vehicles in results relative to the baseline test result. This demonstrates that quantifying CO_2 reduction is very specific to the vehicle under consideration.

Detailed test results are shown in the appendices.

Conclusions

This report concludes the following:

- “The results of this programme clearly show that optimized CO_2 emissions and fuel consumption figures can be obtained in type approval testing if the vehicle is appropriately prepared and the conditions for measurement are appropriately selected. The variation of different parameters showed that CO_2 reductions of the order of 20% can be reached by optimized type approval testing. In this context, parameters such as influences on the determination of driving resistance measurement on the test circuit, optimized gear shift points, and additional emissions caused by ancillaries have not even been taken into consideration.”

A summary table of the potential CO_2 reduction available from each parameter is reported in Table 17 below.

Table 17 Summary of the vehicle test results presented as percentage CO_2 deviation from a baseline test resulting from a specified change in test conditions

Parameter	Measuring conditions	Effect on CO_2 emissions
Inertia mass	Increase of about 2 classes in inertia mass	Increase of up to 10%
Driving resistance	Reduction in the load setting of about 20% at 20 km/h and about 10% from 40 km/h to 120 km/h	Reduction of up to 11%
Influence of the driver	Use of the tolerances on the driving curve	Increase/reduction of up to 2%
Ambient conditions	Conditioning of the vehicle to 28°C for at least 6 hours before starting the test	Reduction of up to 4%
Optimized measurement	Inertia mass in accordance with type approval conditions, lower load setting, use of the tolerances on the driving curve, conditioning to 28°C, gear shifting in accordance with the Directive, start-stop system activated, starter battery fully charged	Reduction of up to 17%
Gear shifting	Optimized gear shift points	Reduction of up to15%
Start-stop system	Deactivating the start-stop system	Increase of up to 4%
Low battery	Battery charging during tests	Increase of up to 30%

Road Load Determination – Vehicle Preparation

[STA/T&E 2011]

Summary
This report specifically looks at the procedure for ‘road load determination’. This is also referred to as the ‘coast down measurement’. It is the process by which the road loads are determined, which will then be matched by the dynamometer settings for the NEDC test. This is a sub-topic of the wider topic of developing a new world-harmonized light-duty test procedure (WLTP).

The report aims to help explain the apparent differences between type approval and independently measured CO_2 results, as described here:

- “During the expert meeting in Brussels on 5-6 October 2010 it became apparent that the current road load test procedure has a number of omissions that may result in influencing the test results. As a consequence, the road load of production vehicles may be higher in comparison to the road load of the homologation vehicle. This has a direct effect on the fuel consumption and CO_2 emissions of a given vehicle. Some first exploratory tests have shown that CO_2 figures may be 10% too optimistic, which is one of the reasons that the officially declared fuel consumption by a manufacturer does not match the customer’s experience.”

The specific aims of the study are outlined below:

- “This investigation sums up the “flexibilities” in the ISO 10521 test procedure as well as the tolerances that may be stretched to the most favourable end.”

The following statement compares the effect of using independently measured coast downs to those used in type approval:

- “Over the NEDC test, the difference in CO_2 emissions between type approval value and the measurement with real-life road load was 17% on average, ranging from 9 to 24%. The difference was explained to be the result of higher driving resistance due to optimization of the

tire and road surface combination, tire pressure and beneficial ambient conditions." ('Road Load Determination – Vehicle Preparation').
- "A road load verification program at EPA that dates back to 1984 revealed that the differences in coast down times measured on 24 different LD vehicles and LD trucks amounted to 7% on average [1]. The range of shortfalls was from almost 0 up to almost 15%."
- "A recent study performed by TÜV Nord for UBA showed the effect on CO_2 measured over the NEDC test cycle for several test parameters [2]. They showed that if the maximum allowed tolerance in road load deviation is applied (-20% at 20 km/h and -10% from 40 to 120 km/h) the CO_2 emission is reduced by 5.3% on average in a range from 2 to 11% for a total number of 5 LD vehicles."

The report analyses the wording of the current regulations compared with other possible wording. It furthermore makes recommendations on how legislation can be improved in order to reduce some of the more significant flexibilities currently available.

Conclusions
This report specifically looks at the procedure for 'road load determination'. It aims to help explain the apparent differences between type approval and independently measured CO_2 results. The flexibilities identified are as follows:
- wheel alignment
- adjustment of brakes
- ambient conditions
- tyre wear
- tyre pressure
- tyre choice
- test track
- vehicle weight
- vehicle body
- transmission

Key values identified include test results of various studies, quoted in this report. An average reduction in CO_2 on the NEDC test of 5.3% is observed when utilising the full range of tolerances of the road load determination. It also quantifies the difference between type approval CO_2 and measured CO_2 using independently measured coast downs as 17% on average, indicating that flexibilities in the test procedure overall may have a significant impact on measured CO_2 emissions.

The report makes the following recommendation on how legislation can be improved in order to remove some of the larger flexibilities currently available:
- "To guarantee the best representative results of road load tests, it is recommended to include road load tests on a production vehicle in the CoP or in-use conformity tests and demand that the road load of the production vehicle is the same or lower than measured on the earlier tested vehicle for homologation (feed-back approach)."

Development of a Worldwide Harmonized Light Vehicles Test Procedure (WLTP) ICCT contribution No. 3 (focus on inertia classes)

[ICCT 2011]

Summary
This report is also written in the context of developing the worldwide harmonized light vehicles test procedure (WLTP), this time focussing on inertia classes.

Currently vehicles are grouped into different inertia classes based on the vehicle reference mass. These classes are made up of discrete steps, typically 110kg apart. The report analyses actual vehicle data to show how type approval reference masses often fall just under the threshold of an inertia class. It analyses the impact on CO_2 of shifting one inertia class up or down:
- "Figure 5 also illustrates that most of the EU inertia steps represent a range in CO_2 emissions of about 4-7 g/km."

The report further concludes:

- "This blurriness with respect to CO_2 is one of the reasons for the limited accurateness of CO_2 testing, and the resulting poor information for consumers under the current inertia class based system."

Conclusions

This report is written in the context of developing the worldwide harmonized light vehicles test procedure (WLTP), this time focussing on inertia classes. It states that one inertia class represents a CO_2 range of 4-7g/km. A stepless inertia class system is proposed in order to resolve the artificial effect of grouping vehicles together at the high end of each inertia class.

Parameterisation of fuel consumption and CO_2 emissions of passenger cars and light commercial vehicles for modelling purposes

[LAT 2011]

Summary

This report is based on work carried out to parameterise a simulation tool, in order to then make predictions of real world fuel economy (hence CO_2). The report includes the following comment relating to data collected as part of the investigation:

- "There were significant differences in the definition of in-use fuel consumption between the various sources, including the measurement procedure used (road or chassis dynamometer), mix of driving situations tested, vehicle mix in the sample, etc. This leads to a significant variation of the average in-use consumption values reported by each source."

The subject of real world fuel economy is covered in the report in detail, however there is limited information regarding flexibilities within current legislation. Nevertheless the study contains the following observations on this issue:

- "Although this is not directly an outcome of the study, this is an important conclusion from relevant work that should be re-iterated. Type-approval tests of fuel consumption are conducted on chassis dynamometer using resistance settings provided by the manufacturer. These settings are derived from coast-down vehicle tests. It appears that resistance of actual vehicles measured by independent test centres are higher than the ones submitted by the manufacturers for the type-approval tests. There are several reasons why this can be happening, i.e. manufacturers test vehicles in ideal conditions (tarmac condition, weather, vehicle run-in, configuration such as tyre dimensions, trained drivers to perform the test, etc.). Unfortunately, type-approval resistance settings are confidential."
- "Using of real vehicle resistances instead of type-approval resistances has been shown to lead to fuel consumption increases of up to 17%. This is even beyond the in-use over type-approval fuel consumption ratio developed in this report. As a minimum impact this means that maybe the NEDC is not a bad (underpowered) cycle to report fuel consumption but that maybe the actual test is an idealistic one. It can be recommended that vehicle resistance settings become public together with the type-approval fuel consumption value, so that independent authorities can check both whether these represent reality and whether the type-approval test has been conducted as required."

Conclusions

The report concludes the following:

- "However, all sources report higher in-use fuel consumption than the type approval values, mostly in the range from 10% to 15% for petrol cars and 12% to 20% for diesel cars."

It furthermore states that differences seen in independent testing over real-world derived test cycles generally do not include possible impacts of optimised coast-down values.

Use of a vehicle-modelling tool for predicting CO_2 emissions in the framework of European regulations for light goods vehicles

[LAT/TNO 2007]

Summary
This report presents results of simulation work carried out to understand how different parameters affect measured CO_2 on the NEDC test. The simulation results are compared to real test data for validation purposes. This test data is useful to help estimate how each parameter affects the measured CO_2 result.

Table 18 shows the simulation-based results which include variations of the main parameters such as mass, drag, and gear ratios. Percentage change in fuel consumption is shown for each vehicle studied:

Table 18 Effect of mass, air drag, and gear ratio on CO_2 compared to a baseline for each vehicle simulated

Model	Base gear ratios				Gear ratios × 108% (shorter gears)			
	FC base (l 100 km^{-1})	Mass +220 kg	Air drag 115%	Combined	108% base (deviation from base)	Mass +220 kg	Air drag 115%	Combined
Golf	4.82	5.4%	2.6%	8.1%	4.6%	5.4%	2.5%	12.6%
Berlingo	5.87	4.4%	3.5%	8.0%	5.9%	4.4%	3.5%	13.8%
Caddy	5.62	3.3%	3.3%	6.6%	5.0%	3.3%	3.1%	11.4%
Daily	9.38	2.1%	3.7%	5.7%	9.4%	2.2%	4.0%	15.5%
Ducato	9.82	2.1%	3.6%	5.6%	8.5%	2.2%	3.9%	14.4%
Partner	5.90	3.0%	3.4%	6.4%	5.5%	3.0%	3.3%	11.9%
Boxer (2200cc)	9.27	2.6%	4.4%	6.9%	8.6%	2.5%	3.8%	14.8%
Transporter	7.44	2.4%	3.7%	6.3%	3.9%	2.7%	3.9%	10.3%
Boxer (2800cc)	9.49	1.9%	3.4%	5.4%	10.1%	2.0%	3.4%	15.5%
Average	-	3.0%	3.5%	6.5%	6.8%	3.1%	3.5%	13.4%

Conclusions
For the range of light goods vehicles assessed the average increase in fuel consumption associated with an increase in mass of two inertia classes was 3%. The average increase in fuel consumption associated with an increase in aerodynamic drag of 15% was 3.5%. The average increase in fuel consumption associated with 8% shorter gear ratios was 6.8%.

In addition, it can be seen that applying the same modifications to both inertia and drag (2 inertia classes, 15% increase in drag), after applying the modified gear ratios, does not result in identical percentage fuel consumption increase. This indicates that adding together percentage effects of individual tests is not exactly the same as testing all effects at the same time.

On the way to 130g CO_2/km — Estimating the future characteristics of the average European passenger car

[LAT 2010]

Summary
This report assesses which vehicle characteristics affect fuel consumption, and aims to quantify the changes required in vehicle technologies in order to bring real world fuel economy in line with type approval declared values. Although this subject itself is outside the scope of this literature review, some of the data presented is of use in quantifying CO_2 reduction potential from various changes in key parameters. This data is simulation based.

Relevant plots are shown below correlating each key parameter with resultant percentage change in NEDC CO_2:

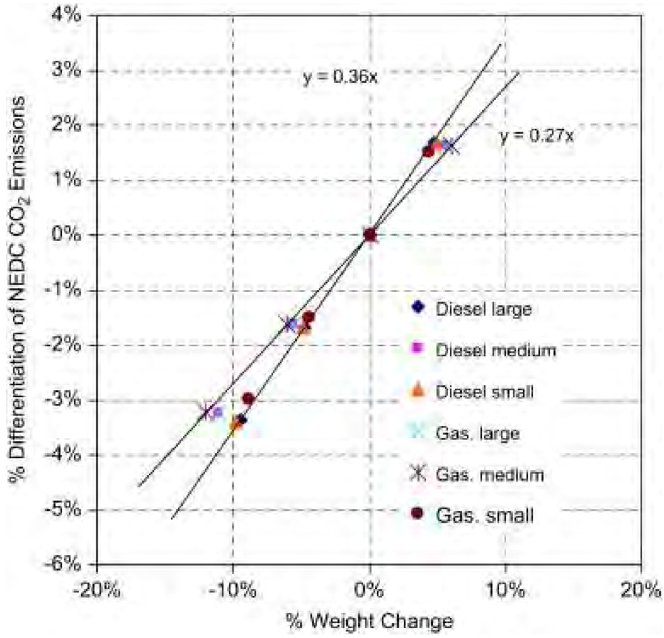

Figure 11 Effect of vehicle weight on NEDC CO_2 emissions for a range of vehicle categories. Trend-lines correspond to the vehicles affected the most and the least by weight change.

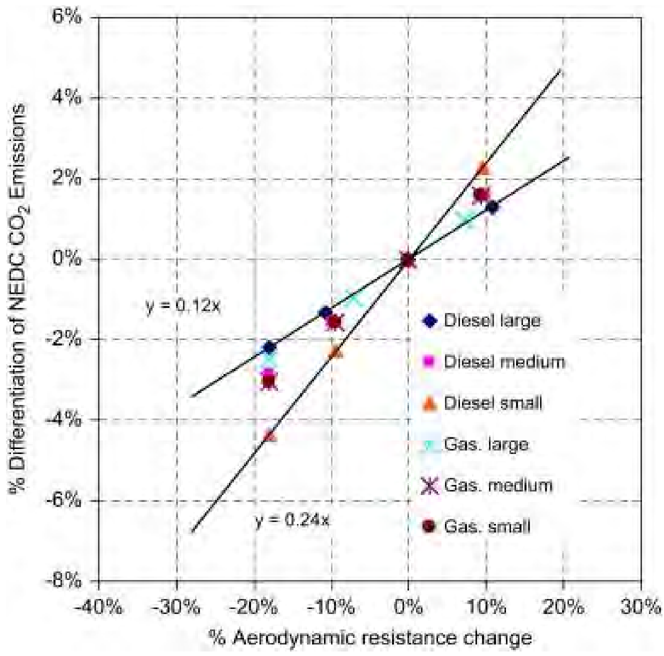

Figure 12 Effect of aerodynamic resistance on NEDC CO_2 emissions for a range of vehicle categories

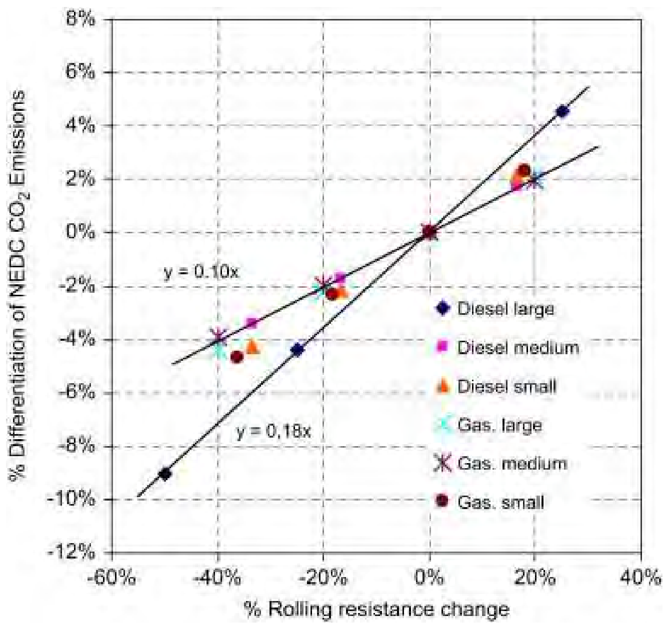

Figure 13 Effect of rolling resistance on NEDC CO_2 emissions for a range of vehicle categories

Conclusions

This report concludes the following regarding effects of each parameter on NEDC CO_2:

- A reduction in vehicle weight of 10% yields a reduction in CO_2 of approximately 3.1%;
- A reduction in aerodynamic drag of 10% yields a reduction in CO_2 of approximately 1.8%;
- A reduction in rolling resistance of 20% yields a reduction in CO_2 of approximately 2.8%.

These figures are averaged across a range of vehicles of different sizes, both diesel and gasoline.

Road load determination of passenger cars

[TNO 2012b]

In a project for the Dutch Ministry of Infrastructure and The Environment and the European Climate Foundation TNO has independently measured coast-down curves of 8 passenger cars, and has carried out CO_2 emission tests over the NEDC using both the independently measured coast down curve and the curve as used by the manufacturer for the Type Approval testing.

Road load curves of six modern passenger car models (Euro 5/Euro 6) and two older variants (Euro 4) of the same models have been determined on test tracks in The Netherlands and Belgium. The results have been compared to the road load settings used for Type Approval, (as specified by the manufacturer). The results, expressed as Road Load Ratios, are presented in Figure 14.

The road loads measured under realistic conditions, representative for in-use vehicles driven on actual roads, are found to be substantially higher than the Type Approval road loads. At high speeds the road load differences are up to 30%. At low speeds, with very low road load forces, these differences are on average up to 70%.

For the older models the difference between the road load used in Type Approval and the independently determined road load is only half of what is found for the modern vehicles. Based on NEDC weighted road loads, the Euro 4 models from 2009 have a 19% higher road load. On average the Euro 5/Euro 6 models have a 37% higher road load, with the same weighting (see Figure 15). This suggests that from Euro 4 to Euro 5 / 6 the utilization of flexibilities related to the coast down test has increased.

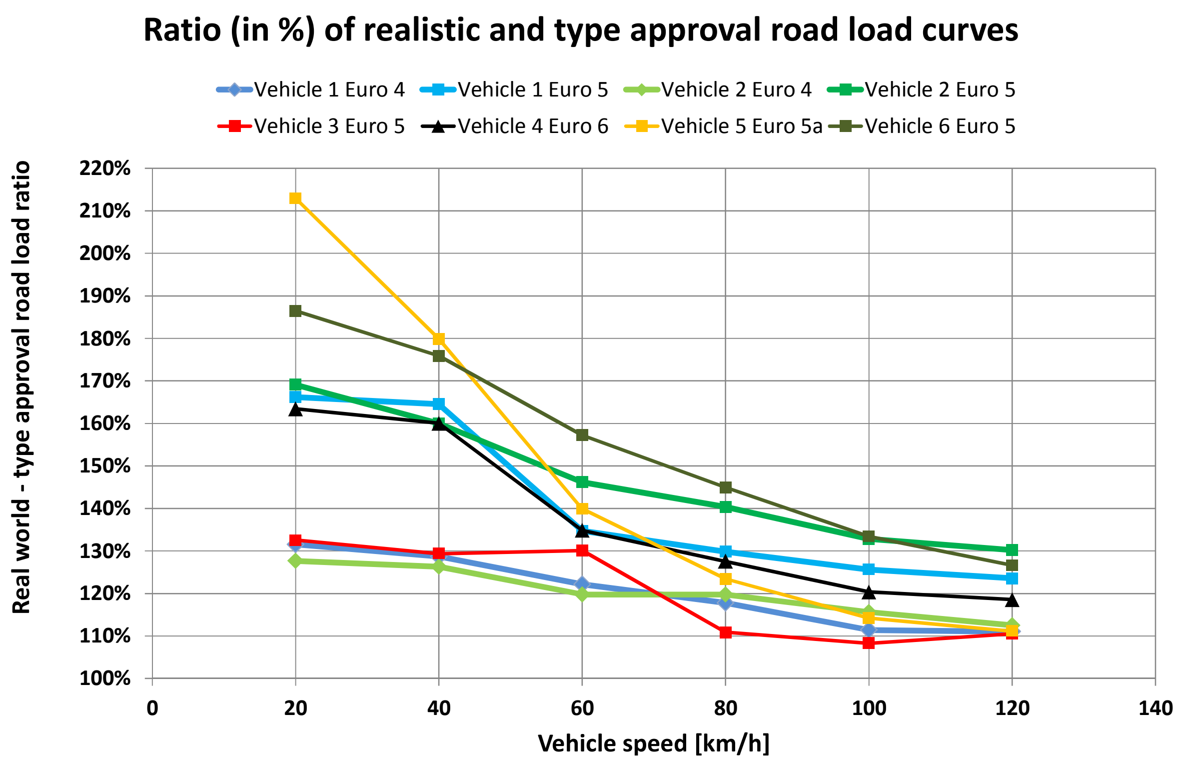

Figure 14 Ratio of Type Approval and realistic road load test results of all tested vehicles

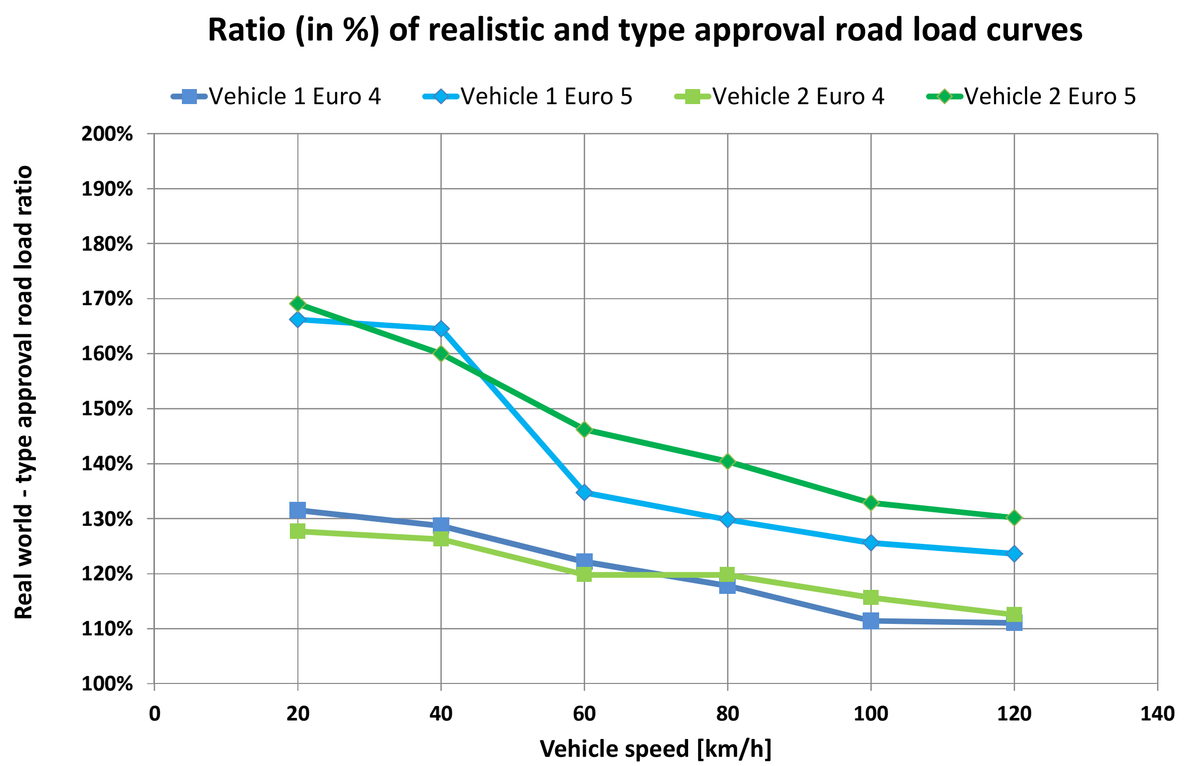

Figure 15 Road Load Ratios (NEDC weighted value for independent measurement divided by average Type Approval road load) of 2 vehicle models, of which both Euro 4 and 5 configurations have been tested (TA = 100%)

Comparing the Type Approval road load curves with the independently determined road load curves, the difference is an additional force that only weakly varies across the whole range of vehicle speeds. This suggests a specific type of optimization of the road load curve. Likely candidates for this optimization are reduced rolling resistance of tyres (high tyre pressure, low thread, possible pretreatments), reduced resistances of wheel bearings, optimized warming up procedure of the test vehicle, optimized wheel alignments of the vehicle, optimized resistance of the road surface of the test track and optimized road inclination of the test track.

Emission tests have been carried out on five vehicles to assess the impact of different road load curves on fuel consumption and CO_2 emissions. Chassis dynamometer tests have been carried out with Type Approval road loads and with the independently determined road loads, using the NEDC test cycle. In Figure 16, the declared and measured CO_2 emission results of NEDC tests with Type Approval and real-world road load settings are presented for Euro 5 and 6 vehicles.

NEDC tests with Type Approval road load settings show on average 12% higher CO_2 emission levels than the declared CO_2 emissions of the manufacturer. NEDC tests with road load settings measured by TNO show on average 11% higher CO_2 emission levels than tests carried out with the manufacturer specified road load settings. NEDC tests of Euro 5 and 6 vehicles with road load settings measured by TNO (which are on average 37% higher than Type Approval settings) show on average 23% higher CO_2 emissions than the declared CO_2 emissions of the manufacturer.

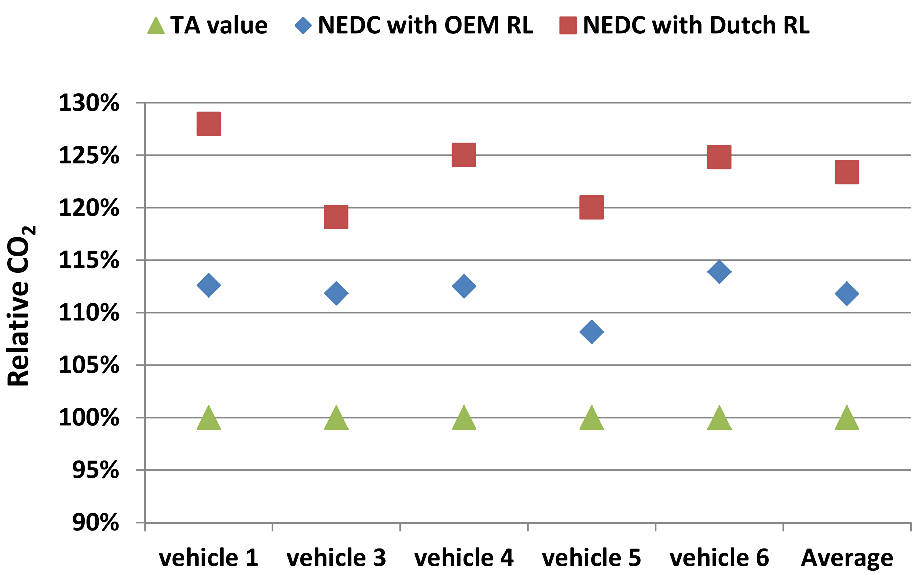

Figure 16 Relative CO2 emissions of Euro 5 and 6 vehicles in a NEDC test with different road load settings

The observed differences between Type Approval CO_2 values and those measured on in-use vehicles using the NEDC cycle and independently measured coast-down curves provide strong indications that flexibilities within the current test procedures for road load determination and CO_2 emission measurement offer significant scope for optimizing the test vehicle and test conditions and that these flexibilities are being used to achieve low Type Approval CO_2 emissions. The results also indicate that the CO_2 reduction potential associated with flexibilities of the road load test is of the same order of magnitude as flexibilities associated with the Type I test.

The results of [TNO 2012b] furthermore indicate that the observed increase in the difference between real-world and type approval CO_2 emissions and fuel consumption may to a large extent be attributable to increased utilization of test procedure flexibilities.

2.6 Information available through the WLTP working group on test procedures

In recent years the development of the World harmonized Light duty Test Procedure is on-going in UNECE(GRPE & WP.29) and it is decided to develop a Global Technical Regulation (GTR). Currently Validation Phase II has started and results will be available in autumn 2012.

DG Enterprise has published some information of this development process on http://circa.europa.eu/Public/irc/enterprise/wltp-dtp/library.

Members of different subgroups report clearly that the WLTP is under construction and an on-going process of improvements of current legislation. The next fundamental steps are under consideration to decrease the amount of flexibilities:

- Stepless approach of the simulation of the vehicle inertia
- Removal of maximum simulated vehicle mass
- More representative vehicle test mass
- CO_2 regression line, to accurately determine CO_2 for the actual vehicle weight (depending on selected options)
- More representative test cycle with better coverage of engine map (reduced possibilities for cycle optimisation)
- More defined set point test room temperature (25 instead of 20-30 °C)
- More defined battery condition and no external charging of the battery
- Road load determination procedure improvements: better or more representative definitions for tire pressure, tire selection (no specially prepared tires!), tire wear, vehicle selection (aerodynamic options that need to be installed), brakes and wheel alignment.

In 2012 Validation Phase II has been started. In this validation emission tests will be carried out in chassis dynamometer test programs. Special attention will be paid to

- Vehicle classes with different power-to-weight ratios (pwr)
  - pwr < 22 W/kg
  - 22 < pwr < 34 W/kg
  - pwr > 34 W/kg
- Test cycle WLTC version 5 with four phases
  - Urban part (589s, average speed 26 km/h)
  - Sub-urban part (433s, average speed 45 km/h)
  - Rural part (455s, average speed 61 km/h)
  - Highway part (323s, average speed 94 km/h)
- Mode construction (cold and hot testing)
- Low powered vehicle test cycle (pwr < 22 W/kg)
- Vehicle test weight (options, passengers, luggage)
- Gear shift patterns
- Soak room and test cell temperature and forced cool down
- Batteries RCB measurement (State Of Charge (SOC)),
- PM and PN measurements (during DPF regeneration)
- Testing of electric and hybrid vehicles

From the results of the WLTP development and validation it can be concluded that flexibilities are recognised and partly quantified in validation phase II. In future processes decisions must be taken to develop a more defined test procedure. In November 2012 detailed results of the total Validation Phase II will be reported.

2.7 Overall conclusions from the literature review

The literature review revealed useful data, calculations, and discussion points. Various topics emerged from the review, which relate to flexibilities within current legislation. These topics include: proposed changes to regulation wording to tighten up current flexibilities, analysis of current usage of certain flexibilities, and estimation of real world fuel economy/CO_2 from type approval data. Although some of these topics are outside the scope of this review, the data presented is of use in helping to quantify how various parameters may reduce type approval CO_2.

A measureable difference is reported between type approval CO_2 and independently measured CO_2 in service. This is demonstrated in test data presented in reports such as [Millbrook 2010] and [Millbrook 2011]. This test data shows on average that diesel vehicles tested were 4% higher in CO_2 than their type approval values. The gasoline vehicles tested were on average 4.3% higher than their type approval values. In some cases the vehicles measured produced less CO_2 than the type approval values. Some of this difference is likely to come from coast down derivation. It is emphasised in the in service-testing reports that the road loads used in these tests originated from manufacturers own coast down measurements rather than being independently measured.

Key flexibilities identified in the literature review are discussed below. They fall into two categories, firstly those that affect the coast down measurement test, secondly those that affect the type approval or NEDC test.

For road load determination test (coast down measurement) the main identified issues are:

- wheel alignment, adjustment of brakes, transmission and driveline preparation;
- ambient conditions – temperature, pressure, wind;
- tyres - type, pressure, and wear;
- test track – surface type and slope;
- vehicle weight as tested;
- vehicle body type.

The effect of these flexibilities on NEDC CO_2 is estimated in the report: [STA/T&E 2011]. These include test results of various studies, quoted in this report. An average reduction in CO_2 on the NEDC test of 5.3% is observed when utilising the full range of tolerance of road load. Also, a range of light duty vehicles averaged 7% shorter coast down times than their type approval values.

[STA/T&E 2011] also quantifies the increase in NEDC test CO_2 using independently measured coast downs compared to the type approval value as 17% on average, with results ranging from 9% to 24%. It explains this as follows:

- “The difference was explained to be the result of higher driving resistance due to optimization of the tire and road surface combination, tire pressure and beneficial ambient conditions.”

For the NEDC type approval test the main issues found are:

- inertia class;
- factors affecting driving resistance on the dynamometer;
- influence of the driver - using the tolerances in the driving cycle;
- preparation of the test vehicle;
- optimised measurement;
- variation in gear shifting;
- battery state of charge;
- laboratory soak temperature.

For the NEDC test flexibilities, summarised test results are quoted in Table 17 above, taken [TÜV Nord 2010b]. These figures do not necessarily represent what is actually possible within the regulations, but give an indication of the size of CO_2 reduction for a given change in the key parameters. The values quoted in the table are based on a range of test results covering different vehicle types.

Laboratory soak temperature is a clear flexibility in type approval regulations and mentioned in several reports including [JRC 2011]. This study establishes a relationship between temperature and CO_2 as follows: 1°C rise in temperature = 0.17% reduction in CO_2 over the NEDC.

One report in particular, i.e. [TÜV Nord 2010b], concludes that CO_2 total reductions of the order of 20% may be possible by optimising all the factors relating to the NEDC test procedure. It also concludes that further reductions beyond 20% are expected when other factors are considered such as the coast down derivation test.

3 Assessment of available flexibilities in the legislation

3.1 Objectives

The objective of this section is to review the current legislation to identify and understand the significant flexibilities available within the type approval procedures that may impact on measured CO_2 emissions. The activities have been the following:

- Reviewing the current legislation and associated type approval test procedures to identify flexibilities with respect to testing of light duty vehicles with conventional powertrains to obtain CO_2 emissions figure;
- Estimating the possible impact of identified flexibilities on CO_2 emissions (and other noxious emissions);
- Assessing any specific flexibilities in the test and evaluation procedures for hybrids and plug-in hybrids.

3.2 Overview of relevant type approval test procedures

The procedure for measuring fuel consumption and CO_2 emissions, as part of European type approval testing, is defined UNECE R101. While this procedure details specific aspects for measuring fuel consumption and CO_2 emissions, the main test procedure as such is defined in UNECE R83, which focusses on measurement of pollutant emissions. R83 details the test cycle to be used, requirements for the vehicle to be tested, as well as various conditions for the tests to be carried out.

In order help explain the detailed analysis presented in subsequent sections, some basic background is given here regarding how the type approval test procedure works.

Type I emissions test or NEDC test
Currently, light duty vehicle emissions are governed by a vehicle-based test known as the ‘type I test’ or ‘new emissions drive cycle’ (NEDC) test. This is a vehicle based test for both diesel and gasoline passenger cars and light commercial vehicles. The test is performed in a purpose built facility known as a vehicle emissions laboratory. The laboratory consists of a chassis dynamometer (or ‘rolling road’), onto which the vehicle is secured, which provides a controlled load onto the driven wheels. The laboratory also contains emissions measurement systems and is held at defined temperature and humidity conditions.

The vehicle is then driven over a defined speed vs. time trace referred to as the NEDC. This test cycle is made up of the low speed phase, commencing with a cold start, referred to as the ECE, and the higher speed phase known as the EUDC (extra urban drive cycle).

Whilst the vehicle is driven over the NEDC all exhaust emissions are collated into sealed bags via a constant volume sampling system (CVS). These bags are analysed by gas analysers at the end of the test and results combined with the distance driven in order to give a cycle result in g/km of each pollutant.

Road load determination
In order to perform the emissions test described above, the dynamometer must be set up to correctly replicate the loads experienced by the vehicle for any given speed. These loads come from various sources such as aerodynamic drag and rolling resistance. There are two methods of defining this road load: the ‘Coast down’ method, and the ‘Cookbook’ method.

The two methods can be summarised as follows:

Coast down method
This method aims to accurately assess the actual loads experienced by the vehicle as it coasts down to a standstill, from a high speed, with the engine switched off and transmission in neutral. A test

track is used for this purpose and a representative vehicle is driven up to the defined speed and allowed to coast down until it stops, meanwhile vehicle speed and time are measured. This data is then used as a target curve (speed vs. time), which the dynamometer should match with the vehicle in position on the rolling road. 'Coast down matching' is carried out at the end of the emissions test to ensure this curve has been followed accurately enough.

Cookbook method
This method aims to estimate the road load by applying a prescribed set of load terms, which are dependent on vehicle mass. The mass is looked up in the 'cookbook' or table in UNECE Regulation No. 83 (version 4), Annex 4A, Chapter 5, page 103 and the appropriate set of load terms read off and entered into the dynamometer control system. With this method there is no coast down matching as there is no target speed vs. time curve.

The following regulations were identified for review:
1. UNECE Regulation No. 101, defining procedures for measuring CO_2 emissions and energy consumption of light duty vehicles;
2. UNECE Regulation No. 83, defining procedures for measuring pollutant emissions of light duty vehicles;
3. Commission Regulation (EC) No 692/2008, on the on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6)

3.3 Methodology

This chapter is a hypothetical exploration of a best case interpretation of the legislative procedure with an express intent to achieve a low drive cycle CO_2 result. The work was conducted through review of the legislation by experts including those who are regularly involved in the testing of light duty vehicles. The legislation and rules which govern the execution of CO_2 measurements over the NEDC for new vehicle type approval were analysed to pinpoint the sources of flexibility.

Each flexibility that was identified was summarised along with the supporting legislation reference. An estimate of the potential CO_2 benefit was derived in each case.

Various methods were used to calculate the CO_2 benefit, including the following:

- Use of formulae and data sourced from the literature review (chapter 2)
- Use of engineering calculations from first principles (vehicle simulation)
- Use of Ricardo empirical data to derive suitable formulae

The first method uses equations taken directly from the literature review in chapter 2 and these are quoted where used.

The second method is discussed in more detail in the paragraph 3.5.2. It is based on the use of a vehicle simulation tool, using theoretical calculations.

The third method acts as a comparison to the first two methods and is based on accumulated test data from a wide range of vehicle based test projects at Ricardo. The guidelines have been revisited specifically for the purposes of this report in order to ensure the most representative data is used to generate CO_2 benefit estimates. It is important to note origins of this data. It originates from tests carried out as part of the normal research and development activities at Ricardo. For example, during vehicle development certain characteristics of the vehicle may change, such as expected mass. This may then result in emissions testing to assess the impact of testing in a different inertia class. The same process may apply to gear ratios, or factors affecting road load for example. It should not be inferred that the existence of data from which CO_2 benefit can be assessed, means that flexibilities have been assessed by vehicle manufacturers.

3.4 Results with respect to the family grouping of Light Duty vehicles

In this section, an analysis is performed on family grouping and vehicle type approval extensions for Light Duty vehicles. A possible use of flexibilities in this grouping procedure is relevant for an additional understanding of the trends in the type approval process. Therefore the current European legislation and regulations were analysed. The European Commission (EC) Directive 70/220 indicates that each vehicle type must be approved on emissions (type 1 test). This directive, has been updated with directive 46/2007 and regulation 692/2008. Complementary information for these directives can be found in the regulation No 83 and 101 of the UNECE.

A vehicle, representative of the vehicle type for which the type approval test is performed, can be initially defined by the manufacturer. The vehicles considered to be included in the same vehicle group do not differ in the equivalent inertia, see Table 19 and in the engine and vehicle characteristics[4]. The concession of extensions to this group may be conceded for CO_2 emissions type approval if the conditions described in the current section are met. For the initial type approval test the selection of a vehicle, representative of a vehicle type, should respect the following conditions[5]:

a. Body. The test shall be performed on the least aerodynamic body (with manufacturer's data);
b. Tyres. If more than three tyre rolling resistances, the second highest one shall be chosen (EC Regulation 692/2008);
c. Testing mass. Shall be the reference mass of the vehicle with the highest inertia range. According to the Regulation No. 83 of UN/ECE the reference mass indicates the unladen mass vehicle increased by a uniform figure of 100 kg. This unladen mass refers to the mass of the vehicle in running order without the 75 kg of driver weight but with a fuel tank of 90%. As indicated in EC Directive 92/21/EC this vehicle mass doesn't include equipment such as sunroof, air conditioning or coupling device. Due to this regulation, and considering that 1 inertia level has a range of 110 kg (which represents an average increase of 0 – 7,5 g/km) one can assume that a realistic reference mass of the vehicle is underestimated.
d. Engine. The one with the largest heat exchanger;
e. Transmission. For each type of transmission a correspondent test shall be performed.

Regarding the family grouping of vehicles for CO_2 emissions type approval, the previously referred EC legislation includes the following regulations, which shall be understood individually as eliminating factors:

1) Reference Mass (section 3.1.1 of EC Regulation 692/2008). The approval of a vehicle type may be extended to vehicles where the reference mass corresponds to the next two higher equivalent inertia (or to any lower equivalent inertia). In Table 19 the equivalent inertia in relation to the reference mass is presented:

   For N vehicles an extension may be granted for vehicles with lower reference mass if the emissions of the vehicles for which an extension is required are within the limits prescribed[6], considering as reference the emissions of the already approved vehicle.

As defined in Appendix 3, of Annex 1 of 70/220/EC.
[5] Source: Appendix 3 of Annex 4 in Regulation No. 83 of the UN/ECE.
[6] These limits are not clearly defined in the original text, but it may be referring to the limits described in point 4 of the current text.

Table 19 Reference mass related to the equivalent inertia (source: Regulation No. 83 UN/ECE)

Reference mass of vehicle RW (kg)	Equivalent inertia I (kg)
RW ≤ 480	455
480 < RW ≤ 540	510
540 < RW ≤ 595	570
595 < RW ≤ 650	625
650 < RW ≤ 710	680
710 < RW ≤ 765	740
765 < RW ≤ 850	800
850 < RW ≤ 965	910
965 < RW ≤ 1080	1020
1080 < RW ≤ 1190	1130
1190 < RW ≤ 1305	1250
1305 < RW ≤ 1420	1360
1420 < RW ≤ 1530	1470
1530 < RW ≤ 1640	1590
1640 < RW ≤ 1760	1700
1760 < RW ≤ 1870	1810
1870 < RW ≤ 1980	1930
1980 < RW ≤ 2100	2040
2100 < RW ≤ 2210	2150
2210 < RW ≤ 2380	2270
2380 < RW ≤ 2610	2270
2610 < RW	2270

2) Vehicle differing in gear ratio (section 3.1.2 of EC Regulation 692/2008).

Considering as E the transmission ratio, with

$$E = \frac{V_2 - V_1}{V_1},$$

where V_1 is the speed of the vehicle-type approved and V_2 is the speed of the vehicle type for which an extension is applied, the following conditions are applied for extending the approval:

a. If for each gear ratio, $E \leq 8\%$, the type I and VI test don't need to be repeated;
b. If $E \leq 8\%$, for at least one gear ratio, and for each gear ratio $E \leq 13\%$ the emissions test (type 1 and 6) must be repeated.

If these conditions are complied with and the reference mass is the same, the approval will be extended. In case of different reference masses, the conditions of section 1 shall be fulfilled (as indicated in section 3.1.3 of EC Regulation 692/2008).

3) Vehicles with periodically regenerating systems (section 3.1.4 of EC Regulation 692/2008).

The extension, and consequent family grouping, may be performed if the following characteristics are within tolerance (UNECE Regulation No 101) and the regenerating factor Ki is the same:

a. Engine
   i. Number of cylinders;
   ii. Engine capacity ±15%;
   iii. Number of valves;

iv. Fuel system;
v. Combustion process (2 stroke, 4 stroke, rotary);

b. Periodically regenerating system (i.e. catalyst, particulate trap)
   i. Construction (i.e. type of enclosure, type of precious metal, type of substrate, cell density);
   ii. Type and working principle;
   iii. Dosage and additive system;
   iv. Volume ±10%;
   v. Location (temperature ± 50°C at 120 km/h or 5% difference of maximum temperature / pressure);

The Ki factor is related to the regeneration of the system, and is dependent of the mass emission of the pollutant related to the number of operating cycles required for regeneration[7]. As indicated in 3.1.4.2 of EC Regulation 692/2008, its value may be extended from a vehicle with a type approval to other vehicles if the reference mass fulfils the conditions described previously in point 1) and the periodically regenerating system of these vehicles meet the conditions described in a) and b) of the current section[8].

4) Light duty vehicles of the category N. For these vehicles the previously indicated conditions (points 1, 2, 3 and 4) are also applicable and are complemented with the information of section 3.6 of EC Regulation 692/2008. Here, it is referred which characteristics shall be followed for the family grouping of N vehicles, considering the CO_2 emissions type-approval. The first condition is that the following parameters shall be identical or within the indicated tolerances:
   a) manufacturer and type[9];
   b) engine capacity;
   c) emission control system type;
   d) fuel system type (direct injection/indirect injection);

Also the range of the following parameters shall be fulfilled:
   a) transmission overall ratios (no more than 8%);
   b) reference mass (no more than 220 kg lighter than the heaviest);
   c) frontal area (no more than 15% smaller than the largest);
   d) engine power (no more than 10% less than the highest value);

If the previous conditions are met, one of the following procedures for defining type approval shall be chosen:

5) a. For a common CO_2 emission and fuel consumption within a family, the member with the highest CO_2 emission shall be chosen. The results shall[10] be used as type approval values for all the members of the family.

The values for new vehicles may be extended to vehicles within a family if the technical service estimates that the fuel consumption of the new vehicle does not exceed the fuel consumption of the vehicle on which the fuel consumption is based.

This type approval may also be extended to vehicles if:

- they are up to 110 kg heavier than the family member tested, provided that they are within 220 kg of the lightest member of the family;

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[7] The meaning and of the Ki factor can be found in the annex 13 of UN/ECE Regulation No 83.
[8] The same regulation doesn't indicate if the limits of section 3.1.2 should be followed in case of different gear ratios.
[9] As described in Section 1, Appendix 4 of the EC regulation 692/2008.
[10] The measurement procedure is described in section 5.5 of UN/ECE Regulation No 101.

- they have a lower overall transmission ratio than the family member tested due solely to a change in tyres sizes and conform with the family in all other respects.
- these vehicles conform with the family in all the other items.

6) b. In a family the testing service chooses the vehicle with the highest and lowest individual CO_2 emission and fuel consumption. If the manufacturers data fall within the tolerances defined for these vehicles (4% [11]), the CO_2 emissions declared by the manufacturer for all members of the vehicle family may be used as type approval values. If they do not fall within the tolerance, the results to be used follow the measurement method included in section 5.5 of UNECE Regulation No. 101 (and the technical service shall select other family members for further testing).

   The values for these vehicles may be extended within the same family, without further testing, if the technical service estimates that the fuel consumption of this vehicle falls within the range set by the vehicles of the family with lower and higher consumption.

   In Table 20 the parameters that characterize the family grouping and CO_2 emissions extension approval of vehicles are summarized (M category vehicles, with a periodically regenerating system):

Table 20 Parameters of vehicle family grouping (M-category)

Parameter	Tolerance Range
Reference mass (section 3.1.2 of EC 692/2008)	Up to two higher equivalent inertia levels Any lower equivalent inertia level
Gear ratio (3.1.2 of EC 692/2008)	Gear ratio, $E \leq 8\%$
Vehicles with regenerating systems (Annex 10 of Regulation No. 101 UN/ECE)	
Engine	
Number of cylinders	Same
Engine capacity	±15%
Number of valves	Same
Fuel system	Same
Combustion process (2 stroke, 4 stroke, rotary)	Same
Periodically regenerating system	
Construction	Same
Type and working principle	Same
Volume	±10%
Location	± 50ºC at 120 km/h or 5% difference of maximum temperature / pressure
Transmission (front-wheel drive, rear-wheel drive, full-time 4x4, part-time 4x4, automatic gearbox, manual gearbox) – section 4.1.5 of Annex 4a of Appendix 7 of Regulation No. 83.	Same

For vehicles that do not comply with the previously indicated parameters the test shall be carried out separately.

Considering the information of Table 20, the type tests have to be performed separately, and no family grouping is possible, for M category vehicles, if:

[11] As indicated in section 5.5 of UN/ECE Regulation No 101.

- the vehicles do not belong to the same reference mass level or don't comply with the tolerance described in Table 20;
- $E \geq 8\%$ [12];
- engine, in-service requirements and periodically regenerating systems aren't within the limits described in Table 20;
- the transmission is not of the same type.

The category N1 vehicles have specific parameters and tolerance ranges that characterize the family grouping and CO_2 emissions extension approval of vehicles. These are described in Table 21.

Table 21 Specific parameters for characterizing a family N1-category vehicles (section 3.5.5 of EC Regulation 692/2008)

Parameter	Tolerance Range
Engine capacity	Same
Emission control system type	Same
Fuel system type[13]	Same
Transmission ratio	$E \leq 8\%$, For a transmission change due to tyre replacement, the type approval value may be extended (in 5.1 is considered for type-approval)
Reference mass	No more than 220 kg lighter than the heaviest Vehicle can be 110 kg heavier than the tested vehicle (if 5.1 is considered for type-approval)
Frontal area	No more than 15% smaller than the largest
Engine power	No more than 10% less than the highest value

In the case of N1 vehicles the requirements of Table 21 are complemented with the conditions of Table 20. This way, the tests have to be performed separately, and no family grouping is possible, if:
- the reference mass of a vehicle is more than 220 kg lighter than the heaviest, or 110 kg heavier than the tested vehicle;
- the frontal area is 15% smaller in comparison with the largest vehicle of the vehicle;
- engine capacity and fuel systems is not the same;
- emission control system is not the same;
- the engine power is more than 10% of the highest value inside a family;
- If $E \geq 8\%$ and this fact isn't related with a tyre replacement.

Estimated potential CO_2 variations resulting from the identified flexibilities, associated with the family grouping are presented in Table 22 for M category vehicles and in Table 23 for N category vehicles.

Due to the unfavourable properties of a reference or parent vehicle in a vehicle group, such as highest mass and highest performance, this vehicle has the highest CO_2 emission in the group. Other members of the vehicle group might emit less CO_2 and their CO_2 emissions can be reported separately in the type approval document.

This is based on type approval document information; a specific type approval certificate of a representative European vehicle contains 2 pollutant test results of 2 vehicle groups (sedan and station wagon) but 20 CO_2 test results of different vehicle group members. From this vehicle group the reference vehicle has the highest CO_2 emission (100%) but most vehicles have significant lower emissions and the lowest is 86%.

[12] If for each gear ratio $E \leq 13\%$ and for at least one $E \leq 8\%$ the type tests shall be repeated. The regulation is not clear about future developments for this situation.
[13] As defined in point 1.10.2 of Appendix 4.

Table 22 Variation of CO_2 considering the different vehicle type and family grouping options (M vehicles)

Grouping	Criteria	CO_2 Impact
Vehicle Type grouping		
Reference Mass	Highest Inertia Range	5% [TÜV Report]
Tyres	Tyre with highest rolling resistance If more than three tyre rolling resistances, the second highest one shall be chosen	2% [TÜV Report]
Engine	Largest heat exchanger	n/a
Body	Worse aerodynamics	n/a
Transmission	Same	n/a
Type Approval Extension		
Reference mass	Up to two higher equivalent inertia levels Any lower equivalent inertia level	10%
Gear ratio	Gear ratio, $E \leq 8\%$	3% [TNO 2011]
Vehicles with regenerating systems		
Engine		
Number of cylinders	Same	n/a
Engine capacity	±15%	4% [TNO 2011]
Number of valves	Same	n/a
Fuel system	Same	n/a
Combustion process (2 stroke, 4 stroke, rotary)	Same	n/a
Periodically regenerating system		
Construction	Same	n/a
Type and working principle	Same	n/a
Volume	±10%	n/a

Conclusions with respect to the definition of vehicle family groups

After the review of the current regulations and legislation that cover the grouping of vehicles theme some further flexibilities were identified.

The definition of a vehicle group contains flexibilities that are associated to the vehicle type grouping, type approval extension and CO_2 variation extension. The worst case rule is the basis for the vehicle type grouping, but the associated conditions, like the unladen mass factor or tyre selection also showed the existence of flexibilities. The type approval may be extended to other vehicles if the grouping factors presented in Table 22 and Table 23 are followed.

The regulation that defines this grouping can lead to different interpretations. One example is the selection of a body type that can meet the grouping conditions, using the regulation included in section 3.5. Although the extension of a CO_2 type approval needs to fulfil the 4% CO_2 variation rule (for M category vehicles), there is no indication if a body with worse aerodynamics characteristics may be also grouped. Like aerodynamics, the extension of the CO_2 emissions approval is also not very clear for powertrain, engine or gear ratio variations. Looking at some practical data it can be concluded that the definition of a vehicle group or family has been denied for CO_2 purposes because the CO_2 emission of every single model has been reported separately and is mostly far lower than the reference vehicle for the family.

This analysis demonstrates that in one family group there can exist vehicles that strongly differ in the CO_2 emission values. In Table 22 and Table 23 these variations are demonstrated, per flexibility item. As a consequence in the view of vehicle CO_2 emissions the application of the vehicle group definition has been partly ignored because the individual CO_2 results of certain vehicle group members (sedan, station wagon, standard and eco vehicles in different inertia classes) are reported in the type approval certificates.

Table 23 Variation of CO_2 considering the different vehicle type and family grouping options (N vehicles)

Grouping Vehicle Type grouping	Criteria	CO_2 Impact
Reference Mass	Highest Inertia Range	5% [TÜV Rapport]
Tyres	Tyre with highest rolling resistance If more than three tyre rolling resistances, the second highest one shall be chosen	2% [TÜV Rapport]
Engine	Largest heat exchanger	n/a
Body	Worse aerodynamics	n/a
Transmission	Same	n/a
Type Approval Extension		
Emission control system type	Same	n/a
Fuel system type[14]	Same	n/a
Gear ratio	$E \leq 8\%$, For a transmission change due to tyre replacement, the type approval value may be extended (if point 5.1 is considered for type-approval)	3% [TNO 2011]
Reference mass	No more than 220 kg lighter than the heaviest Vehicle can be 110 kg heavier than the tested vehicle (if point 5.1 is considered for type-approval)	5% [TÜV Rapport]
Frontal area	No more than 15% smaller than the largest	2% [TNO 2011]
Engine power	No more than 10% less than the highest value	2%

3.5 Identification of flexibilities and their CO_2 impact

In the sections 3.6 to 3.8, flexibilities relating to allowable bandwidths specified in the type approval test procedure for light duty vehicles are identified and discussed in detail. A separate section 3.9 deals with any flexibilities specific to hybrid vehicles, in addition to those discussed here. Further on in the report, in section 5.12, a brief overview is presented of findings with respect to other types of flexibilities, generally related to test aspects that are not or not clearly defined in the test protocol.

3.5.1 *Identified flexibilities*

The analysis is split into two main areas, with flexibilities grouped into sub-categories as follows:

1. Those that affect the derivation of the coast down curve
   a. Wheel and tyre specification
   b. Tyre pressure
   c. Brakes
   d. Preconditioning
   e. Running-in period
   f. Ambient conditions
   g. Test track design

2. Those that affect the Type I emissions (NEDC) test directly
   a. Reference mass
   b. Wheel and tyre specification, and rolling resistance
   c. Running in period of test vehicle
   d. Laboratory instrumentation and fuel specification

[14] As defined in point 1.10.2 of Appendix 4.

e. Laboratory altitude (air density)
f. Temperature effects
g. Coast down curve or cookbook load terms
h. Battery state of charge
i. Gear change schedule and definition
j. Driving technique
k. DPF related Ki factor (distance between DPF regenerations) for calculating total cycle CO_2
l. Declared CO_2 value

3.5.2 *Approach for estimating CO_2 benefits using theoretical calculations*

The following approach was used to provide a theoretical estimation of CO_2 benefits where appropriate.

A standard Ricardo vehicle simulation tool was used to carry out parameter swings of relevant parameters, in order to see the effect on NEDC cycle CO_2. The input data to this tool was based on a typical Euro 5 C/D class passenger car, in the 1470kg inertia class. The purpose of using the tool was not to produce accurate predictions for one particular vehicle, but to assess the impact of each flexibility in terms of the variation in CO_2 emissions versus a baseline case. The calculations within this simulation tool are based on the following principles.

Engine speed (rpm) and load (Nm) are estimated based on the equations below. For each second in the NEDC test the speed and load are used to perform a lookup on a map of CO_2 mass flow rate. The CO_2 map was based on real test data of the engine being modelled. This CO_2 mass flow is then integrated over the duration of the test, and divided by distance to get the cycle result in g/km. The following components are used in this model (example equations shown):

- Rolling resistance component = $m \cdot f_{rr} \cdot g$
- Aerodynamic drag component = $1/2 \cdot \rho \cdot C_d \cdot A \cdot v^2$
- Acceleration component = $m \cdot a$
- Drivetrain power losses = $1/\eta_d$

Where: m = mass, f_{rr} = coefficient of rolling resistance, g = acceleration due to gravity, ρ = density of air, C_d = coefficient of drag, A = frontal area, v = velocity, η_d = efficiency of drivetrain

Table 24 Results based on vehicle simulations varying key parameters, translated into % change from baseline result

	NEDC CO_2	Change		ECE CO_2	Change		EUDC CO_2	Change
Description of simulation (compared to baseline)	**g/km**	**%**		**g/km**	**%**		**g/km**	**%**
Baseline Euro 5 result simulated	161.8			218.1			150.2	
Gear schedule change (use 2nd to 5th gears)	149.1	-7.8		186.7	-14.4		147.9	-1.5
Vehicle mass reduced by 110kg (1360kg)	157.8	-2.5		213.2	-2.2		146.1	-2.7
Vehicle mass reduced by 220kg (1250 kg)	153.6	-5.1		208.1	-4.6		141.8	-5.6
Tyre change resulting in f_{rr} reduced by 20% (0.008)	157.3	-2.8		213.7	-2.0		144.8	-3.6
Increase tyre rolling radius by 5%	158.6	-2.0		214.3	-1.7		146.9	-2.2
Driving style (minimum speed and acceleration)	159.8	-1.2		218.0	0.0		147.9	-1.5
Revised baseline for alternator test (start from 420W)	161.7							
Alternator charging reduced at start (start from 215W)	160.5	-0.74						

Table 25 NEDC simulated CO_2 emissions with optimized road load curve

Description of simulation (compared to baseline)	NEDC CO_2 g/km	NEDC Change %	ECE CO_2 g/km	ECE Change %	EUDC CO_2 g/km	EUDC Change %
Baseline Euro 5 result simulated	161.8		218.1		150.2	
Coast down curve test track design 1.5% slope	161.3	-0.31	217.7	-0.18	149.6	-0.40
Optimise all available factors relating to rolling resistance (resulting in f_{rr} reduced by 30% to 0.007)	155.0	-4.2	211.4	-3.1	142.1	-5.4

Other factors are also included in the simulation such as inertia of rotating parts, electrical energy and alternator efficiency, energy dissipated in braking, gear and final drive ratios.

This tool was used to assess the impact on cycle CO_2 in g/km of changes to key parameters such as mass, coefficient of rolling resistance, gear shift schedule, tyre rolling radius, and alternator load. This information was then combined with that derived from the literature review (chapter 2), and test data, to derive an overall assessment of the CO_2 benefit for each flexibility.

Additional simulation runs were performed based on flexibilities in the coast down test and the knock-on effect of the improved coast down curve on the NEDC test result in
Table 25.

These simulation results are discussed below in the derivation of CO_2 estimates for each flexibility.

3.6 Flexibilities affecting the derivation of the coast down curve

Coast down curves are generated by the manufacturer according to the prescribed test procedure, in order to characterise the total vehicle resistance as a function of speed. Some flexibilities exist within this process, therefore for a particular vehicle a range of coast down results are possible. An improved coast down curve will yield an associated CO_2 benefit realised during the NEDC emissions test if the coast down method is used to set the road load for that test. In cases where the “cookbook” method is used to set road load (discussed later in section 3.7.8), the following flexibilities will not apply.

3.6.1 *Test vehicle mass*

UNECE R83 4.1.3 states: “The testing mass shall be the reference mass of the vehicle with the highest inertia range.” Mass would typically be added or removed from the vehicle at the test site in order to achieve the correct reference mass. This would correct for any differences in the test vehicle such as interior trim, as well as adding the appropriate mass for driver/luggage as specified for the reference mass.

No tolerance on the mass is stated here. Increasing mass will increase momentum, which is beneficial in extending coast down times. But increased mass will also increase rolling resistance, which reduces coast down times. Therefore the end result of a change in is unclear and cannot easily be quantified here. Test vehicle mass is therefore discounted as a flexibility for the purposes of this analysis.

3.6.2 *Wheel and tyre specification*

Manufacturers often have a range of wheel and tyre size options available within a family of vehicles. The legislation includes some flexibility in the choice of wheel and tyre used in both the coast down measurement test, and the NEDC test.

Regarding the tyre choice for coast down measurement, UNECE R83 – Annex 4a, Appendix 7, 4.1.2 states: "The widest tyre shall be chosen. If there are more than three tyre sizes, the widest minus one shall be chosen."

Tyre specification has a significant effect on rolling resistance, and tyre width has an effect on aerodynamic drag. The flexibility in tyre choice may be used to optimise rolling resistance and drag for the coast down test, when in reality incentives could be used or be present to sell the majority of vehicles with different wheels and tyres.

CO_2 benefit
Quantifying the CO_2 benefit available from this flexibility is difficult as it depends greatly on the extent to which the flexibility is applied. It could be possible to specify very extreme tyres as the "widest minus one" in the range, therefore gaining significant benefit on the coast down test. However this may not be viable in practice, as the manufacturer would have to ensure no customers purchase vehicles with such extreme tyres due to the reduced grip. A more viable approach might be to specify reasonably low rolling resistance tyres as standard, and make other tyres available as an option for more performance oriented customers.

The CO_2 benefit from this is assessed at the end of the coast down section in conjunction with the other flexibilities.

3.6.3 *Tyre pressure*

Tyre pressure is also a significant factor in rolling resistance, therefore coast down performance. For the coast down test, UNECE R83 – Annex 4a, Appendix 7, 4.3 specifies that "The following checks shall be made in accordance with the manufacturer's specifications for the use considered: Wheels, wheel trims, tyres (make, type, pressure), front axle geometry, brake adjustment (elimination of parasitic drag), lubrication of front and rear axles, adjustment of the suspension and vehicle level, etc."

As many manufacturers specify different pressures for different conditions, it may be possible to use the wording of the vehicle handbook to maximise tyre pressures for the coast down test.

Tyre pressures are set when the tyres are 'cold', however the exact temperature is not specified. Therefore there is some flexibility in the change of pressure during the course of the coast down procedure. If the ambient temperature is low when pressures are set, any increase in ambient temperature during the day will be of benefit as increased tyre pressures will result.

In addition to the effect of ambient temperature, the vehicle operating temperature will also have an effect on tyre pressure. It is advantageous to get the tyres to the highest temperature possible during the preconditioning phase of the test (as referred to below), in order to further increase tyre pressure. This benefit is offset somewhat as the tyres become softer with increased surface temperature, increasing rolling resistance.

CO_2 benefit
The CO_2 benefit from this is assessed at the end of the coast down section in conjunction with the other flexibilities.

3.6.4 *Brakes*

Also mentioned in UNECE R83 – Annex 4a, Appendix 7, 4.3 on "brake adjustment (elimination of parasitic drag)," are adjustments that may be made to certain components. The adjustment of brakes to remove parasitic drag in particular is likely to improve coast down performance relative to a vehicle in service.

CO_2 benefit
The CO_2 benefit from this is assessed at the end of the coast down section in conjunction with the other flexibilities.

3.6.5 *Preconditioning*

Another flexibility apparent in the legislation is the preconditioning of the vehicle prior to coast down testing. This is referred to in UN/ECE R83 – Annex 4a, Appendix 7, 4.4.4 “Immediately prior to the test, the vehicle shall be brought to normal running temperature in an appropriate manner.” The temperature of vehicle components affects rolling resistance, therefore maximising the vehicle temperature at the start of the coast down test can further improve the coast down curve.

CO_2 benefit
The CO_2 benefit from this is assessed at the end of the coast down section in conjunction with the other flexibilities.

3.6.6 *Running-in period*

The legislation states the following regarding the condition of the vehicle used for the coast down test (UNECE R83 – Annex 4a, Appendix 7, 4.2): “The vehicle shall be in normal running order and adjustment after having been run-in for at least 3,000 km. The tyres shall be run-in at the same time as the vehicle or have a tread depth within 90 and 50 per cent of the initial tread depth.”

This includes some flexibility in the running in distance, and the tread depth on the tyres. It is advantageous to use tyres with minimum tread depth to reduce rolling resistance. It is also advantageous to cover enough distance to minimise friction losses throughout the vehicle.

CO_2 benefit
The CO_2 benefit from this is assessed at the end of the coast down section in conjunction with the other flexibilities.

3.6.7 *Ambient conditions*

Other flexibilities exist in the legislation regarding the conditions of the test. This includes the influence on aerodynamic drag of ambient temperature and air pressure, wind direction and speed, and humidity. UNECE R83 – Annex 4a, Appendix 7, 3.1 states: “Testing shall be limited to wind speeds averaging less than 3 m/s with peak speeds of less than 5 m/s. In addition, the vector component of the wind speed across the test road shall be less than 2 m/s.” Also, UNECE R83 – Annex 4a, Appendix 7, 3.2 states that “Humidity: The road shall be dry.”, while in UNECE R83 – Annex 4a, Appendix 7, 3.3 the following is prescribed: “Pressure and Temperature: Air density at the time of the test shall not deviate by more than ±7.5 per cent from the reference conditions, P = 100 kPa and T = 293.2 K.”

In general a low ambient pressure and a high ambient temperature with low humidity are considered to be optimal for best coast down performance within the ranges specified above. However, the power determined from the coast down test is corrected by a formula given in UNECE R83 – Annex 4a, Appendix 7, 5.1.1.2.8, “The power (P) determined on the track shall be corrected to the reference ambient conditions (20 °C and 100 kPa).” Consequently the effect of altitude of a test track is assumed to be negligible.

For humidity no correction is made. In reality, humidity does influence the density and viscosity of air, and in general may deserve consideration. The effect of these variations on vehicle drag cannot easily be quantified within this analysis, however, and for this report humidity is not considered to be a significant test flexibility.

CO_2 benefit
The CO_2 benefit from this is assessed at the end of the coast down section in conjunction with the other flexibilities.

3.6.8 *Test track design*

Regarding the test track used for coast down testing, the following statement includes a tolerance for the slope of the track: UNECE R83 – Annex 4a, Appendix 7, 2 “Definition of the road: The road shall be level and sufficiently long to enable the measurements specified in this appendix to be made. The slope shall be constant to within ±0.1 per cent and shall not exceed 1.5 per cent.” It may be possible to use this tolerance to gain advantage.

It may also be possible to optimise track surface to minimise its contribution to the overall rolling resistance of the vehicle. For example, a smooth surface is expected to generate less resistance than a rough surface. Currently characteristics of the road surface are not specified in the test procedure. To what extent this constitutes a flexibility, as well as adds to deviations between type approval and real-world CO_2 emission, depends on the actual surface conditions of test tracks relative to the average real-world road conditions. It makes sense, however, to include specifications on road surface in the procedure for coast down testing.

The regulations require the coast down test to be repeated in opposite directions in order to account for the wind direction on the day of testing. This provision counteracts the effect of a slope in the test track to a large extent but not entirely. Additionally, it is also important to note that this provision does not specify that the repeat test in the opposite direction has to be carried out on exactly the same piece of track. Therefore it is theoretically possible to use a track which has two straight sections, such as an oval shape, where each straight has a downwards slope of up to 1.5%. This would allow the maximum benefit to be gained on both coast down tests. It is not clear whether such conditions exist at the test facilities used for determining road loads.

CO_2 benefit
The CO_2 benefit from this is assessed at the end of the coast down section in conjunction with the other flexibilities.

3.6.9 *Overall CO_2 benefit for all coast down flexibilities*

The combined effect of optimising wheel and tyre specification, tyre pressure, preconditioning, and running-in period leads to an overall reduction in the coefficient of rolling resistance. As discussed, the reduction in the coefficient of rolling resistance is difficult to quantify, and will vary from vehicle to vehicle. The potential to reduce rolling resistance in the coast down test is greater than during the NEDC test due to the extra flexibilities in warming up the vehicle etc. Assuming an overall reduction in this coefficient of 30%, the theoretical calculations predict a reduction in CO_2 on the NEDC cycle of 4.2%.

The effect of ambient conditions on aerodynamic drag is expected to be very small due to the corrections applied for pressure and temperature in the regulatory calculations, therefore 0% is assumed here. As mentioned above, however, the impact of humidity deserves further attention. Humid air has a relative high density and high viscosity.

The effect of holding back brake pads equates to a relatively constant deceleration force, applied to the vehicle normally, that can be removed for the purposes of these calculations. The size of the force, however, is very dependent on the condition of the brakes and the details of their usage prior to the test. Therefore the size of this flexibility cannot readily be quantified and it is not included within this analysis.

The impact of the test track slope is assessed using theoretical calculations. This gives the effect on the coast down curve of using a track with a 1.5% downward slope. Using this coast down curve in the simulation tool gives a small reduction in CO_2 of 0.3%.

Effect on other emissions
With all flexibilities relating to the coast down test, an improved coast down result leads to reduced road load on the NEDC test. This is likely to reduce NO_x and PM due to lower engine loads, but increases the warm-up time, potentially leading to higher CO and HC emissions as the exhaust aftertreatment takes longer to warm up.

Summary table
Table 26 shows the potential effect of utilising all the flexibilities within the coast down test. There will be significant variation in these figures depending on the extent to which each flexibility is applied, as discussed in the text. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 26 Potential effect on emissions due to coast down test flexibilities

Vehicle	CO_2	NO_x	PM	CO	HC
Gasoline	-4.5%	Down	Down	Up	Up
Diesel	-4.5%	Down	Down	Up	Up

3.7 Flexibilities directly affecting the Type I vehicle emissions test (NEDC)

Flexibilities relating to the Type I emissions test (or NEDC test), as carried out in the lab on a chassis dynamometer, are dealt with in this section. Also included is a discussion of the relative benefits of choosing the 'cookbook' method over the coast down method for setting road load.

3.7.1 *Reference mass*

The reference mass is significant to cycle CO_2 as it determines the chassis dyno inertia setting used for the test. It is a benefit to use any flexibility in the legislation to claim a lower inertia class for achieving reduced CO_2 emissions. It also has a knock-on effect of reducing road load in tests where cookbook loads are used because these loads are related to the reference mass.

Definition of reference mass depends on which parts of the vehicle are considered to be fitted by the manufacturer, and which are fitted at a later stage (for example as aftermarket or dealer fitted options). This may include the vehicle body in the case of some 'chassis cab' type light commercial vehicles.

UNECE R83 – Annex 1, 2.6, specifies the reference mass to be used as: "Mass of the vehicle with bodywork and, in the case of a towing vehicle of category other than M1, with coupling device, if fitted by the manufacturer, in running order, or mass of the chassis or chassis with cab, without bodywork and/or coupling device if the manufacturer does not fit the bodywork and/or coupling device"

This statement allows room to specify certain items as dealer fitted optional extras, therefore not fitted by the manufacturer, which may result in a reduced inertia class if the vehicle is close to the lower end of the class boundary.

CO_2 benefit
Due to the inertia class boundaries, any reduction in reference mass will only be of benefit if it drops the vehicle into the next lower inertia class. This would result in a reduction of approximately 110kg, depending on the inertia class. For example, for a vehicle weighing 1440kg, the reference mass specified for the inertia class is 1470kg. It may be possible to use flexibilities to specify a mass 35kg lower. This would then bring the vehicle into the next lower inertia class, resulting in an inertia setting of 1360kg, a reduction of 110kg.

Based on theoretical calculations, the effect of 110kg reduction in mass equates to approximately 2-3% reduction in CO_2. The benefit is expected to be similar in both gasoline and diesel vehicles because there is a reduction in the power required to accelerate the vehicle. Therefore less energy is dissipated in the braking phases of the cycle. This reduction does not include additional benefit from reduced cookbook load terms, when using the cookbook method to control road load.

Effect on other emissions
Reduction in other emissions is expected along with the reduction in CO_2, except for the effect of increased aftertreatment warm-up time due to the lower engine loads experienced. The increased warm- up time may also result in the 'warm-up calibration' operating for longer, which may also affect other emissions.

Summary table
For a reduction in vehicle mass of 110kg (one inertia class) the following are estimated. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 27 Potential effect on emissions due to reference mass flexibilities

Fuel type	CO_2	NO_x	PM	CO	HC
Gasoline	-2.5%	Down	Down	Up	Up
Diesel	-2.5%	Down	Down	Up	Up

3.7.2 *Wheel and tyre specification, and rolling resistance*

For the NEDC test, standard wheels, tyres, and tyre pressures are used, as specified by the manufacturer. However, there is some flexibility in the sense that low CO_2 wheels and tyres could be specified by the manufacturer as standard, but not used in practice due to strong incentives for customers to choose alternative dealer-fitted options.

The combination of wheel and tyre specification affects gearing, due to the effective rolling radius. The flexibility in wheel/tyre choice could potentially be used to optimise gear ratios for the NEDC test, if alternative wheels/tyres are offered as a dealer fitted option. In general, it is anticipated that higher gear ratios are beneficial for CO_2 reduction due to the improvement in brake specific fuel consumption occurring at lower engine speeds. There is also a secondary effect of reduced drivetrain power losses when the overall ratio approaches 1:1.

Tyre specification can also be used to improve rolling resistance on the NEDC test, by specifying low rolling resistance tyres, and high tyre pressures, for the tyres that will be used.

When a twin roller chassis dynamometer is used, the tyre pressures are allowed to be higher: UNECE R83 – Annex 4a, 6.2.3 states that: “The tyre pressure may be increased by up to 50 per cent from the manufacturer's recommended setting in the case of a two-roller dynamometer.” However, twin rollers may increase rolling resistance due to the increased tyre deformation experienced, so it is not clear if this is a CO_2 benefit overall.

Other factors also affect rolling resistance on the chassis dynamometer, including: tension of tie-down straps holding the vehicle to the floor, weight and weight distribution of vehicle and occupants. These factors can increase, or reduce, CO_2 depending on how they affect the tyre deformation on the rolls, and the geometry of the drivetrain components such as constant velocity joints. The optimal arrangement is one which minimises weight acting on the driven wheels, but keeps the drive shafts alignment as straight as possible.

It should be noted here that wheel and tyre specifications only offer a flexibility and room to optimise for low CO_2 test results, if the resistance factors of the rollerbench are based on ‘çookbook’ values. If the dyno setting is based on coast-down test results, the procedure prescribes that the resistance factors are adjusted such that the coast down curve, as measured on the test track, is reproduced on the rollerbench. In this approach possible impacts of the characteristics tyres as used in the type I test are automatically compensated for in the adjusted resistance factors of the rollerbench.

CO_2 benefit

If cookbook factors are used, a reduction in rolling resistance due to the choice of tyres is of direct benefit to CO_2. It is, however. very difficult to quantify this benefit as it depends on how the flexibility is implemented by a manufacturer. Theoretical calculations (paragraph 2.4.1) show that an overall reduction in coefficient of rolling resistance of 20% gives a 2.8% reduction in cycle CO_2. Assuming this reduction comes from reduced rolling resistance tyres, it may be difficult to achieve in practice. If a manufacturer were to specify very extreme tyres with very hard surface compound, purely for the type I test, these may have reduced grip compared to more conventional tyres. Therefore they would have to ensure that customers do not choose these tyres in practice, due to the risk of handling issues. This effectively limits how far the flexibility can be applied in practice.

Any benefit from optimising wheel size to optimise gear ratio is dependent on how unsuitable the original gear ratios are for the NEDC cycle. The effect of gear ratio is assessed in more detail in the paragraph relating to gear change schedule and definition, where the effect of starting in 2^{nd} gear is discussed.

In paragraph 2.4.1 theoretical calculations are used to assess the effect of increasing the tyre rolling radius by 5%. These calculations estimate a CO_2 benefit of 2%. It should be noted that this is dependent on the original gear ratios being non-optimal; hence CO_2 improves when rolling radius increases.

Effect on other emissions

The result of increased gear ratios is lower engine speed, higher engine load. This generally reduces CO_2 but increases NO_x in both diesel and gasoline engines. The effect on CO and HC is likely to be minimal due to the use of oxidation catalysts. It could be argued that any increase in NO_x emissions may require the engine calibration to be modified to compensate. These modifications may then increase CO_2 again. However, the overall effect is anticipated to be a reduction in CO_2.

Summary table

Optimising wheel and tyre specification to increase rolling radius by 5% is expected to have the following effect on emissions. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 28 Potential effect on emissions due to wheel and tyre specification flexibilities

Fuel type	**CO_2**	**NOx**	**PM**	**CO**	**HC**
Gasoline	-2%	Up	Up	Similar	Similar
Diesel	-2%	Up	Up	Similar	Similar

Reducing overall rolling resistance by 20% is expected to have the following effect on emissions. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise, under the condition that the test is performed using ‘cookbook’ values for the rollerbench settings.

Table 29 Potential effect on emissions due to rolling resistance flexibilities

Fuel type	**CO_2**	**NO_x**	**PM**	**CO**	**HC**
Gasoline	-2.8%	Down	Down	Similar	Similar
Diesel	-2.8%	Down	Down	Similar	Similar

3.7.3 *Running-in period of test vehicle*

Regulation UNECE R83 – Annex 4a, 3.2.1 specifies a minimum distance is to be recorded before the NEDC test:, “The vehicle shall be presented in good mechanical condition. It shall have been run-in and driven at least 3,000 km before the test.” However, there are potential flexibilities in this running-in period in order to achieve the minimum possible friction losses in the engine and vehicle.

CO_2 benefit

For a vehicle that has been run-in over a distance of 15,000km compared to a vehicle run-in over 3,000km the CO_2 benefit can be significant. The actual benefit may vary depending on factors including the design of affected components such as bearings, and the speed/load profile of the running-in cycle. A vehicle with particularly poor friction characteristics at zero kilometres may benefit more than one which is relatively good from the start. However, analysis of the Ricardo vehicle testing database demonstrates CO_2 reductions of 5% are possible by extending the running-in distance from the minimum of 3,000km to 15,000km.

However, it should be stated that coast down matching would reduce this benefit. Any improvement in coast downs due to reduced friction in vehicle components would be compensated by the chassis dynamometer. This would not be the case for a vehicle test using cookbook load factors, as the chassis dynamometer load is not dependent on matching a coast down curve. Reduced engine friction however, would still be of benefit even if the coast down method was used.

Effect on other emissions

Reductions in other emissions are expected along with the reduction in CO_2, except for the effect of increased aftertreatment warm-up time due to lower engine loads experienced. The increased warm-up time may also result in the 'warm-up calibration' operating for longer, which may also affect other emissions. These effects, however, are expected to be relatively small.

Summary table
The impacts summarised in Table 30 are based on increasing the running-in distance from 3,000km to 15,000km. This assumes the cookbook method is being used. A smaller benefit is expected when using coast-down results as explained above. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 30 Potential effect on emissions due to running-in period flexibilities

Fuel type	CO_2	NO_x	PM	CO	HC
Gasoline	-5%	Down	Down	Up	Up
Diesel	-5%	Down	Down	Up	Up

3.7.4 *Laboratory instrumentation*

The legislation covers measurement accuracy and tolerances for a range of instrumentation equipment. If the true accuracy of instrumentation lies well within the allowable tolerance band, then it may be possible to deliberately utilise some of that tolerance band to reduce the measured CO_2 result, e.g. by careful calibration of equipment towards one end of the allowable range. It should be noted however, that in order to be confident of remaining within the regulations for a type approval test some margin would still need to be reserved on each tolerance.

For example: UNECE R83 – Annex 4a, 4.6 contains the following specifications with respect to "General test cell equipment

> The following temperatures shall be measured with an accuracy of ±1.5 K:
> (a) Test cell ambient air;
> (b) Intake air to the engine;
> (c) Dilution and sampling system temperatures as required for emissions measurement systems defined in Appendices 2 to 5 of this annex.
> The atmospheric pressure shall be measurable to within ±0.1 kPa.
> The absolute humidity (H) shall be measurable to within ±5 per cent."

The regulations also state individual tolerances for other items of measuring equipment, for example: accuracy of CO_2 analyser, accuracy of load measurement on the dynamometer, and background emissions measurement.

- UN/ECE R83 – Annex 4a, 6.5.3.6 "After the analysis, zero and span points shall be rechecked using the same gases. If these rechecks are within ±2 per cent of those in paragraph 6.5.3.3. above, the analysis shall be considered acceptable."
- UN/ECE R83 – Annex 4a, 6.5.3.3 "The analysers shall then be set to the calibration curves by means of span gases of nominal concentrations of 70 to 100 per cent of the range."
- UN/ECE R83 – Annex 4a, Appendix 3, 1.3.7 "Measurement error shall not exceed ±2 per cent (intrinsic error of analyser) disregarding the true value for the calibration gases."
- UN/ECE R83 – Annex 4a, Appendix 1, 1.2.3 "It shall be possible to measure and read the indicated load to an accuracy of ± 5 per cent."
- UN/ECE R83 – Annex 4a, Appendix 1, 1.2.4 "In the case of a dynamometer with a fixed load curve, the accuracy of the load setting at 80 km/h shall be ±5 per cent. In the case of a dynamometer with adjustable load curve, the accuracy of matching dynamometer load to road load shall be ±5 per cent at 120, 100, 80, 60, and 40 km/h and ±10 per cent at 20 km/h. Below this, dynamometer absorption shall be positive."

Some other tolerances are allowed on measurement equipment, but are cancelled out due to the arrangement of the system. For example the same analyser is used to measure background CO_2 as to measure vehicle CO_2, therefore increase in background CO_2 (due to analyser over reading) will also increase the vehicle CO_2 result, cancelling out the potential benefit.

CO_2 benefit

Laboratory calibration documents are provided to the certification authority during the type approval process. However it is theoretically possible to utilise the tolerances available to gain a measured CO_2 benefit. In practice, this requires significant effort, and would affect results on all other tests performed in the laboratory during the same period.

It is possible to add the various tolerances available to calculate overall potential CO_2 benefit :

- Ambient air temperature +1.5K leads to CO_2 benefit of 0.3g/km (using the calculation discussed in section on temperature effects)
- Accuracy of CO_2 measurement: 2%
- Accuracy of coast down curve matching, 5% load, 10% load below 20km/h. Using the Ricardo vehicle testing database it is possible to establish an estimation of the relationship between coast down time and CO_2 reduction. Using this method a relationship of: 1% increase in total coast down time = 0.23% CO_2 reduction on NEDC is established. Therefore if the full 5% and 10% margin is used, the CO_2 benefit would be 1.2%. The actual reduction will vary depending on the vehicle and the shape of the coast down curve. It may not be feasible to increase coast down time in a way that is follows the 5% and 10% margin exactly.
- Accuracy of road load measurement needs to be 5% of the load. This leads to further CO_2 benefit of 1.2% following the same analysis.

These flexibilities add up to a total of 4.7% CO_2 benefit if the full range is used for each one.

Effect on other emissions

Some of the above flexibilities relate to CO_2 measurement specifically, therefore have no direct effect on other emissions. Others, however, affect road load and ambient temperature. These may have some effect on other emissions as discussed in the sections on these topics. Some of the above flexibilities are likely to slightly increase NO_x, others are likely to slightly reduce NO_x; the overall effect on other emissions is likely to be small.

Summary table

Based on implementation of all laboratory instrumentation flexibilities discussed to the full extent, the following reduction in CO_2 is estimated. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 31 Potential effect on emissions due to instrumentation and fuel specification flexibilities

Fuel type	**CO_2**	**NO_x**	**PM**	**CO**	**HC**
Gasoline	-4.7%	Similar	Similar	Similar	Similar
Diesel	-4.7%	Similar	Similar	Similar	Similar

3.7.5 *Fuel specifications*

Fuel consumption and emission tests for type approval purposes are carried out with European reference fuels. This fuel has a very tight specification and a very narrow band of tolerance. The specifications of reference fuels (in UNECE R83) mainly contain physical parameters, there is no specification for carbon content. However for emission and fuel consumption calculations the actual carbon and hydrogen content are specified in the fuel test report. I.e. a petrol fuel contains 84 m% carbon. On the contrary commercial diesel fuels (EN590) or petrol fuel (EN228) are specified with a wider band. For the comparison between reference fuels and commercial fuels, see Table 32.

Due to the very narrow band of specifications of reference fuels it is expected that the carbon content is relatively stable and does not result in a possible flexibility with respect to measured CO_2 emissions. Whilst a reference fuel within specifications with 83.5 m% C will result in 1% lower vehicle CO_2 emissions than a fuel with 84.5 m% C, the ability of manufacturers to actively influence this through the use of specially targeted fuel characteristics in this way is considered to be very limited.

Table 32 Example parameters for diesel reference fuel and trade fuels

Parameter	Unit	Specification	Minimum	Maximum	Delta
Density	[kg/m^3]	EN590	820.0	845.0	25.0
		UNECE R83	833.0	837.0	4.0
Viscosity	[[mm2/s]	EN590	2.00	4.50	2.50
		UNECE R83	2.30	3.30	1.00
Polycyclic aromatic hydrocarbons	[% m/m]	EN590	-	11	11
		UNECE R83	2.0	6.0	4.0
Biofuel content FAME	[% v/v]	EN590	-	7.0	7.0
		UNECE R83	4.5	5.5	1.0

3.7.6 *Laboratory altitude (air density)*

The density of the intake air used during the NEDC test is largely dependent on laboratory altitude. This varies between facilities and may have some impact on CO_2 directly or indirectly.

Diesel engines in particular can be sensitive to altitude regarding the way they control NO_x emissions, and depending on the control strategy used these may have a knock-on effect on CO_2 emissions as a result. Depending on engine hardware, it may not be possible to compensate for reductions in ambient air density through boost control (especially at the low load levels typical of the NEDC), which may result in reduced combustion efficiency and thus increased CO_2 emissions. The degree of impact on CO_2 emissions at altitudes typically seen for homologation is likely to be small, however.

In general, diesel NO_x emission limits are perceived to be more challenging at higher altitudes, therefore it is likely to be preferred to choose a test facility located at sea level, especially in the case of vehicles for which the achievement of legislated NO_x emissions limits is a challenge.

For gasoline engines the lower air density at high altitude will tend to increase engine efficiency slightly due to wider throttle openings, however as for diesel this effect and the associated impact on CO_2 emissions are likely to be small.

CO_2 benefit
The CO_2 benefit of testing at higher altitudes is regarded as relatively small, compared to other flexibilities, and the choice of facility will be dependent on many other factors. It is likely that the impact on other emissions, especially NO_x, is likely to be the overriding factor.

Effect on other emissions
Higher altitudes may result in increased NO_x emissions in diesel vehicles, depending on what method of NO_x reduction is used. Calibration corrections may correct for this however.

3.7.7 *Temperature effects*

Regulations governing the Type 1 (NEDC) test procedure state the following:

- UNECE R83 – Annex 4a, 3.1.1 “During the test, the test cell temperature shall be between 293K and 303K (20°C and 30 C).”
- UNECE R83 – Annex 4a, 6.3.1 “After this preconditioning, and before testing, vehicles shall be kept in a room in which the temperature remains relatively constant between 293 and 303K (20°C and 30°C). This conditioning shall be carried out for at least six hours and continue until the engine oil temperature and coolant, if any, are within ±2K of the temperature of the room.”

This clearly shows flexibility in temperature within the specified range. There is a CO_2 benefit from higher vehicle soak temperature due to the reduced friction in the engine and vehicle components.

The temperature variation may also have an impact due to the necessary calibration settings required to warm the engine quickly at the start of the test. These settings may cause higher fuel consumption; therefore any reduction in warm-up time is likely to improve CO_2 in addition to the reduced friction.

The effect of intake air temperature during the test itself is less clear. It may be possible to improve combustion efficiency by setting the air temperature to the minimum (20 C), thus slightly reducing CO_2.

Specific technologies to retain heat energy in the drivetrain or engine bay are dealt with in separate regulations. These allow the manufacturer to demonstrate CO_2 reduction and calculate a reduction in the cycle result according to prescribed formulae. This process is outside of the scope of this report as it relates to technologies rather than legislative flexibilities. However, a calculation defined in the relevant document (shown in the literature review in chapter 2) allows CO_2 benefit to be calculated, for the flexibility of using a 30°C soak temperature. The source [JRC 2011] defines the CO_2 benefit of starting the NEDC test at a higher temperature as 0.17% per 1°C increase in temperature. [JRC 2009], also quoted in the literature review in chapter 2, mentions a relationship of 0.16% per 1°C.

CO_2 benefit
Using the formulae quoted above, the CO_2 difference between a test at 20°C and a test at 30°C gives a theoretical range of 1.7%.

It should be noted that the soak temperature must never exceed 30°C; therefore some margin must be allowed for the oscillatory nature of temperature control. It should also be noted that a ‘nominal’ test is unlikely to be carried out at 20°C, but is more likely to fall somewhere in the middle of the range.

Effect on other emissions
Starting the test at a higher temperature is likely to reduce aftertreatment warm-up times, which may give a benefit in other emissions. It may also contribute to an increase in NO_x emissions due to higher engine temperatures at an earlier stage in the test. However, this may be offset by reduced requirement for temperature based calibration corrections that limit NO_x reduction strategies such as EGR (exhaust gas recirculation).

Summary table
The effect of testing at a soak temperature of 30°C compared to 20°C is estimated here. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 33 Potential effect on emissions due to soak temperature flexibilities

Fuel type	**CO_2**	**NO_x**	**PM**	**CO**	**HC**
Gasoline	-1.7%	Similar	Similar	Down	Down
Diesel	-1.7%	Similar	Similar	Down	Down

3.7.8 *Coast down curve or cookbook load terms*

The NEDC test can be performed with chassis dynamometer load controlled in one of two ways:
1. Road load simulation matched to a coast down curve based on real test data;
2. Load governed by ‘cookbook’ load factors or ‘table values’ according to the reference mass of the vehicle.

This flexibility in the legislation may be used for CO_2 benefit as the two methods will not result in identical load during the NEDC test. The method that produces the lowest CO_2 result depends on several factors, discussed here.

The cookbook method does not include a measurement of aerodynamic drag or rolling resistance for the vehicle being tested, it only contains typical factors. Therefore it is beneficial to use this method for vehicles that have relatively high drag and/or rolling resistance, for example light goods vehicles or all-wheel drive vehicles.

For the coast down measurement test, the legislation (UN/ECE R83 – Annex 4a, Appendix 7, 4.1.1) specifies the following: "If there are different types of body, the test shall be performed on the least aerodynamic body. The manufacturer shall provide the necessary data for the selection." Therefore any vehicle with high aerodynamic drag will result in a poor coast down times at higher speeds. Using the cookbook method would replace this measured curve with a generic one, which may result in lower road loads for the NEDC test, hence lower CO_2.

The legislation (UNECE R83 – Annex 4a, 6.2.1.2) also states: "In the case of vehicles other than passenger cars, with a reference mass of more than 1,700 kg or vehicles with permanent all-wheel drive, the power values given in Table 3 are multiplied by a factor 1.3." Therefore the benefit of using the cookbook method is reduced for vehicles falling into this category. However, overall there is still likely to be a benefit to using the cookbook method for the larger vehicles.

For other vehicles, the coast down matching method leads to lower CO_2. This is the case if the vehicle has relatively low aerodynamic drag, and/or rolling resistance. This in itself is not considered a flexibility as the coast-down test is intended to provide realistic resistance factors for the tested vehicle. The method for coast-down testing, however, does allow for certain flexibilities to be utilised. These flexibilities are covered separately in the section relating to the coast-down derivation (2.4.2).

CO_2 benefit

The CO_2 benefit of using cookbook load terms rather than measured coast down times is highly dependent on the vehicle. It is very difficult to quantify because manufacturers will generally not measure / publish coast downs if they have already decided to use cookbook load factors. Any CO_2 benefit estimation would need to be derived from a vehicle that was previously tested using coast downs, and now is tested using cookbook factors.

Supporting data for the report 'Light Goods Vehicle – CO_2 Emissions Study, Framework Ref: PPRO 04/045/004' contains vehicle test results of a diesel light goods vehicle, tested with cookbook load terms. The same vehicle was tested using the coast down method and results compared. The comparison shows a CO_2 reduction of 3% is possible if cookbook terms are used. It should be noted that this does not apply to vehicles with relatively low aerodynamic drag and/or rolling resistance, for example many passenger cars.

Effect on other emissions

If using cookbook load factors reduces overall road load during the test, the effect on other emissions is likely to be reduced NO_x and PM, and slightly increased CO and HC due to the longer warm up time for exhaust aftertreatment.

Summary table

The effect of using cookbook load factors compared to coast down terms, is shown here. This only applies to vehicles with relatively high aerodynamic drag and rolling resistance, for example light goods vehicles and all terrain, all-wheel drive vehicles. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 34 Potential effect on emissions due to cook book load factors flexibilities

Fuel type	**CO_2**	**NO_x**	**PM**	**CO**	**HC**
Gasoline	-3%	Down	Down	Up	Up
Diesel	-3%	Down	Down	Up	Up

3.7.9 *Battery state-of-charge*

The state-of-charge of the starter/auxiliary battery at the start of the NEDC test is significant due to the additional electrical load placed on the alternator as it charges the battery during the test. If the battery is fully charged prior to the test the load will be reduced compared to a test starting with a battery in a low state-of-charge requiring more alternator charging during the NEDC.

State of charge also affects the 'stop/start' strategy employed on some vehicles. This technology has a measureable effect on CO_2 on the NEDC due to the engine not running during idle periods. However, the engine control system may disable the stop/start strategy if the battery is not sufficiently charged at the start of the test, leading to increased CO_2.

CO_2 benefit
CO_2 benefit is dependent on type of alternator, and change in battery charge level. Some smart alternators are able to utilise the braking sections of the emissions cycle to charge the battery. In these sections additional engine load is does not lead to increased fuel usage. Therefore reducing the charging required will not necessarily result in CO_2 benefit.

Using theoretical calculations (section 2.4.1), the effect of different alternator electrical power requirements were assessed in terms of the effect on cycle CO_2. The analysis is very dependent on the definition of the nominal condition for comparison. A case where the initial charging requirement was 420W, dropping to 215W over 300 seconds, compared to a case where the charging requirement was 215W throughout the test, gives a reduction in CO_2 of 0.7%. Ricardo test data was also analysed to compare test results with a fully charged battery to those with a partially discharged battery. These results show that a 2% reduction in CO_2 is possible. However, this does not mean that a reduction in CO_2 of 2% is always available, as a 'nominal' test may already start with a fully charged battery.

Effect on other emissions
A small reduction in other emissions is expected along with the reduction in CO_2, except for the effect of increased aftertreatment warm-up time due to lower engine loads experienced. The increased warm-up time may also result in the 'warm-up calibration' operating for longer, which may also affect other emissions.

Summary table
The table shows the potential effects of starting the test with a fully charged battery (due to external recharging during the soak period) compared to starting with a partially discharged battery. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 35 Potential effect on emissions due to battery state of charge flexibilities

Fuel type	**CO_2**	**NO_x**	**PM**	**CO**	**HC**
Gasoline	-1%	Down	Down	Up	Up
Diesel	-1%	Down	Down	Up	Up

3.7.10 *Gear change schedule and definition*

Gear number and change points are pre-defined in the NEDC cycle. However, some flexibilities exist in the following text:

- UNECE R83 – Annex 4a, 6.1.3.1 "If the maximum speed which can be attained in first gear is below 15 km/h, the second, third and fourth gears shall be used for the urban cycle (Part One) and the second, third, fourth and fifth gears for the extra-urban cycle (Part Two). The second, third and fourth gears may also be used for the urban cycle (Part One) and the second, third, fourth and fifth gears for the extra-urban cycle (Part Two) when the manufacturer's instructions recommend starting in second gear on level ground, or when first gear is therein defined as a gear reserved for cross-country driving, crawling or towing."

This allows scope to use higher gears on the NEDC test, which may reduce CO_2, depending on how the instruction manual is worded.

CO_2 benefit
If higher gear ratios are used, cycle CO_2 is reduced by two mechanisms. Firstly, the engine operates in a more efficient region of the BSFC (brake specific fuel consumption) map, due to the lower engine speeds associated with higher gearing. Secondly, the power losses in the drivetrain reduce as the overall ratio approaches 1:1. These two mechanisms combine to give an overall benefit in CO_2.

Theoretical calculations were carried out (section 2.4.1) comparing a gear shift strategy of 1st to 5th gear, to a strategy using only 2nd to 5th gear. This analysis showed a significant CO_2 reduction is possible, of 8% over the NEDC cycle. This result compares with test data from the Ricardo vehicle test database which indicated that a benefit of 5% is shown in some cases. The difference in the two numbers is partly due to non-identical vehicle characteristics; for example the exact shape of the BSFC map affects, and the number and ratio of gears. It is also partly due to the difficulty in driving the NEDC cycle smoothly in the higher gears, such as pulling away in second gear. So the overall benefit can be said to be in the region of 6%, depending on the vehicle.

Effect on other emissions
NO_x emissions generally increase due to the higher engine loads required to provide the same power at a lower engine speed. This may have a knock on impact on CO_2 emissions if recalibration is required to redress the increased NO_x.

Summary table
Estimates are shown for the effect of using a higher gear at each stage of the NEDC test, for example 2nd to 5th gear rather than 1st to 5th gear. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 36 Potential effect on emissions due to gear change schedule flexibilities

Fuel type	**CO_2**	**NO_x**	**PM**	**CO**	**HC**
Gasoline	-6%	Up	Similar	Similar	Similar
Diesel	-6%	Up	Similar	Similar	Similar

It should be noted that this significant benefit is only available for vehicles that meet the criterion that the maximum speed which can be attained in first gear is below 15 km/h. The criterion generally does not apply to modern passenger cars and vans.

3.7.11 *Driving technique*

Speed/time tolerance bands apply to the NEDC target cycle. It is impossible for a driver to exactly follow the target speed trace, so tolerances are applied to account for this.

- UNECE R83 – Annex 4a, 6.1.3.4, “A tolerance of ±2 km/h shall be allowed between the indicated speed and the theoretical speed during acceleration, during steady speed, and during deceleration when the vehicle's brakes are used.”
- UNECE R83 – Annex 4a, 6.1.3.5, “The time tolerances shall be ±1.0 s. The above tolerances shall apply equally at the beginning and at the end of each gear-changing period for the urban cycle (Part One) and for the operations Nos. 3, 5 and 7 of the extra-urban cycle (Part Two). It should be noted that the time of two seconds allowed includes the time for changing gear and, if necessary, a certain amount of latitude to catch up with the cycle.”

It may be possible to use these tolerance bands to achieve a lower CO_2 result. This may be achieved by reducing the rate of acceleration as much as possible, making smooth transitions between start and end of each acceleration phase, and minimising the time taken to change gear. Likewise, a higher CO_2 result may occur if the driving style includes higher rates of acceleration, and sharp changes of accelerator pedal position. A particularly high CO_2 result would be measured if the driver uses lots of corrective pedal movements to follow the speed/time profile. This would introduce many small accelerations and decelerations within the boundaries of the target speed trace.

CO_2 benefit
The reduction in CO_2 depends on the driving style for a nominal test. Using the theoretical calculations discussed in section 2.4.1, a revised vehicle speed trace was used to assess the effect of utilising the tolerances available. This gave a CO_2 reduction of 1.2% over the NEDC, compared to a baseline where the vehicle speed trace was followed precisely. In reality the benefit varies considerably depending on how well the baseline test is driven, and on transient factors such as speed of gear change, pull away and clutch control.

Effect on other emissions

Generally the driving style that reduces CO_2 will also reduce other emissions, especially NO_x in the case of diesel vehicles (for which HC and CO will be less affected due to the presence of oxidation catalysts.)

Summary table

Estimates are shown for a test driven with minimum acceleration rate and minimum vehicle speed, compared to a test driven exactly to the target cycle. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise.

Table 37 Potential effect on emissions due to driving techniques flexibilities

Fuel type	**CO_2**	**NO_x**	**PM**	**CO**	**HC**
Gasoline	-1.2%	Down	Down	Similar	Similar
Diesel	-1.2%	Down	Down	Similar	Similar

3.7.12 *DPF related Ki factor (distance between DPF regenerations) for calculating total cycle CO_2*

For vehicles fitted with a diesel particulate filter (DPF), the total CO_2 result includes an additional factor to take into account emissions whilst regenerating the DPF. The weighting factor applied to the regeneration test relative to the standard test (known as the Ki factor) is dependent on the expected interval between DPF regenerations. It is likely that the CO_2 will be higher during the regeneration test; therefore, a shorter interval between regenerations will increase total CO_2.

The flexibility in the legislation relates to the definition of this interval. It is advantageous to choose the method giving the longest interval between regenerations. UNECE R83 – Annex 13, states that "Exhaust emission measurement between two cycles where regenerative phases occur:

- 3.1.1: Average emissions between regeneration phases and during loading of the regenerative device shall be determined from the arithmetic mean of several approximately equidistant (if more than 2) Type I operating cycles or equivalent engine test bench cycles. As an alternative, the manufacturer may provide data to show that the emissions remain constant (±15 per cent) between regeneration phases. In this case, the emissions measured during the regular Type I Test may be used. In any other case emissions measurement for at least two Type I operating cycles or equivalent engine test bench cycles must be completed: one immediately after regeneration (before new loading) and one as close as possible prior to a regeneration phase. All emissions measurements and calculations shall be carried out according to Annex 4a, paragraphs 6.4. to 6.6. Determination of average emissions for a single regenerative system shall be calculated according to paragraph 3.3. of this annex and for multiple regeneration systems according to paragraph 3.4. of this annex.
- 3.1.2: The loading process and Ki determination shall be made during the Type I operating cycle, on a chassis dynamometer or on an engine test bench using an equivalent test cycle. These cycles may be run continuously (i.e. without the need to switch the engine off between cycles). After any number of completed cycles, the vehicle may be removed from the chassis dynamometer, and the test continued at a later time.
- 3.1.3: The number of cycles (D) between two cycles where regeneration phases occur, the number of cycles over which emissions measurements are made (n), and each emissions measurement (M'_{sij}) shall be reported in Annex 1, items 4.2.11.2.1.10.1. to 4.2.11.2.1.10.4. or 4.2.11.2.5.4.1. to 4.2.11.2.5.4.4. as applicable."

In addition to the soot produced by the engine during DPF loading it is important to consider any 'passive' regeneration that may occur as a result of naturally occurring conditions within the exhaust system. This is where NO_2 (usually formed in the diesel oxidation catalyst) is fed into the DPF, at the correct temperature range, combining with carbon on the DPF to form CO_2. Passive regeneration occurs at different rates depending on the quantity of soot in the DPF. Therefore the curve of DPF soot load vs. distance is not linear. If it can be shown that this non-linearity extends the regeneration interval, then the Ki factor will be reduced, leading to lower total CO_2.

CO_2 benefit
The potential benefit is estimated for a typical example of CO_2 in normal operating mode of 161.8g/km (based on the calculations shown in 2.4.1), and a CO_2 in regeneration mode of 185g/km. If the regeneration interval is equivalent to 50 NEDC tests, and the regeneration length is 2 NEDC tests, the overall CO_2 is 162.69g/km. If this interval is extended to 100 NEDC tests the overall CO_2 is 162.25g/km. The Ki factors are 1.0055 and 1.0028 respectively.

Effect on other emissions
A similar effect is calculated for the other emissions to give a Ki factor for each. The most affected is expected to be NO_x, as this NO_x emissions increase significantly during regeneration. It may also slightly reduce the CO and HC cycle results although not in every case. This flexibility is applicable only to diesel engines.

Summary table
Effect on emissions is shown when the DPF regeneration interval is extended from 50 NEDC tests, to 100 NEDC tests. These estimates relate to both passenger car and light commercial vehicles unless stated otherwise, and apply only to diesel vehicles.

Table 38 Potential effect on emissions due to DPF regenerating interval flexibilities

Fuel type	**CO_2**	**NO_x**	**PM**	**CO**	**HC**
Gasoline	N/A	N/A	N/A	N/A	N/A
Diesel	-0.3%	Down	Similar	Similar	Similar

3.7.13 *Declared CO_2 value*

Once the CO_2 test result is known, the manufacturer can decide what value to declare, taking into account the margin required to pass conformity of production checks, and in service testing. The declared value can be up to 4% lower than the actual measured result:

- UNECE Regulation No. 101, 5.5.1 “The CO_2 value or the value of electric energy consumption adopted as the type approval value shall be the value declared by the manufacturer if the value measured by the technical service does not exceed the declared value by more than 4 per cent.”

CO_2 benefit
The CO_2 benefit available compared to the measured result is 4%. However, the benefit of declaring a low value would have to be weighed up against the risk of penalties from conformity of production checks and in service testing. This risk increases with the level of vehicle-to-vehicle variation resulting from production tolerances.

Effect on other emissions
As this flexibility relates to CO_2 calculation only, there are no effects on other emissions.

3.8 Summary of the analysis of potential CO_2 benefits of test procedure flexibilities

A summary table is shown below (Table 39) for all flexibilities identified in previous sections, but it should be noted that the stated reductions in CO_2 for each flexibility are not simply additive. This table should not be read in isolation as the comments in the above discussion are needed to explain when each flexibility can be applied, and to what extent. The comments also discuss which flexibilities cannot be used in parallel, and hence cannot be added together to calculate a total CO_2 benefit. These estimates relate to both passenger cars and light commercial vehicles unless stated otherwise.

Table 39 Summary of all flexibilities identified and their potential effect on CO_2 and other emissions

	Fuel type	CO_2	NO_x	PM	CO	HC
Utilising all flexibilities relating to the coast down test	Gasoline	-4.5%	Down	Down	Up	Up
	Diesel	-4.5%	Down	Down	Up	Up
Reduction in vehicle mass of 110kg (one inertia class)	Gasoline	-2.5%	Down	Down	Up	Up
	Diesel	-2.5%	Down	Down	Up	Up
Optimising wheel and tyre specification to increase rolling radius by 5%	Gasoline	-2%	Up	Up	Similar	Similar
	Diesel	-2%	Up	Up	Similar	Similar
Reducing overall rolling resistance by 20%	Gasoline	-2.8%	Down	Down	Similar	Similar
	Diesel	-2.8%	Down	Down	Similar	Similar
Increasing the running-in distance from 3000km to 15000km (for cookbook method only)	Gasoline	-5%	Down	Down	Up	Up
	Diesel	-5%	Down	Down	Up	Up
Implementation of all laboratory instrumentation flexibilities, to the full extent	Gasoline	-4.7%	Similar	Similar	Similar	Similar
	Diesel	-4.7%	Similar	Similar	Similar	Similar
Testing at a soak temperature of 30°C compared to 20°C	Gasoline	-1.7%	Similar	Similar	Down	Down
	Diesel	-1.7%	Similar	Similar	Down	Down
Using cookbook load factors compared to coast down terms, (applies to light goods vehicles and all-terrain vehicles only)	Gasoline	-3%	Down	Down	Up	Up
	Diesel	-3%	Down	Down	Up	Up
Starting the test with a fully charged battery (due to external recharging throughout the soak period) compared to a partially discharged battery	Gasoline	-1%	Down	Down	Up	Up
	Diesel	-1%	Down	Down	Up	Up
Using a higher gear at each stage of the NEDC test, for example 2nd to 5th gear rather than 1st to 5th gear	Gasoline	-6%	Up	Similar	Similar	Similar
	Diesel	-6%	Up	Similar	Similar	Similar
Using driving technique to minimise acceleration rate and vehicle speed within the tolerance allowed, compared to a test driven exactly to the target cycle	Gasoline	-1.2%	Down	Down	Similar	Similar
	Diesel	-1.2%	Down	Down	Similar	Similar
Extending DPF regeneration interval from 50 NEDC tests, to 100 NEDC tests to reduce Ki factor	Gasoline	N/A	N/A	N/A	N/A	N/A
	Diesel	-0.3%	Down	Similar	Similar	Similar
Declaring for homologation a lower CO_2 value than has been achieved in testing: declared value is allowed to be up to 4% lower than the measured result	Gasoline	-4%	N/A	N/A	N/A	N/A
	Diesel	-4%	N/A	N/A	N/A	N/A

As can be seen from Table 39, the estimated potential associated with utilising all flexibilities within allowable bandwidths relating to the coast down test is 4.5%. However, [TNO 2012b] (one of the studies included in the literature review described in chapter 2) presents independent measurements on vehicles comparing CO_2 emissions measured using the type approval rollerbench settings as reported by the manufacturer and settings based on independently conducted coast down test. Observed differences are of the order of 10%. This seems to suggest that in coast-down testing also flexibilities may be utilised which are outside allowable bandwidths or related to test conditions which are not or not clearly defined in the test procedure.

3.9 Flexibilities specific to hybrid electric vehicles

Test procedures for hybrid vehicles differ from those for internal combustion engine only vehicles. Therefore, some flexibilities exist that are specific to hybrid vehicles only, compared to conventional 'internal combustion engine only' vehicles.

3.9.1 *Classification of hybrid electric vehicles*

In order to understand these flexibilities it is important to define the classification of hybrid vehicles and the terminology used. Hybrid electric vehicles are subject to the following definitions in UNECE Regulation No. 101:

- 2.13.1: “"Hybrid electric power train" means a power train that, for the purpose of mechanical propulsion, draws energy from both of the following on-vehicle sources of stored energy/power:
  - a consumable fuel
  - an electrical energy/power storage device (e.g.: battery, capacitor, flywheel/generator...)”
- 2.14.1: “"Hybrid electric vehicle (HEV)" means a vehicle powered by a hybrid electric power train.”

These definitions clearly describe that any vehicle deriving its propulsion energy from an engine and an electrical source can be classified as a hybrid electric vehicle. This may include so called 'mild hybrids' such as belt driven starter/generators that are able to provide a limited amount of torque increase from the starter/generator unit. However, vehicles with only 'stop/start' technology, or intelligent alternator charging do not class as hybrids as they cannot apply a propulsion force using the electrical power source.

Classifying a vehicle as a hybrid allows the flexibilities defined in this section to be applied. Therefore it may be possible to gain a CO_2 reduction based on these flexibilities alone, by making the minimum changes required to classify a vehicle as a hybrid.

The classification is further broken down into 'off vehicle charging', OVC (also referred to as 'plug-in hybrid electric vehicles', PHEV), and 'non off vehicle charging', NOVC. The off vehicle charging element refers to the capability to receive electrical energy from an external source, for example being plugged into a mains electrical supply whilst the vehicle is parked.

CO_2 benefit
The CO_2 benefit available is dependent on which further flexibilities are then utilised as a result of classifying the vehicle as a hybrid. As these are discussed as separate items the CO_2 benefit is not estimated here.

3.9.2 *CO_2 calculations for hybrid and plug-in hybrid electric vehicles*

The legislation governing CO_2 calculations varies depending on the type of hybrid (OVC or NOVC). The key difference between the two is that OVC HEVs can include range covered whilst utilising energy added to the vehicle during off vehicle charging.

For OVC HEVs two verification tests are performed, one starting with a fully charged battery, and one starting with a fully discharged battery. These two test results are combined with the vehicle's electric range, and a parameter that can be interpreted as the assumed distance between opportunities to recharge (25km), to get an overall CO_2 result. The calculation does not take into account the CO_2 used to generate the electricity utilised during plug-in recharging. Electrical energy consumption is reported separately to cycle CO_2. This method of calculation leads to significantly lower CO_2 results for OVC HEVs compared to NOVC HEVs.

The OVC HEV CO_2 calculation is defined as follows in UNECE Regulation No. 101:

"3.4.2. The weighted values of CO_2 shall be calculated as below:

$$M = (D_e \cdot M_1 + D_{av} \cdot M_2)/(D_e + D_{av})$$

Where:

M = mass emission of CO_2 in grams per kilometre
M_1 = mass emission of CO_2 in grams per kilometre with a fully charged electrical energy/power storage device
M_2 = mass emission of CO_2 in grams per kilometre with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity)
D_e = vehicle's electric range, according to the procedure described in Annex 9, where the manufacturer must provide the means for performing the measurement with the vehicle running in pure electric operating state.
D_{av} = 25 km (assumed average distance between two battery recharges)"

It is not clear whether the procedures for preconditioning for the two tests contain flexibilities. This would deserve further investigation.

The main flexibility within this calculation is the value of 'D_e', the vehicle's electric range. A test procedure is defined to measure this value, however some flexibilities exist. Any increase in the value of 'D_e' will lead to a lower overall CO_2 value, so it is beneficial to measure the maximum possible vehicle range in this test.

Range measurement is therefore a flexibility for OVC HEVs. The test procedure requires that consecutive NEDC cycles are driven for as long as possible until some 'end of test criteria' are reached. The exact definition of the end of test has a significant impact on measured range (the 'D_e' value), and therefore cycle CO_2. Flexibilities exist in defining this end point:

- UN/ECE Regulation No. 101, Annex 9, 4.2.2.1.2.: "To measure the electric range the end of the test criteria is reached when
  - the vehicle is not able to meet the target curve up to 50 km/h, or
  - when an indication from the standard on-board instrumentation is given to the driver to stop the vehicle or
  - when the battery has reached its minimum state of charge.

  Then the vehicle shall be slowed down to 5 km/h by releasing the accelerator pedal, without touching the brake pedal and then stopped by braking."

These statements contain some flexibility as the method of determining battery minimum state of charge is not defined. There is also opportunity to increase the range during the period where the accelerator pedal is released, as the distance covered will be a function of how much regenerative braking occurs under these conditions (lift-off braking). Minimising the regenerative braking at this point will increase the measured electric range of the vehicle.

For NOVC HEVs the overall CO_2 is calculated based on an NEDC test corrected by a factor to account for the change in state-of-charge of the vehicle's battery as recorded during the test. The aim of this approach is to estimate the CO_2 that represents zero energy balance of the battery throughout an NEDC test.

The correction factor is determined by the manufacturer by performing a series of tests starting at different initial battery states-of-charge, some of which will have a positive battery energy balance and some a negative. This data is then used to calculate a CO_2 correction factor, which equates electrical energy balance to CO_2. The correction factor is applied to the NEDC verification test result to establish overall CO_2.

CO_2 benefit
The additional benefit of classifying a vehicle as an OVC HEV as opposed to a NOVC HEV is significant. The different methods of calculating CO_2 give additional flexibilities for OVC HEVs. The key advantage of OVC HEVs is that the energy added to the vehicle during off vehicle charging is not

accounted for in terms of CO_2. This benefit is difficult to quantify as it depends on the chosen battery capacity of the vehicle. However, a CO_2 reduction of 20-50% is potentially possible with a high capacity battery. Other flexibilities also apply only to OVC HEVs such as the detailed test procedure for measuring vehicle electric range. This can lead to additional opportunities to reduce CO_2 for OVC HEVs that are not available to NOVC HEVs.

3.9.3 *Operating mode switch*

The type approval test procedure for the two types of hybrid electric vehicles, OVC HEVs and NOVC HEVs, differ in the way operating modes are used.

For NOVC HEVs the test is run in the mode that is automatically set when the ignition is switched on. In real-world use it would be possible for the driver to select a different mode when driving. However this does not represent a type approval flexibility as the test conditions are fully specified.

For OVC HEVs the test is conducted according to a matrix (UNECE Regulation No. 101, Annex 8, 4.1.3) to determine which operating mode should be selected for each stage of the type approval test:

Table 40 Matrix to determine which operating mode should be selected for each stage of the type approval test as provided in UNECE Regulation No. 101, Annex 8, 4.1.3

Hybrid-modes / Battery state of charge	↳ Pure electric ↳ Hybrid Switch in position	↳ Pure fuel consuming ↳ Hybrid Switch in position	↳ Pure electric ↳ Pure fuel consuming ↳ Hybrid Switch in position	↳ Hybrid mode n*/ ↳ ... ↳ Hybrid mode m* Switch in position
Condition A Fully charged	Hybrid	Hybrid	Hybrid	Most electric hybrid mode**/
Condition B Min. state of charge	Hybrid	Fuel consuming	Fuel consuming	Most fuel consuming mode***/

Modes ‘n’ or ‘m’ can be a mixture of electric and fuel consuming operation with a bias towards certain driving styles such as ‘eco mode’, ‘sport mode’, or ‘urban mode’. This matrix allows some flexibility to define the modes in a way that will give the lowest overall CO_2 result. This is an additional flexibility compared to a NOVC HEV with a mode switch.

CO_2 benefit

The CO_2 benefit of optimising with respect to the classification of operating modes is linked to the intrinsic CO_2 benefit of hybrid technology. Therefore it is not possible to separate the benefit from a mode switch from other hybrid vehicle benefits when comparing to non-hybrid vehicles.

It is also important to state that providing an operating mode switch does not allow the manufacturer to have a ‘type approval calibration’ (for low CO_2) and a separate ‘real-world calibration’ for normal use. For NOVC HEVs the mode used in the type approval has to be selected by default at ignition on. For OVC HEVs various modes are tested, including the most fuel consuming mode.

3.9.4 *Regenerative braking*

Both OVC HEVs and NOVC HEVs typically utilise regenerative braking to charge the battery. This takes place when the rate of deceleration is appropriate, and only on the driven axles (assuming two wheel electric drive). The NEDC test is conducted with only the driven wheels rotating on the chassis dynamometer. Therefore the energy dissipated by conventional brakes on the non-driven axles is not accounted for during the NEDC test, as these wheels are held stationary. On a conventional vehicle the effect is accounted for because the driven axles will experience higher braking forces; on a hybrid, the increased regenerative braking leads to artificially high battery charging. This can be seen as a flexibility for hybrid vehicles, compared to conventional vehicles.

Furthermore, it is potentially possible to calibrate the regenerative braking strategy to take maximum advantage of this set up. This may involve biasing the braking force towards the driven axles, and maximising the regenerative braking rather than using the conventional brakes on those axles. This approach would need to ensure brake balance for real-world operation is not compromised too much.

CO_2 benefit
This flexibility is largely dependent on vehicle and braking system design. The total amount of regenerative braking that can be utilised is influenced by many factors, such as: vehicle weight distribution, tyre and suspension set up, vehicle driveability characteristics, and energy storage capacity. The potential CO_2 reduction can be estimated as follows.

For the same vehicle model used in chapter 3, the total energy requirement for driving the vehicle over the NEDC cycle is calculated. The total energy dissipated in the braking system for deceleration, after considering aerodynamic drag and rolling resistance, is also calculated. The proportion of braking energy throughout the NEDC test is approximately 29% of the total energy required to drive the vehicle over the NEDC.

However, the potential energy available for recovery is much lower than this. Typically hybrid vehicles can only perform regenerative braking on the driven axle. The assumption here, based on a front wheel drive vehicle, is that 60% of the total braking occurs at the front wheels. Also, the total proportion of regenerative braking to conventional braking is limited by the handling of the vehicle. In order to maintain driver control, and achieve good driveability, some conventional braking is maintained. The assumption here is that 70% is regenerative braking. The efficiency of energy recovery, storage, and re-use also needs to be considered. The assumption here is 50% ‘round trip’ efficiency.

After taking all these factors into consideration the total reduction in energy required for this vehicle to drive the NEDC is 6.1%. This estimate may be further reduced by complicating factors such as battery state-of-charge throughout the cycle. When the state-of-charge is too high for the battery to store additional energy, the benefit is lost.

3.9.5 *Gear shift schedule*

The gear shift schedule for hybrid electric vehicles on the NEDC is different to that of conventional vehicles. There is greater flexibility for hybrid electric vehicles in choice of gear. This is implemented by defining optimum change points for low CO_2, and displaying a dashboard indicator to communicate the gear changes to the driver at the appropriate time.

The flexibility is clearly stated in UN/ECE Regulation No. 101, Annex 8, 1.4.2:

- “For vehicles with a special gear shifting strategy the gear shifting points prescribed in appendix 1 of Annex 4 to Regulation No. 83 are not applied. For these vehicles the driving cycle specified in paragraph 2.3.3. of Annex 4 to Regulation No. 83 in force at the time of approval of the vehicle shall be used. Concerning gear shifting points, these vehicles shall be driven according to the manufacturer’s instructions, as incorporated in the drivers’ handbook of production vehicles and indicated by a technical gear shift instrument (for drivers information).”

This difference is anticipated to have a significant impact on cycle CO_2 for two reasons. Firstly, the choice of gear selections allows lower gears to be chosen during the deceleration phases, leading to more energy recovery in regenerative braking. Secondly, gear selection alone can significantly improve CO_2 results (as discussed in the gear schedule section for conventional vehicles). This is due to the combined effect of better brake specific fuel consumption at lower engine speeds, and the reduced drivetrain power losses at lower shaft speeds. Although this mechanism for CO_2 reduction is the same for hybrid and non-hybrid vehicles, the flexibility is only available to hybrid vehicles in the regulations.

CO_2 benefit
Investigations into gear shift strategies on both hybrid and conventional vehicles have shown a significant benefit in using optimised gear shift points. Potential for CO_2 reduction is expected to be greater than 10%.

3.10 Conclusions

Through a review of the legislation a number of flexibilities to achieve a low drive cycle CO_2 result were identified within the type approval procedure. The potential impact of these flexibilities on CO_2 and other emissions was assessed for gasoline and diesel passenger cars and light commercial vehicles (LCVs).

As indicated in this assessment, it may be advantageous to make use of some of the flexibilities for several different reasons, for example to help meet legislated emissions limits, even if reduction of CO_2 emissions is not a priority. Also a proportion of the theoretically available flexibilities may not be practical to implement in every vehicle and whilst some reduce CO_2 they can have an adverse effect on other emissions (such as increasing NO_x). Thus it cannot be assumed that the full theoretical range of flexibility is available in every case.

The analysis of a vehicle group (family) demonstrates that in one family there can exist vehicles that strongly differ in the CO_2 emission values, and it would be very disadvantageous to report only the reference vehicle with a relative high CO_2 emission. As a consequence, in view of vehicle CO_2 emissions the application of the vehicle group definition has been ignored because all individual CO_2 results of all vehicle group members are reported in the type approval certificates.

In addition with regards to the CO_2 benefits for each identified flexibility there are flexibilities that definitely cannot be used in parallel (for example the flexibilities related to coast-down times and cookbook approach). For the remaining flexibilities no structured experiments have been carried out to validate the extent to which the variations in CO_2 identified are additive. It is entirely possible that there will be complex interactions between the various factors and an experimental study would be necessary to verify these cumulative effects.

4 Past use of flexibilities

4.1 Objectives

The objective of this chapter is to assess the extent to which flexibilities in the type approval test procedures have already been utilised prior to the period in which upcoming or existing CO_2 legislation for light duty vehicles increased the focus on the measurement of CO_2 emissions in the type approval test.

The activities reported within this chapter are:

- Review of the flexibilities identified in chapter 2 and 3 from the viewpoint of pollutant emission legislation.
- Indication of a link between each of the issues/flexibilities and potential benefits.
- Identification of possible synergies or trade-offs between utilising test procedure flexibilities in the context of meeting pollutant emission standards and the goal of minimising CO_2 emissions on the type approval test.
- Inventory of vehicle/engine technology available to passenger cars as of model year 2002 that allow dedicated calibration, the extent to which dedicated calibrations may have contributed to lowering emissions as measured on the type approval test and whether this may have influenced the CO_2 emissions as measured on the test.

4.2 Methodology

This chapter deals with different subjects which are related to flexibilities which have been applied in the past. The work was conducted through review of the experiences of experts including those who are regularly involved in the testing of light duty vehicles. The interpretation of the legislation and rules which govern the carrying out of CO_2 measurements over the NEDC for new vehicle type approval were analysed to pinpoint the sources of flexibility. The activities are:

- Assessment of type approval experiences
- Assessment of characteristics of different applied technologies
- Assessment of different legislations
- Assessment of different type approval authorities and test houses
- Assessment of historical databases

Various methods were used to describe the level playing field, including the following:

- Use of knowledge and experiences of (technical) experts
- Use of available information of automotive stakeholders
- Use of type approval databases

This chapter describes the use of flexibilities qualitatively. In chapter 5 the quantification of the use of flexibilities in the past is reported.

4.3 Identification of flexibilities with regard to legislation of pollutant emissions

4.3.1 *Technology and flexibilities*

In the European Directives 70/220/EEC, 98/69/EC and 2003/76/EC CO, THC, NO_x and PM light duty vehicle emission limits are set in order to protect people and the environment. For Euro 5 vehicles new regulations have been introduced: Regulation EC 715/2007 and EC 692/2008. Both these regulations refer to ECE R83 for the details of the test procedure. In Table 41 the emission limit values of Euro 3 up to Euro 6 vehicles are reported. Due to the different nature of petrol and diesel engines and the developments in their technologies (and fuels) different emission limit values have been chosen. Therefore the application of these two types of engines require a different approach of the flexibilities.

Table 41 European emission limit values of passenger cars (class M < 3500 kg).

Vehicle	Euro Class	CO	THC	NO_x	THC+NO_x	PM	PN	CO_2
		[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[-/km]	[g/km]
Petrol	3	2.30	0.200	0.150		-	-	-
Petrol	4	1.00	0.100	0.080		-	-	-
Petrol	5	1.00	0.100	0.060		0.0045	-	-
Petrol	6	1.00	0.100	0.060		0.0045	Tbd	-
Diesel	3	0.640	-	0.500	0.560	0.0500	-	-
Diesel	4	0.500	-	0.250	0.300	0.0250	-	-
Diesel	5	0.500	-	0.180	0.230	0.0045	$6 * 10^{11}$	-
Diesel	6	0.500	-	0.080	0.170	0.0045	$6 * 10^{11}$	-

Engines, aftertreatment systems and flexibilities
The combustion of a modern engine still produces too much undesirable emissions and the application of an aftertreatment technology (i.e. a three-way or oxidation catalyst) reduces the vehicle emissions below a certain emission limit value. Different aftertreatment technologies have been applied for petrol and diesel engines. Due to the very different nature of petrol and diesel engines and their different aftertreatment systems very specific flexibilities can be expected.

From these findings it can be concluded that the applied engine technology and the aftertreatment technology play an important role for application of flexibilities.

Manufacturers mostly develop an engine with a (relatively powerful) exhaust aftertreatment system at a safe emission level, i.e. 70-80% of the type approval limits. Due to the spread of vehicle production and deterioration of the system all production vehicles meet the type approval emission limits in Conformity Of Production tests.

4.3.2 *Type approval operating window and flexibilities*

For some vehicles it is needed to perform an emission test strictly in a certain area of the type approval operating window. Especially diesel vehicles have been very closely optimised near the limit values because fuel consumption is inversely proportional to NO_x emission, and because available emission control technologies did not provide sufficient ‘headroom’.

TNO specialists with more than 20 years of experience have mentioned the following flexibilities which were sometimes applied in the past:

1. Vehicle drive line preparation for decrease of rolling resistances.
2. Use of dedicated test track for determination of road load curve.
3. Determination of road load curves at higher ambient temperatures.
4. Vehicle preconditioning at certain engine operating levels. This was mainly done for preconditioning purposes of the exhaust aftertreatment system.
5. Vehicle soak near 30°C. This measure promotes a relative fast light-off of the catalyst.
6. Optimisation of forced cooling of the vehicle.
7. Application of dedicated test fuels (within the band of reference fuels), i.e. fuel without sulphur (< 10 ppm). This minimises the PM emission of a diesel vehicle (without DPF).

4.3.3 *Developments of petrol engines and aftertreatment technologies*

Most petrol vehicles are equipped with a stoichiometric engine, a fuel injection system and a three-way catalyst which is a very powerful tool for reduction of CO, THC and NO_x emissions. Conversion efficiencies of 80 - 95% are very common. After the cold start (20 - 30°C) and during the warming up phase the light-off temperature of a catalyst must be reached as fast as possible. Moreover the catalyst must also be activated in the type VI emission test carried out at -7°C.

The application of an engine management system with integrated ignition system and an active engine knock control system creates a possibility for improved engine efficiency (compared to carburettor engines). Due to the availability of temperature and engine load sensors more precise engine operation is possible which results in better engine speed control, better driveability and slightly improved engine efficiency in the warming-up phase. The corresponding estimated CO_2 reduction is 2%.

A very good means to reduce the cost of a catalyst is reduction of precious metals in the catalyst. As a consequence the light-off temperature of the catalyst will increase. This may be compensated by an increase of the test cell temperature, a restricted activation and modified flow direction of the cooling fan of the test cell and adjustments of the engine management system (i.e. retarding of ignition timing). The latter will result in an increase of CO_2 emissions. Some Euro 3 vehicles are equipped with lean burn engines and EGR-systems. These technologies are less powerful and flexibilities may be more important than in stoichiometric engines. For Euro 3 petrol engines the cooling air flow of the chassis dynamometer fan can be marked as a flexibility.

The 3-way catalyst technology has been further developed for Euro 4, 5, and 6 vehicles. In order to reach its operating temperature faster, the catalyst has been mounted very close to the engine. Additionally optimisation of precious metals in the catalyst has taken place. These developments result in a more robust concept which is less sensitive to cooling air.

The limit values of Euro 5 and 6 petrol vehicles are equal and it might be concluded that petrol vehicles are ready with their emission development. Petrol engines and aftertreatment technologies are emission-wise fully developed and do not really need flexibilities to comply with the regulations. However in the future their CO_2 emissions must be further reduced and flexibilities definitely contribute to lower CO_2 emissions.

4.3.4 *Developments of diesel engines and emission control technologies*

In 2002 the development of the diesel engine technology was at an impressive level. Fuel injection technologies, engine management systems and turbo chargers were implemented but also the naturally aspirated version was still very popular. It resulted in an increase of the specific power and people accepted the disadvantages (noise and odours) because the diesel vehicle was not slow anymore, relatively cheap and reliable.

The application of an engine management system with integrated fuel injection system and an active engine speed control and injection timing system creates a possibility for a slightly improved engine efficiency (compared to mechanical injection systems). Due to the availability of temperature and engine load sensors more precise engine operation is possible which results in better engine speed control. The corresponding estimated CO_2 reduction is 0.5%.

At that time the European emission limit values for diesel vehicles were also less stringent than the petrol limit values. The main reason for this increased emission level was the lack of available engine and emission reduction technologies and partly due to their (historically) restricted market share. Although the NO_x and PM emission limit values of diesel vehicles were relatively high the engine and fuel injection technologies could hardly meet the requirements because efficient combustion results in high NO_x emission. The absence of sulphur free fuel was also a barrier for implementation of exhaust aftertreatment technologies. Therefore Euro 3 vehicles with their sensitive technologies (fuel injectors, turbo chargers and high pressure pumps) passed their emission tests with relatively high emission levels. The majority of diesel vehicles has been adjusted at 90-95% of the NO_x limit value.

Note: The NEDC test cycle with its relatively low load and low speed profiles and the lack of emission testing at -7°C could be marked as favourable for diesel engines.

Further reduction of the PM and NO_x emissions of Euro 4 and 5 diesel vehicles has been achieved by application of (cooled) EGR, improved fuel injection technology and improved EGR control strategies. Again some of these vehicles perform near their NO_x emission limit values, others run well below the limit values. PM emissions have been reduced by application of diesel particulate filters with a PM filtration efficiency of more than 99%. Regarding pollutants flexibilities were not very important because NO_x and PM emissions were mainly dependent on engine parameters and the performance of EGR-technology and DPF-technology. For Euro 3 diesel engines the cooling air flow of the chassis dynamometer fan can be marked as a flexibility because the light off temperature of the oxidation catalyst will be influenced.

4.3.5 *Engine management systems and CO_2 emissions*

The application of sensors and an engine management system create the possibility to define an engine state and certain emission strategies at certain times. Coolant, air and lubricant temperature sensors as well as wheel speed sensors register the vehicle conditions and may be used to set a certain emission strategy to be applied when the vehicle is undergoing emission testing. One of the possible measures in this emission test mode is a modification (retarding) of the timing of combustion. More thermal energy will be offered to the catalyst and its light off temperature will be reached faster. As a drawback engine efficiency will decrease and CO_2 emissions per kilometre will increase.

If a system doesn't recognise the emission test mode, it can be set in a fuel efficient mode and CO_2 emissions in real world will be relatively lower. These technical features of an engine management system create a positive effect on real world CO_2 emissions because vehicles can run in a more fuel efficient mode (compared to mechanical systems).

It can be concluded that engine management systems give the possibility to manufacturers to make better specific emission strategies under emission test conditions and better fuel consumption or CO_2 strategies under real world conditions.

Since the introduction of CO_2 legislation in 2007 the total package of requirements has increased and vehicles must comply with certain pollutant emission limit values and vehicle fleets of manufacturers must comply with certain CO_2 emission targets as well. As a consequence application of flexibilities has become more attractive because many flexibilities can contribute to CO_2 reduction. Last but not least the very powerful technologies such as cooled EGR, SCR and diesel particulate filters in combination with engine management systems create more possibilities for application of flexibilities because NOx and PM emissions are mostly well below the limit values.

4.3.6 *Administrative flexibilities*

For economic reasons the application of (administrative) flexibilities has been very important. In general the type approval procedure of a vehicle is a massive (administrative) burden for a manufacturer which costs a lot of time, money and human capacity. In order to reduce costs it makes sense to optimise this process, and reduction of the number of vehicle type approvals and their exhaust and vehicle emission tests is very effective. The total costs of vehicles and their type approvals are influenced by the following items:

- Definition of vehicle family (number of vehicle types per type approval).
- Development and engineering of vehicles.
- Administrative and operational type approval test activities.

The main parameter which might be applied as an administrative flexibility is the definition of a vehicle group or a family because the more types and models belong to the group the more cost savings can be achieved. In 3.4 the characteristics of a vehicle group or family have been described. They have been defined in order to reduce type approval efforts and costs. One member of the family, the reference vehicle (the worst case), must be subjected to type I emission tests and represents a whole family. On the contrary for CO_2 certification manufacturers tend to measure every individual type/variant because these type/variants have lower CO_2 emissions than the reference vehicle. Sometimes type approval certificates contain one pollutant result and many CO_2 test results. Given the current existence of CO_2 legislation, and of fiscal stimulation of the purchase of fuel efficient cars by Member States, it pays off to carry out separate CO_2 emission tests on many or all model variants.

4.3.7 *Conclusion*

In the past (2009 and earlier), when CO_2 emission legislation was not applicable, technical flexibilities were hardly needed to reach a certain emission performance and type approval test result. In some cases chassis dynamometer cooling fan strategies were applied. However the nature of vehicle emission legislation (with certain fixed limit values of pollutant emissions) didn't force manufacturers to apply the full extent of available flexibilities.

The introduction of engine management systems has given the possibility to manufacturers to make better specific emission control strategies in emission tests and better fuel consumption or CO_2 strategies under real world conditions.

4.4 Assessment of the role of CoP for the possible limitation of the utilization of flexibilities in the TA test

Application of flexibilities in the type approval test procedure that cannot be applied in the Conformity of Production (CoP) procedure might create a non-conformity of production vehicles because the CO_2 emission of these vehicles, as measured in the CoP process, might be too high. The question is whether CoP requirements might limit the use of flexibilities in the test procedure.

The requirements for Conformity of Production and CO_2 emissions are:
- Vehicles approved according to UNECE Regulation 101 shall be so manufactured as to conform to the type approved vehicle.
- The control of production conformity is based on an assessment made by the competent authority of the manufacturer's auditing procedure in order to ensure conformity of the vehicle type with respect to the emission of CO_2.

For comparison of the type approval and conformity of production procedures three different items must be investigated:
- The specifications and properties of the test facilities
- The specifications of the road load curves and test fuels
- The specifications and condition of the vehicles

For CoP test purposes the specifications of the CoP test facility, the test procedure, the road load curve and the test fuel can be chosen equal to the type approval test specifications. Consequently deviating properties of production vehicles (tires, internal friction, bearings etc.), that might affect the road load settings and real world CO_2 emissions, will not be measured in the CoP test.

However vehicles with properties at the outer end of the band of tolerance or with non-optimized parts might have higher CO_2 emissions. For this category the 4% CO_2 band of tolerance and CoP statistical criteria are applicable.

Conclusion
These results indicate that the CoP test procedure does not limit the use of flexibilities in the TA-procedure.

4.5 Results of consultations of type approval authorities and technical services

A consultation of type approval authorities and technical services regarding past use of flexibilities was combined with the consultation about present use of flexibilities. The results are reported in chapter 5.

4.6 Results of reviews of historical databases of type approval authorities

In addition to the evaluation presented in previous sections, also some historical databases of type approval authorities have been reviewed. The spread of type approval CO_2 values is analysed for a limited selection of vehicle models.

A first aspect to analyse is whether family thought or grouping is applicable for manufacturers of light duty vehicles. This has been realised by reviewing historical data for a selection of vehicle models, starting with data from 2002 up to 2012 to observe trends within the usage of test procedure flexibilities related to one single type approval test. RDW and KBA type approval information is used to identify the number of vehicles approved under one type approval document. In general, results received from type approval authorities were not detailed enough to summarise and conclude the applied flexibilities per model. The lack of numbers of type approval certificates in the data files are the main cause for not being able to draw the conclusions that were intended for this part of the work.

With the restricted databases of RDW and KBA, an internal expert discussion was held with the following outcome:

- A first registration results in a first type approval certificate. Different vehicle group members are registered on this certificate.
- In many cases, several members are added to the vehicle group in the following years. They are described in extensions and versions.
- In the year before the introduction of a new Euro class (e.g. Euro 5) the number of extensions and versions are strongly reduced. Probably the upcoming market for vehicles with new emission limits dominates and suppresses the need for extensions and versions.
- From these findings it may be concluded that market developments have a strong influence on the number of vehicle group members and the length of such a cycle is 4-5 years. An analysis in a certain year (e.g. 2002 or 2010) does not provide the correct results.
- In order to obtain a good view on the number of members of a vehicle group a long term analysis per vehicle type per Euro class is needed.
- The analysis of databases can be improved because detailed knowledge about the contents of these complex databases will result in better output. The most convenient approach may be to involve type approval authorities in the analysis. Such an improved analysis could not be carried out in this project.
- Probably, detailed type approval documentation is needed to determine the right number of vehicle group members. This documentation is not available in the public domain.
- And last but not least type approval authorities are not familiar with very specific research questions from external parties.

From these results it can be concluded that current information of historical databases has given insufficient insight in the number of vehicles per type approval certificate.

4.7 Conclusions

Pollutant emissions are mainly dependent on the applied fuel, the engine and aftertreatment technology. Nevertheless, test procedure flexibilities in principle can have a significant effect on measured pollutant emissions. For petrol vehicles there has generally been no need to use them due to the high effectiveness of applied aftertreatment technologies. For diesel vehicles it is considered more likely that flexibilities have been used. But flexibilities that reduce NO_x emissions of diesel vehicles tend to increase CO_2 emissions.

Overall it is concluded that in the past decades (up to 2002) flexibilities were applied on a restricted scale in the context of meeting pollutant emission limits. These pollutant emissions are mainly dependent on the applied fuel, the engine and aftertreatment technology and as a consequence the effect of flexibilities on pollutant emissions generally is very poor.

A quantitative estimate of the level of utilisation of flexibilities in 2002 and the impact on measured CO_2 emissions is given in section 5.9.

Since the introduction of European CO_2 legislation and of CO_2-based taxation and other fiscal incentives in Member States, the role of flexibilities is expected to have grown significantly because financial, commercial and political factors feed the need for low CO_2 vehicles.

National tax regimes are a primary driver for low CO_2 vehicles. Especially specific fixed CO_2 emission thresholds (such as 95 or 110 g/km) between taxation categories force manufacturers to deliver vehicles which comply with these emission targets.

5 Assessment of the present use of flexibilities

5.1 Introduction and objective

In this chapter results are presented of an assessment of the extent to which various identified flexibilities may have been used in 2010. By comparing this to the estimated level of utilisation in 2002 and combining the results with the impact potentials estimated in chapter 3, an estimate can been made of the level of reduction in type approval CO_2 emissions between 2002 and 2010 that could be attributed to the increased utilisation of flexibilities over that period. This is done in section 5.9.

5.1.1 *Objectives of the work*

The principal objective of work reported in this chapter is to obtain evidence as to how the range of flexibilities available (identified in chapter 2 and 3) are currently used when type approving light duty vehicles in order to obtain lower CO_2 values. The level of utilisation of these flexibilities, when multiplied by the impact on CO_2 emissions that each has, will enable an assessment to be made as to how much they currently contribute, both individually and collectively, towards the present CO_2 emissions figures of new cars sold in Europe. From the present use of flexibilities and the past use of flexibilities, researched in chapter 4, an assessment can be made of the contribution of the use of flexibilities towards the actual reductions that have occurred for new passenger cars between 2002 and 2010. The general approach for obtain the required information has been to have a dialogue with appropriate type approval stakeholders regarding the practices routinely used when type approving vehicles.

The activities that have yielded the results reported within this chapter were:

- Obtaining an overview of type approval testing activities in Europe to identify the key countries and stakeholders.
- The generation of the matrix of issues to be discussed during interviews and visits with these stakeholders.
- Conducting interviews and visits with the stakeholders.
- The collation and reporting of the findings.

5.2 Consultation of type approval authorities and technical services

5.2.1 *Preparation of briefing notes*

Three different types of stakeholders were consulted:

- type approval authorities
- independent test houses
- manufacturers

The approach to these different stakeholder groups varied because they each had their own perspectives regarding the current use of flexibilities. This influenced their willingness to discuss the way in which the flexibilities were being used.

Cooperation was sought with a range of TA authorities and test laboratories in various relevant countries. Ultimately, only UK and Dutch NL organisations agreed to cooperate so that these were the ones that were consulted.

In addition also interviews have been held with 3 vehicle manufacturers.

Table 42 Overview of the interviewed stakeholders

Country	Type organisation	Name	Date	Position
United Kingdom	Type Approval Authority	VCA	March 2012	Principal engineer
United Kingdom	Type Approval Authority	VCA	March 2012	Engineer
United Kingdom	Test house	Millbrook Proving Ground	March 2012	Principal engineer
United Kingdom	Test house	MIRA	March 2012	Principal vehicle emissions engineer, and manager
United Kingdom	Vehicle manufacturer		March 2012	Homologation manager for specific model
Netherlands	Type Approval Authority	RDW	April 2012	Inspector
Netherlands	Type Approval Authority	RDW	April 2012	Officer
Netherlands	Test house	TNO-Homologations	April 2012	Test engineer and certification officer

The analysis from chapter 3 identified the flexibilities that exist within the current regulations. These were subdivided into two groups, those concerning the derivation of the coast down data, and those that affect the Type I emissions tests.

The full list, generated from chapter 3 is:

1. Those that affect the derivation of the coast down curve
   a. Wheel and tyre specification
   b. Tyre pressure
   c. Brakes
   d. Preconditioning
   e. Running-in period
   f. Ambient conditions
   g. Test track design

2. Those that affect the Type I emissions (NEDC) test directly
   a. Reference mass
   b. Wheel and tyre specification, and rolling resistance
   c. Running in period of test vehicle
   d. Laboratory altitude (air density)
   e. Temperature effects
   f. Coast down curve or cookbook load terms
   g. Battery state of charge
   h. Gear change schedule and definition
   i. Driving technique
   j. DPF related Ki factor (distance between DPF regenerations) for calculating total cycle CO_2
   k. Declared CO_2 value

The extents to which these flexibilities are currently used were sought from the interviews.

It is also noted that there are a considerable number of other potential variables that are not included in the specification, e.g. the surface of the test track used to derive the coast down curve and the wheel alignment for the vehicle, and the battery state of charge. Information regarding these was also gleaned when volunteered.

5.3 Consultation with Type Approval Authorities – information regarding the type approval system

5.3.1 *Introduction*

Several different type approval authorities were consulted. Their principal focus is to answer the question: “Does the test they are witnessing comply with the regulations?” If the test does comply with the regulations, then the testing authority representative often will not record the value of the individual parameters that describe the test conditions and settings, but merely that they were within the permitted windows of values.

A second message that came from the consultations with the type approval authorities was that whilst they are all overseeing the same regulations, there are areas of subjective interpretation, and it would be wrong to assume that “the interpretation of all type approval authorities are the same”. Further, there are some other aspects of their role, the differences in culture between OEMs based in different parts of the world, and the competitive nature of the type approval authorities businesses. Therefore, before considering the details of the current use of flexibilities some comments are made regarding the type approval authorities’ “business” and the market they are operating in.

5.3.2 *Cultures, developments, markets and manufacturers*

Homologation of vehicles is a worldwide activity which has been influenced by cultures, markets and manufacturers. However, the current actual situation shows three different legislative regimes: Japan, United States and Europe. In these three regimes three different cultures can be recognised.

- In the United States no formal legal independent type approval test activities are needed. The manufacturer has to declare the vehicle emission performance. Afterwards they might be forced to prove the emission performance of a few in-use vehicles. In case of a proven incorrect declaration of emissions levels, manufacturers could be prosecuted and face large financial penalties.
- In Europe all new vehicle types must prove their emission performance based on type approval procedures. The independent, or witnessed, test results are part of the original vehicle certification documentation and emission performance of vehicles in the fleet is measured in in-use compliance programs. In the case of non-compliant vehicles a range of legal sanctions is available including the revoking of the certificate of conformity.
- In Japan there is a very well defined and applied culture of responsibility and respect of authority. This leads to a very strict level of compliance to the details within the regulations. As a result, the Japanese do not tend to apply flexibilities.

The manufacturers can be categorised by country, market share, brand and position (new, upcoming, established and main player). In the best case a dedicated homologation department prepares the complete process and development departments deliver vehicles with sufficient and robust emission performance. For low CO_2 emission purposes some flexibilities may have been applied. In general the type approval processes are knowledge and experience based and contain high levels of quality assurance . At the other end of the spectrum is a small manufacturer who enters a market with a first prototype. They meet a massive burden of type approval activities and rapidly have to learn to pass all the requirements. Sometimes they need and use their creativity in an exhausting way to find sufficient flexibilities.

For small series (maximum 100-150 vehicles per year) a “reduced” type approval procedure can be followed. In some countries this possibility has been applied frequently. However, virtually by definition, the relative numbers of such vehicles entering the fleet are low.

Markets and CO_2 taxation have become very strong drivers for manufacturers to comply with certain CO_2 limit values because they cannot afford to lose their market share. Since 2009, the formal introduction of the regulation for passenger cars, the view offered by TA authority staff interviewed is that manufacturers have increasingly been applying more flexibilities during the R101 test.

In Europe type approval certificates generally are not in the domain of public information. This creates a ‘stand-alone’ type approval world in which external influences are largely excluded.

Moreover type approval authorities are only lightly supervised and as a consequence for consumers and other parties it is extremely difficult to validate the details of type approval results.

In Europe the type approval authority market is competitive. Manufacturers are clients because they pay for services. If a type approval projects does not run as smoothly as a manufacturer would like, the next time a manufacturer can decide to deal with another authority. However, the consultations indicate that generally a company does retain, and develop, the relationship with a specific type approval authority over a considerable time period.

Several interviewees remarked how even with all the details contained in Regulations 83 and 101, the detailed interpretation has a considerable degree of subjectivity. However, once one type approval authority has made a clear advantageous decision of a non-described issue or a certain interpretation manufactures will relate in their discussions with other type approval authorities to that advantageous decision and seek to claim the same advantage. The definition of a “vehicle group” or “vehicle family” has been meant to reduce type approval test activities and costs. In the case of pollutants, a worst case vehicle will be defined which represents the emissions of a group of vehicle types. Since 2009 type approval documents also contain CO_2 test results of all members of the vehicle group. It is from these CO_2 test data that the fleet average is calculated. Factors that influence the CO_2 data will also influence the total fleet average value. This leads to the interest in understanding the flexibilities that exist in connection with the CO2 test regime.

5.3.3 *Type approval activities in the context of automotive processes*

A recurring message that was given during interviews was that the obtaining of the Certificate of Conformity (CoC) should not be considered in isolation. The CoC was described by one Type Approval Authority as being the vehicle’s “birth certificate”. However, the aim of the manufacturers is to sell vehicles, and obtaining a CoC is only part of the process and only one of the final hurdles in the long way to go. The main costs have been made in the research, development and testing phases, and compared to these generally the costs for homologation are relatively low. A wider perspective of the requirements to be able to sell vehicles is shown schematically in Figure 17.

The cycle is initiated by a vehicle manufacturer building a new model (or family of models) to a tightly defined specification. This includes specifying the vehicle’s powertrain components, tyres etc. The vehicle that is tested is produced to comply with this specification. Some apparent flexibilities within the Regulation 101 test also become defined at this stage. An example is the tyre options available, and their correct operating pressures. The test vehicle is fitted with the widest of the range specified (or the second widest if there are 4 or more variants possible). The vehicles coming of the production line for sale must be fitted with one of the specified tyres. If it is not, then conformity of production (CoP) checks identify it as being out of the scope of the CoC.

Prior to witnessing an emissions test, the manufacturer has to “book” a Type Approval Authority staff member’s attendance, and to submit details of the vehicle to be tested. For most passenger car models the test comprises two parts:

- the collection of the coast down data, which is then used to set up the dynamometer load factors, and
- the Type I test measuring CO_2 and fuel economy according to Regulation 101.

Both of these tests are witnessed by the type approval authorities.

Some authorities declared that dedicated vehicles for specific tests (road load determination) have been prepared. I.e. for road load determination some parts (one mirror, spare wheel, navigation systems) have been removed because the standard base vehicle doesn’t contain these ‘options’. Furthermore dedicated and prepared tyres have been applied.

In general during the development vehicles are prepared for specific homologation tests and adjusted to most favourable settings. During homologation processes the current status of some items can be checked but not all the conditions of parts can be judged (bearing conditions, software configurations, tyre rubber specifications and condition, etcetera). This makes clear that a few days of homologation testing doesn’t create a full proof process.

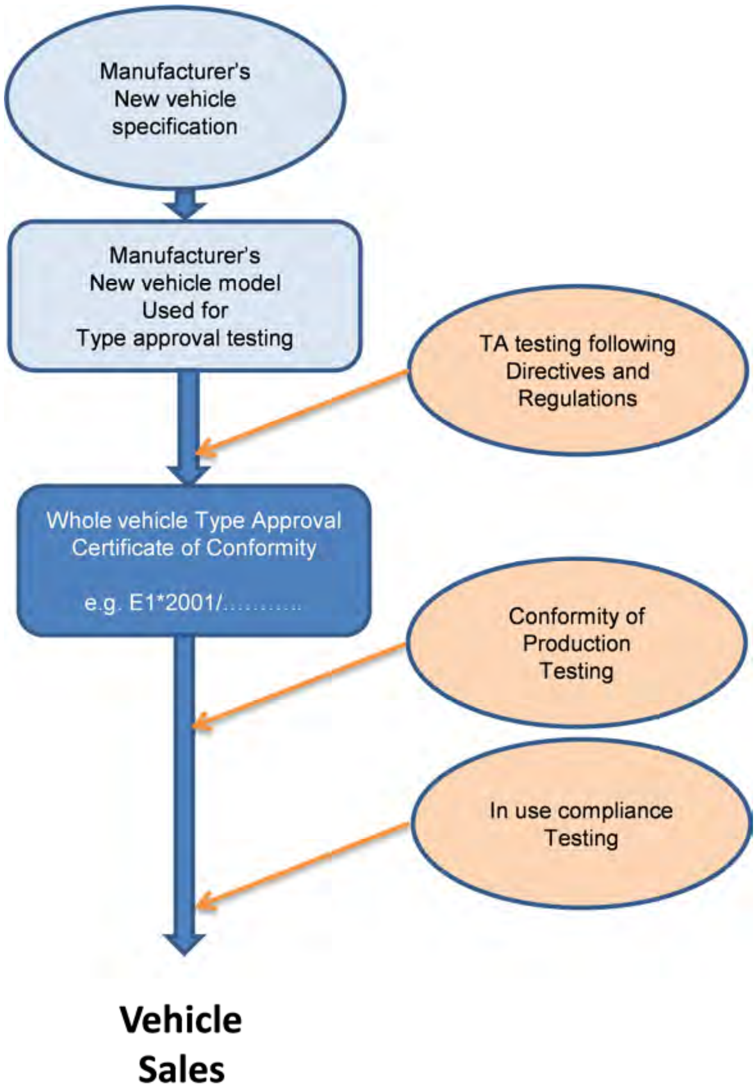

Figure 17 Schematic overview of type approval process

5.3.4 *Coast down data collection*

Table 43 lists the potential flexibilities for the collection of the coast down data, and the feedback obtained from the staff of type approval authorities.

Generally there was little variation between feedback obtained from different type approval authorities.

However, in addition to the flexibilities given in Table 43, some further parameters that are not specified in the Regulation were commented on. These included the surface finish of the test track. The [TÜV Nord 2010a] study showed how the differences in the retarding force increased by 37.2% at 20 km/h and 18.2% at 80 km/h when driving on rough concrete compared to driving on smooth asphalt. Other comments regarding the choice of test track were:

- Most coast down data are collected at the Idiada facility (Spain) with some testing at Wolfsberg (Ehra-Lessien test track (Germany) and Arizona Proving Grounds (US).
- There is limited coast down data collected in the UK (e.g. at MIRA and Millbrook) and that collected is for vehicles for which performance, rather than low CO_2 emissions, are key selling features.

Table 43 Feedback from type approval authorities regarding potential flexibilities available during the collection of coast down data

Potential flexibility	Feedback from type approval authorities
Wheel and tyre specification	Not viewed as a flexibility once the range of wheel and tyre size options within a family of vehicles has been specified by the manufacturer. Vehicles **are** tested when fitted with the widest (for < 4 sizes available), or widest minus one (for > 3 sizes available). One authority mentioned the use of prepared tyres (whose tread was mid-way between that of a new tyre and the legal minimum, and with an optimised surface area). If a manufacturer wants to reduce CO_2 emissions by specifying low rolling resistance tyres, this is usually achieved by specifying an "Eco" model, with a differently calibrated engine (or possibly a different engine) low rolling resistance tyres and other CO_2 emissions reducing measures. The CoC obtained would be for a vehicle built to this specification. CoP checks would ensure that the vehicles going to sales forecourts would meet this specification, including having low rolling resistance tyres.
Tyre pressure	Not viewed as a flexibility once the range of wheel and tyre size options within a family of vehicles has been specified by the manufacturer together with the pressures they should be inflated to. For the collection of coast down data, the vehicle is lightly loaded, only containing the driver. The tyre pressures are set accordingly. Some manufacturers also specify a (higher) ECO-tyre pressure. This may be 3.1 bar relative to the normal 2.2 bar. When these higher tyre pressure are used rolling resistances are relatively lower.
Brakes	For the collection of coast down data brakes can be adjusted to eliminate parasitic drag. This is generally believed to happen. However, it is not a parameter like tyre pressure that is monitored and recorded. Discussions revealed how during coast down testing trained drivers don't brake at any point, instead, for example to reduce speed post data collection before reaching a corner, they use the engine deceleration mode to reduce vehicle speed.
Preconditioning	The requirement is that "immediately prior to the test, the vehicle shall be brought to normal running temperature in an appropriate manner." This flexibility is adhered to, with representatives from type approval authorities reporting that engine oil temperature and gearbox oil temperatures are not important, because the vehicle is in neutral for the coast down test. Important are wheel bearing and tyre temperatures. These are brought to their normal running temperature (which is usually reached sometime after the engine has reached its normal operating temperature).
Running-in period	Running-in period – specified to be at least 3,000 km for coast down test. (For Regulation 101 test the vehicle mileage should also be less than 15,000 km. The feedback from type approval authorities was that vehicles had all covered >3,000 km, but were "young" vehicles, i.e. mileage was often in the 3,000 – 6,000 km range.

Potential flexibility	Feedback from type approval authorities
Ambient conditions The regulation specifies limits on wind speed, humidity and air pressure.	The limitations on wind conditions are viewed by the type approval authorities as being a serious limitation as to when "valid" coast down data can be collected, and it is not a parameter that provides any advantage. Hence testing awaits conditions being within the acceptable window, rather than waiting to be at a particular point within the window. The feedback from type approval authorities is that no-one would test when the road service was wet, so this is not a flexibility. Similarly, air pressure, is generally not seen as a flexibility – it is measured, checked to be within 7.5% of the reference conditions, and then the coast down data is corrected to the reference ambient conditions. One authority explained the regular practice of road load determination. During homologation tests weather conditions might not be optimal. The road load test results of this homologation test are compared with a result of the manufacturer which is measured using more favourite ambient conditions. Generally the latter results are accepted.
Test track design	There is a tolerance noted for the slope of the test track, both in terms of variation and absolute value. Any track meeting these criteria can, in principle, be approved for the collection of coast down data. For manufacturers collecting coast down data, they have to choose from the facilities available – none build their own test track. This tolerance, particularly on absolute slope, is partially nullified as the regulation says you measure coast down speed time characteristics when the vehicle is going **both** ways along the road, i.e. up-hill and down-hill. So any gradient effects cancel each other out to some extent. However, the effect of the slope is only **partially** cancelled if you drive back and forth on the same piece of track. Real world testing might be different because on certain test tracks for safety reasons it is only allowed to drive in one direction. Consequently, the two directions can be driven on opposite sides of an oval track, in which case the slopes do not need to be equal and opposite. Road surface properties are not specified in the regulations and it is well known that the surface condition and quality have impact on rolling resistance. The perspective of the type approval authorities is simply: Is this test track approved for the collection of coast down data?

Additional comments regarding the collection of coast down data were as follows:

- At the Idiada track atmospheric conditions are good, with an increased likelihood of being able to test within the specified ambient conditions.
- The Idiada track has a small gradient of 0.3%.
- Overall, it appears that the Idiada track is optimised for coast down data. This is an oval track with the two directions being driven on opposite sides of the track.
- Generally, the coast down data allows vehicle to vehicle comparison under controlled/repeatable conditions.
- Just as the NEDC-cycle for the Type I test is **not** representative of on the road driving, so too the retarding resistances collected during coast down runs are **not** representative of retarding resistances for real road surfaces.
- Coast down data is often obtained in batches, not all at one, because the length of the test track is restricted. For example 135 – 80 kph, then 90 – 40 kph etc.
- The vehicle tested will be well built, having average/small panel gaps, optimised ground clearance etc. Taping up or filling gaps would not be acceptable to the type approval authorities.
- Type approval authorities are aware that the gear box and bearing losses affect coast down data.
- The whole type approval process involves a degree of trust. Manufacturers do not want the type approval authorities to think they are trying to operate outside the permitted limits.

One key conclusion from the comments above is that Idiada is the test track returning the smallest dynamometer retarding forces, and as a consequence is used by many vehicle manufacturers.

Overall, when asked directly about whether there had been any changes in the use of flexibilities when collecting coast down data over the past decade, the reply obtained was: No there has been no new emphasis on using coast down test flexibilities. However, it is noted that this answer contradicts the evidence from the test houses and manufacturers who say more attention is paid now to vehicle preparation than in the past. It may be that this dilemma is a consequence of the TA staff not seeing all the vehicle preparation that precedes the witnessed coast-down test.

5.3.5 *Regulation 101 (CO_2 emissions and fuel economy) data collection*

Table 44 lists the potential flexibilities identified in chapter 3 for the collection of CO_2 emissions and fuel economy data according the Type I test specified in Regulation 101. For each flexibility the feedback obtained from the staff of type approval authorities is tabulated.

Other comments provided were:

- The vehicle preconditioning is undertaken the day before the cold start test and is possibly not witnessed.
- The Type I emissions (Regulation 83) test and the fuel consumption and CO_2 emissions test (Regulation 101) though different are often conducted as the same test. Indeed the QA test sheet for the two tests are the same.
- The vehicle's oil and water temperatures are checked to be within ± 2°C of the soak room temperature immediately prior to the cold start test beginning.
- Tyre pressures are set (to the standard values for a single roll and 1.5 times for twin rolls).
- The position of the cooling fan is recorded.
- At the end of the test the cell temperature is checked to ensure it is within the 20°C < T < 30°C range, and absolute humidity is also confirmed to be within the specified range.
- New Euro 5 compliant cars and vans are typically well below the pollutant emission limits.

This final comment is potentially very relevant to this study because it means that the use of test flexibilities is not needed to meet the Euro 5 emissions standards, and are available to optimise (reduce) CO_2 emissions. In the past when vehicles have been much closer to the regulated emissions limit, the focus and any flexibilities in the test procedure were used to minimise the pollutant emissions, and were not used to reduce CO_2 emissions.

This agrees with a general comment from type approval authorities that the flexibilities available during the test have always been there, but there has been increased use of these recently.

Table 44 Feedback from type approval authorities regarding potential flexibilities available during the collection of Regulation 101 data

Potential flexibility	Feedback from type approval authorities
Reference mass	No real flexibility as is part of the vehicle specification. Also, doesn't make a massive difference
Wheel and tyre specification, and rolling resistance	Comments as for coast down – not really a flexibility.
Running in period of test vehicle	Always > 3,000 km, as per Directive, usually < 6,000 km at start of testing
Laboratory altitude (air density)	Not really relevant for UK where all test facilities are under 300 m.
Temperature effects	Soak temperature typically 22 – 24°C and test temperature typically 25°C at the start of test. Both temperatures (+ cell temperature at end of test) recorded.
Coast down curve or cookbook load terms	For passenger cars virtually always coast down data, use of "Cook book" figures is rare. For vans usually "Cook book" figures but for car derived vans coast down data are generally used.
Battery state of charge	Not mentioned.
Gear change schedule and definition	As specified in the NEDC for vehicles with manual gear boxes, the vast majority. Hence no real flexibility. There is a provision for vehicles where first gear has a relative low maximum speed (<15 km/h). For such vehicles testing can occur using 2^{nd}, 3^{rd} and 4^{th} gears rather than the first three gears for the UN/ECE urban part of the drive cycle. It was also reported that the manufacturer can declare that for fuel efficient driving the vehicle can be in the second gear. This was investigated further and no evidence was found that this possibility was being used as a flexibility.
Driving technique	The TA staff interviewed commented that this provides little flexibility – driver needs to follow speed trace within tight limits and achieving this with no violations is sufficiently challenging. However, this contradicts feedback from manufacturers' test laboratory engineers, where three different companies (of four approached) indicated they have special NEDC driving techniques that are used to achieve minimum CO_2 emissions. (Hence non-zero value in Table 48.)
DPF related Ki factor (distance between DPF regens) for calculating total cycle CO_2	No flexibility discussed – tested according to Regulation
Declared CO_2 value	The +/- 4% tolerance is used differently by different manufacturers.

5.4 Consultation with test houses

5.4.1 *Introduction*

The feedback from test houses provides a different perspective to that obtained from the type approval authorities. The key question for the latter bodies is: “Does what is being done comply with what is specified in the regulation?” In contrast, the key question for test houses is: “What flexibility does exist and how might using it affect the answers?” In this respect it is a very useful perspective on how the current flexibilities permitted are used.

Traditionally test houses are only a final step in the homologation process for a manufacturer. Vehicles spend relatively small amounts of time being tested by a test house (100-200 hours per session). This means that most manufacturers are very well prepared because they cannot afford a ‘show stopper’. In recent years the very important CO_2 type approval emissions regulation leads to test houses being told what level of flexibilities will be used, by the vehicle manufacturer (most of who have a very high level of knowledge).

Test houses are visited by different clients: Some clients are highly professional, there are foreigners from other cultures and there are new stakeholders who lack some of the most basic knowledge. As a consequence, whilst these customers share the same goals, their approaches can be very different. Highly professional manufacturers mostly are very reliable and open, their processes are under control. On the contrary newcomers may offer non-compliant test samples which might be sent back after a first thorough inspection.

As for the type approval authorities, the vehicle testing is initiated by a vehicle manufacturer having a new model to be type approved. The role of the test house is:

- to provide approved facilities (certified by the type approval authority) and to operate these according to the regulations,
- to test the vehicle according to the details provided by its manufacturer, and
- to be able to offer advice based on experience regarding changes that could be made.

Unlike the type approval authorities the test house providers are often only involved in a sub-set of the whole vehicle emissions testing programme. This is in contrast to the type approval authorities who are often involved in the whole cycle, from Type I tests to Type VI tests, in-service conformity, OBD, Ki factor tests etc. Most importantly for this study the test houses approached (in the UK, Germany, and the Netherlands) undertake very little of the coast down data collection. As noted from the consultations with the type approval authorities, the favoured location for obtaining this data is the Idiada test track in Spain.

5.4.2 *Coast down data collection*

It has been noted that the majority of the coast down data used for defining the dynamometer load settings are recorded at the Idiada test track rather than at the tracks at the test houses consulted. Nevertheless, the test houses consulted also collected limited quantities of coast down data and therefore had first-hand experience in this field. As a consequence they were able to provide experience based answers to the matrix below. Table 45 lists the potential flexibilities for the collection of the coast down data, and the feedback obtained from the staff of vehicle test houses.

Test houses generally commented that, for the Regulation 83 and Regulation 101 dynamometer based testing, they would be given witnessed/approved coast down data and would match their dynamometer loads to reproduce these data. They also commented that generally the road loads from the supplied coast down data were markedly less than the default values specified in the regulation (the cook book figures or table values). Determination of road load curves of external approved parties potentially raises questions because the process of road load determination has been separated from the emission test. In case the total test procedure (road load + emissions) is carried out by a single test house it is expected to have more consistent test results.

When asked why Idiada was viewed as a "better" test track for the collection of coast down data the somewhat enigmatic answer received was: "The facilities are optimised to the regulations". Further comments were:

- the weather is more dependable in Spain,
- the oval configuration of the Idiada track with its approximately 1.5 km long straights is a convenient test configuration,
- the regulations contain little/no details regarding track surfaces.

Table 45 Feedback from test houses regarding potential flexibilities available during the collection of coast down data

Potential flexibility	Feedback from test houses authorities
Wheel and tyre specification	Not viewed as a flexibility for a specified model or family – see comments for type approval authorities
Tyre pressure	Not viewed as a flexibility– see comments for type approval authorities
Brakes	Ensure that they are not rubbing
Preconditioning	Generally run well past the point when the water and oil temperatures have reached their normal operating temperatures to ensure other vehicle components are fully warmed
Running-in period	Generally close to the 3,000 km end of the window
Ambient conditions	Seen as a narrow window of permitted values – with many hours lost waiting for the permitted specified climatic conditions to occur
Test track design	Not relevant to test houses, where their test track has the characteristics it has, and these are difficult to change.

When asked whether there were other "tweaks" that might be applied to vehicles that are not explicitly specified in the regulations it was commented that wheel alignment is carefully checked, with toe-in and camber checked to be within the specified range, but towards the end of the specified range that minimises straight line rolling resistance.

The test house representatives had different views on whether there had been changes in the attention to detail when collecting coast down data. One commented that it had increased, with step changes occurring with the introduction of vehicle CO_2 targets. Another commented "it had not changed much over the past decade".

Overall it was commented that coast down data are very difficult to replicate.

5.4.3 *Regulation 101 (CO_2 emissions and fuel economy) data collection*

Table 46 lists the potential flexibilities for the collection of the Regulation 101 CO_2 emissions and fuel economy data, and the feedback obtained from the staff of vehicle test houses.

Table 46 Feedback from test houses regarding potential flexibilities available during the collection of Regulation 101 data

Potential flexibility	Feedback from type approval authorities
Reference mass	Not flexible because it is part of the vehicle specification, and can be physically checked.
Wheel and tyre specification, and rolling resistance	Not viewed as a flexibility – see comments under coast down data
Running in period of test vehicle	Not viewed as a flexibility – see comments under coast down data
Laboratory altitude (air density)	Not a flexibility because the test house's location is fixed. There were no reports of tests waiting for particular air pressure conditions
Temperature effects	Soak temperature typically around 25°C and test temperature typically 23 - 25°C at the start of test. Both temperatures (+ cell temperature at end of test) recorded
Coast down curve or cookbook load terms	Coast down data for passenger cars virtually always used. For vans, it used to be virtually only default (cookbook) load terms used, but now increasingly coast down data is being used. Also, for N1 vans weighing more than 1,700 kg reference mass, an additional factor of x1.3 is applied to the dynamometer coefficient.
Battery state of charge	Is recognised as being important and steps taken to reduce/eliminate its adverse impact on CO_2 emissions.
Gear change schedule and definition	No flexibility for vehicles with manual gear boxes within the regulations. For hybrid vehicles a dedicated test mode might be applied. Due to the high level techniques it is not possible to gain insight in internal technical processes. As a consequence the test mode might not be representative for real world behaviour.
Driving technique	The test driver follows the speed time line within tight limits. This is sufficiently challenging and leaves little scope for flexibility. In general the driver behaviour creates the biggest part of the spread on test results and therefore tests might be repeated.
DPF related Ki factor (distance between DPF regeneration events) for calculating total cycle CO_2	Measured according to the regulation.
Declared CO_2 value	Is used both ways

5.5 Consultation with manufacturers

For the consultation with manufacturers it was decided during the planning phase, that for understandable commercial reasons little was likely to be learnt from manufacturers if asked questions in the same format as was used for the type approval authorities and for the test houses. Therefore a lighter, more general approach was used.

Detailed consultations were held with three different manufacturing groups. Those interviewed placed more emphasis on the technological measures recently introduced to reduce CO_2 emissions, for example stop/start technology, hybrids and general efficiency improvements, than the use of flexibilities within testing. Two of the manufacturers are large volume light duty vehicle makers, producing both passenger cars and light commercial vehicles. The other company manufactured high value sports cars.

The general commercial strategy of the sports car manufacturer was that they appeared to be using very modest levels of the flexibilities, for example not making any use of the flexibility in the “declared CO_2 value”. For this company, there would be little tax advantage in reducing their CO_2 value by several per cent, but a larger commercial risk of not meeting conformity of production scrutiny as they sold their vehicles globally.

The feedback from the two large volume light duty vehicle manufacturers was different. Both emphasised the importance of the CO_2 measurements to their company’s commercial success. One emphasised on how the “fiscality of CO_2” had become a key driver.

Many general observations already reported were confirmed. For example:
- All their passenger cars were tested using dynamometer settings derived from coast down data;
- For smaller light commercial vehicles (car derived vans) again these were tested using dynamometer settings derived from coast down data;
- For their larger, Class III, vans both manufacturers reported how these were tested using default “cook book” dynamometer settings.

Other general points made were:
- Light-weighting is an expensive option, offering only modest returns because of the current utility function;
- Both companies used **many** of the flexibilities available but were careful to stress these were only used within the ranges permitted in the Directive;
- Both companies expressed some doubts as to whether their competitors behaved in the same manner, with some oblique references to the use of practices either at the boundaries of those permitted, or not covered by the specifications in the Directive;
- Both companies also stressed how they believed the situation will become much less variable because WLTP is looking to redefine the permitted flexibilities and the range permitted.

The information obtained from these interviews was collated with that from the type approval authorities and the test houses when quantifying the estimates of the extent to which flexibilities are currently used during coast down data collection and Regulation 101 CO_2 emissions testing, for both passenger cars and vans.

5.6 Summary of consultations

Chapter 3 of this report reviewed the current legislation and identified the flexibilities within the type approval procedures that may impact on measured CO_2 emissions. This formed the basis for the questions posed during the stakeholder consultation.

However, what has become clear from the stakeholder consultations is that these flexibilities can be categorised into:
1. those flexibilities where once the manufacturer has specified the details of the vehicle group (or family) they become defined, and
2. those flexibilities where the manufacturer can exercise choice after the vehicle has been specified.

Examples of the first category include the vehicle’s reference mass, and the definition of the tyres to be fitted for testing and their pressures. Examples of the second category include the choice of facility used to collect the coast down data and the temperatures of the soak area and test cell for the cold start emissions tests.

In the following sections a brief summary of the consultations is structured with reference to the flexibilities defined in chapter 3, considering:
- coast down data collection and Regulation 101 data collection, and
- flexibilities that become defined with the specification of the vehicle group (or family) and where there remain choices to be made.

The principal objective is to provide an evidence-based quantification of what the current flexibilities are and to which extent they are utilised. This can then be compared with the maximum change in CO_2 emissions identified in chapter 3. Each aspect is given a unique reference number so that it can be cross referenced when totalled in Table 51 and Figure 19.

5.7 Coast down data collection

Firstly, it is important to note that the dynamometer load factors for virtually all passenger cars are derived from their coast down data. In contrast, only for a fraction of light commercial vehicles coast down data are used rather than the default “cookbook” values from within the regulations. This was estimated as being around 20%, and growing each year. Currently the use of coast down data is more important for the smaller vans.

Secondly, the consultation with stakeholders emphasised the importance of the “official” coast down times. Any vehicles selected for conformity of production, or in-use compliance, testing would be tested **using the same, original coast down data**. In the experience of those interviewed, this is not measured again. As a consequence, any CO_2 emissions benefit that occurs because the dynamometer load resistances were measured within these flexibilities available, **are locked in to future testing results**.

5.7.1 *Flexibilities that become defined with the vehicles specification*

Reference mass

This affects the chassis dyno inertia setting. The analysis of chapter 3 concludes that a reduction of 110 kg leads to a -2.5% change in CO_2 emissions (based on theoretical calculations). This is broadly in agreement with a 1.5% to 2.0% reduction in CO_2 emissions per 100 kg reduction in reference mass quoted by staff from a test house.

However, discussions with type approval authorities indicate that the agreed specification for the vehicle tested covers all variants and versions specified for the worse-case vehicle build. Those being consulted did not regard vehicle reference mass as a flexibility when it came to testing pollutant emissions. However, nowadays OEMs perform CO_2 tests, including coast-downs, on almost all individual model variants, specifically for the “eco” variants of a model.

However, it is also evident from a graph, see Figure 18, of the publicly available data showing the distribution of the number of registrations against car mass that there is bunching below the inertia class thresholds. This is not the use of a flexibility within the test regime, but a consequence of vehicle designs and specifications such that few vehicles are designed to have mass just above the inertia class thresholds, but many have a mass just below the inertia class thresholds, leading to the bunching observed. As such it can be argued that this is deliberate, overt CO_2 emissions reduction through the use of strategic light-weighting.

As a consequence, from the evidence provided during consultations, and because checking a vehicle’s weight is relatively easy as part of the conformity of production checking that occurs, it is believed that a vehicles’ reference mass is not a flexibility that is currently used. Rather, deliberate, strategic light weighting occurs at the vehicle design and specification part of the vehicle’s lifecycle, to take best advantage of the current type approval regulations.

Part of the “strategic” light weighting might, however, be to declare some items that would normally be assumed to be part of the standard build, e.g. a spare wheel, as a dealer fitted optional extra. This possibility, and its impact on CO_2 emissions is covered in the next section.

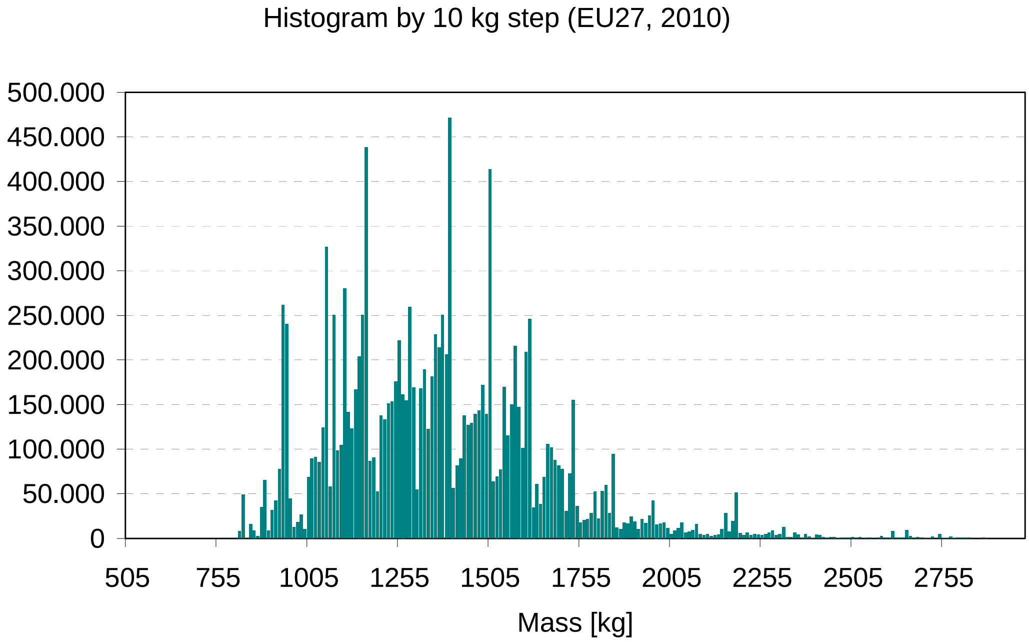

Figure 18 Histogram of light duty registrations within EU27 in 2010 by reference mass[15]

Wheel and tyre specification and reducing rolling resistance

There are two ways in which the current "flexibility" could be used to minimise the R101 CO_2 emission test result:

1. If more than three tyre sizes are specified the widest minus one tyre is used for the CO_2 emissions test. If the majority of vehicles are sold fitted with the widest tyre, then the measured CO_2 emissions value will be systematically less than the test figure.

   Many models have at least four different tyre options specified. However, the widest tyre usually accounts for a relatively small fraction of the vehicle sales, with the majority of vehicles being sold with either the second widest (which may be the same width as the widest but merely a different profile or wheel size) or a narrower tyre.

   This apparent flexibility was not highlighted by type approval authorities or operators of test houses as being currently used.

2. If low CO_2 wheels and tyres are specified by the manufacturer as standard, but not used in practice due to strong incentives for customers to choose alternative dealer fitted options.

   If this way of using the flexibility was occurring, then this would be at the dealer level, and the type approval authorities and operators of test houses would not have first-hand experience of this. There was no suggestion of this occurring during the consultations.

   The specification of (ultra) low rolling resistance tyres for some models does occur. This is part of the vehicle specification, and therefore the coast down data can be collected using these tyres. If vehicles leaving the plant for garage forecourts were not fitted with these tyres, they would fail a "conformity of production" check. Therefore it is not believed that this flexibility is being used to give any advantage to test vehicles relative to those added to the fleet.

As a consequence, the current use of the potential flexibility of optimising wheel and tyre specifications for specified vehicles is estimated as having no impact on CO_2 emissions.

[15] Graph provided by EC DG Clima in a private communication. Similar data providing data used when compiling Table 48 available from ICCT analysis of publically available data, see http://www.theicct.org/blogs/inertia-classes-vehicle-emissions-tests-and-dead-hand-past

Tyre pressure

The tyre pressures are specified as part of the vehicles running configuration, with pressures being given for different tyre types and different levels of vehicle loading. The pressure to be used when testing will be that specified for the tyre type fitted, and that appropriate to light loading. This was not viewed as an area of flexibility by those consulted with.

5.7.2 *Remaining flexibilities*

Choice of facility used to collect the coast down data

The choice of the facility used to collect the coast down data does have a marked impact on the coast down data collected, and as a consequence on the resulting dynamometer setup for the R101 test, on the CO_2 emissions data collected.

A pre-requisite of considering using a test track is that the track has been approved by a Member States type approval authority for the collection of coast down data because it complies with the regulations. Notwithstanding, it is acknowledged in the industry that some test tracks are “faster” tracks, and provide a smaller retarding force than others. The consultations led to the common view that the Idiada test track, in Spain, is the European track that is optimised for the collection of coast down data that is also available for any manufacturer to hire. Therefore most companies use this test track. It was also commented that just as the NEDC, for the Type I test, is **not** representative of on the road driving, so too the retarding resistances collected during coast down runs are **not** representative of retarding resistances for real road surfaces. However, they do provide a like-for-like comparison of vehicles collected under controlled conditions.

In chapter 3 it was concluded that: “using all flexibilities related to road based measurement of the coast down times could lead to a 4.5% reduction in CO_2 emissions”. This was for the combined effect of:

- optimising wheel and tyre specifications, tyre pressure,
- preconditioning and running in period,
- the holding back of brake pads,
- the effect of ambient conditions on aerodynamic drag (small) and
- test track slope.

Whilst some items above are flexibilities that become defined with the specification of the vehicle, others, e.g. test track slope and the condition of the tyres (whose width is defined in the vehicle’s specification) were relevant. It was estimated that the current use of these flexibilities contributes a -2.5% change in CO_2 emissions. This estimate is exclusive of possible impacts of the test track surface which is not well specified and thus formally is not considered a flexibility within allowable bandwidths.

Reference mass

There does remain some flexibility in the reference mass because the definition within UNECE-R83 allows the option for certain items to be specified as dealer fitted optional extras, and as a consequence not part of the “worst case base vehicle”.

Some consultations with type approval authorities did highlight how, for example, one mirror, the spare wheel and navigation systems, have been specified as “options” and therefore these were not included in the reference mass.

It is thought that the extent of this flexibility would be to change the reference mass by several tens of kg, enabling the base vehicle to be tested with a lower inertia class. Whilst this can provide a 2% CO_2 emissions reduction when it occurs, it is estimated that it occurs for only around 10% of vehicles, i.e. its use results in a 0.2% CO_2 emissions reduction.

5.7.3 *Other, non-regulated, flexibilities*

Other aspects of coast down times

In addition to the flexibilities identified from the regulations, consultations with type approval authorities and operators of test houses indicated that there are other aspects of collecting the coast down data not covered in the regulations, which are permitted and used, and very probably contribute to coast down road load factors being smaller than those collected from “standard” roads. Examples provided include:
- the use of carefully prepared tyres,
- setting wheel camber and toe-in to the maximum permitted to provide the lowest rolling resistance,
- careful adjustment of ground clearance.

Clear quantitative data are difficult to acquire, but it is estimated that these aspects contribute a further 3% reduction in CO_2 emissions.

5.8 Regulation 101 data collection

5.8.1 *Flexibilities that become defined with the vehicles specification*

Reference mass, the choice of tyres and their pressure

Flexibilities with respect to reference mass, choice of tyres and tyre pressure are all covered in previous section in the context of collecting the coast down data.

Using a higher gear through the NEDC

Gear number and change point are pre-defined for the NEDC cycle. There is a flexibility that applies to vehicles where “the maximum speed can be attained in first gear is below 15 kph”. For such vehicles “the second, third and fourth gears shall be used for the urban cycle.” The analysis from chapter 3 estimates that this could lead to a 6% reduction in CO_2 emissions. This is the largest of all the CO_2 reductions quantified in chapter 3, see Section 3.4.4.

It is emphasised that there is no disagreement with the existence of this flexibility, or for the estimate of the change in CO_2 emissions that results from its use. However, it has been estimated that the number of light duty vehicles that this applies to is extremely small. Furthermore, for such vehicles, it could be argued that first gear is essentially ignored because it is a crawler, or an off-road gear and the speeds within the urban cycle would normally be driven in the higher gears. Further, this flexibility was never mentioned during any of the stakeholder consultations. As a consequence, it is estimated that its current usage leads to a 0.0% change in CO_2 emissions.

5.8.2 *Remaining flexibilities*

Running in period of test vehicle

The desk study reported in chapter 3 concluded that extending the distance run in for the test vehicle from 3,000 km to 15,000 km could lead to a 5% reduction in CO_2 emissions.

The stakeholder consultations did acknowledge this flexibility, but the general feedback was:
- most modern production lines would make vehicles whose CO_2 emissions would not improve by 5% between having travelled 3,000 km and 15,000 km;
- most vehicle tested had travelled around 5,000 km at the start of testing.

On this basis, it is presumed that the average improvement is around 2.5% CO_2 emissions reduction between the two extreme distances, and the vehicles used have travelled around a fifth of this range. On this basis, this flexibility was estimated to provide a 0.5% CO_2 emissions reduction, and that half of this flexibility has been additionally used in the last decade.

Implementation of laboratory instrument flexibilities

This was considered as part of the chapter 3 desk study, and reported in 3.7. It covers measurement accuracy and tolerances for a range of instrumentation equipment. A key aspect is the +/- 2% measurement error for the CO_2 (and other) analysers against the calibration gas. Coast down matching and the accuracy of the road load measurement were each calculated to add a potential 1.2% CO_2 emissions benefit, while flexibility in the accuracy of air temperature measurement leads to a potential 0.3% CO_2 emissions benefit. The implementation of all these laboratory instrument flexibilities adds up to 4.7% CO_2 benefit if the full range is used for each one.

Conversations with the type approval authorities indicate that what they are seeking is evidence that the dynamometer and gas analyser linearity acceptance criteria are in date (checked monthly for gas analyser linearity) and then that the measurements made as part of the test, the coast down matching, zero and span gas analyser readings etc. are all within the required limits. There was no mention of systematic use being made of the flexibilities.

Conversations with those operating test houses indicated that they were very aware of the intrinsic random errors associated with the instruments and equipment they use. Therefore, the original intention of the flexibility, that was to provide realistic leeway so that tests results are not disqualified because one component of all those involved is outside specification, is welcomed and used. There was no suggestion of any systematic use being made of the flexibilities. However, it should be remembered that test houses undertake a multiplicity of different tests for a wide range of customers, and only a relatively small fraction of these are witnessed type approval tests.

It is possible that the facilities within manufacturers' premises are operated differently. It is likely that with improvements in instrumentation the actual flexibility required to have an acceptably small number of "out of specification" tests is now smaller than was appropriate when the regulations were first written. As a consequence, it is possible that some systematic use of the flexibilities could now be used. However, this argument is based on the performance of modern laboratory instruments, and the importance now attached to the CO_2 emissions measurement. It is not based on evidence that it is occurring.

Using a soak temperature of 30°C rather than 20°C

Cold vehicles emit more CO_2 when travelling the same distance relative to when they are at their normal operating temperature. Chapter 3 estimated that this difference was a CO_2 emissions reduction of 1.7%.

Consultations with stakeholders indicated that generally temperatures around 25°C are used. As a consequence, it is estimated that its current usage leads to a 0.85% change in CO_2 emissions. However, consultations with stakeholders also indicated that for many vehicle tests this has not changed, although some type approval testing does make use of this flexibility. Therefore it is further estimated that the change in usage over the past decade has led to around a sixth of this being new changes, i.e. 0.15% change in CO_2 emissions during the past decade.

Using cookbook dynamometer load values rather than coast down data

Chapter 3 estimated that this difference was a CO_2 emissions reduction of 3% (data taken from limited practical measurements on vans).

Consultations with stakeholders indicated that generally for passenger cars coast down data is used, with cook book data being extremely rarely used. As a consequence, it is estimated that this flexibility's current usage leads to no change in CO_2 emissions for passenger cars.

The same consultations with stakeholders indicated that many vans are tested using cook book data, with under a half using coast down data. Therefore for vans it is assumed that this flexibility provides a 2% CO_2 emissions reduction, and that that this difference has remained unchanged during the past decade.

Ensuring the battery is fully charged

Chapter 3 estimated that optimising the state of battery charge can lead to a CO_2 emissions reduction of 1%.

The consultations with stakeholders indicated that this aspect of testing has increasingly become controlled during both the collection of coast down data, and for the R101 test when the vehicle is run on the dynamometer.

As a consequence, it is estimated that its current usage is the full amount identified in chapter 3, and that this is a change over the past decade because previously it was not considered.

Using driving technique

These flexibilities arise because there is a tolerance of +/- 2 km/h between the driven and target speed, and a time tolerance of +/- 1 second for the gear changing periods. These tolerances are to allow the driver some small leeway before the test is classed as invalid. The chapter 3 analysis indicated that, from a vehicle simulation model, the advantage between following the exact vehicle speed trace and the most advantageous possible would be a reduction in CO_2 emissions of 1.2%.

Consultation with stakeholders, all of who used real rather than robotic drivers, firstly emphasised the skill required to drive a vehicle to the trace sufficiently accurately to provide a valid test. The strong impression given was that no driver was going to try and drive at the lower end of the permitted envelope because the slightest slip would invalidate the test. Notwithstanding, our experience is that there are some very skilled drivers working in the industry, and it is estimated that such a skilled driver could go part way to obtaining the maximum possible benefit. We have therefor assumed that the real usage of this flexibility is half the maximum possible, and that its use has been relatively recent, following the emphasis on CO_2 emissions.

Extending the distance between DPF regenerations (Ki factor)

Chapter 3 provides a detailed explanation of how this effect influences the CO_2 emissions for diesel vehicles only, and estimated how managing to double the distance between regenerations would lead to a CO_2 emissions reduction of 0.3%.

This subject did arise during stakeholder consultations, but was not seen as an area where any significant degree of flexibility was being used.

When considering changes in CO_2 emissions since 2002 it should be noted there were no DPFs in 2002, and the subsequent introduction of DPFs has introduced a CO_2 penalty. The use of this potentially relevant flexibility reduces the CO_2 penalty, and increases the gap between TA and real world driving CO_2 emissions.

An estimate of the actual change in CO_2 emissions from the use of this potential flexibility is based on relatively the weak evidence. If a third of diesel vehicles used the full flexibility presented in Chapter 3, this would lead to a diesel fleet saving of 0.3% x 1/3 CO_2 emissions reduction, i.e. 0.1% reduction. However, for passenger cars, around half new sales are diesel fuelled, the other half being petrol vehicles with no DPF fitted. Therefore, for passenger cars the new fleet average change in CO_2 emissions from the use of this potential flexibility is 0.05%. For vans, where virtually all new vehicles are diesel vehicles, the new fleet average change in CO_2 emissions from the use of this potential flexibility would be 0.1%.

Declaring lower CO_2 value.

The regulation allows for a manufacturer to “declare” a value **up to 4% lower** than the actual measured result (taking into account the margin required to pass conformity of production checks and in-service testing.

The stakeholder consultation reported different approaches to this, with some manufacturers declaring the measured result, and others declaring a value the full 4% lower. As a consequence, our estimate of the extent to which this flexibility is currently used is that it leads to a 2% CO_2 emissions reduction on the measured result. It is also noted that this flexibility has only recently started to be used since the CO_2 emissions data is used much more widely within regulation, Member States tax systems and for marketing.

5.9 Estimation of the actual change in CO_2 emissions since 2002 from increased use of flexibilities

The methodology used to estimate the actual change in CO_2 emissions since 2002 from the use of flexibilities was:

1. To list the maximum change in CO_2 emissions for each flexibility for specified conditions, as defined in chapter 3 (see column 2 in the tables below);
2. From the "change in CO_2 emissions", the specified conditions, and the feedback from the consultations, estimate realistic lower and upper bounds for the flexibility (columns 6 and 7 in the tables below). The lower bound gives an estimate of the "minimum credible" change;
3. From the interviews gauge the extent to which the flexibility was used in 2002 (column 8 in the tables below);
4. From the above data estimate the % of the maximum change in CO_2 emissions that is realistically available from 2002 (column 9 in the tables below);
5. From the interviews estimate the level of uptake of the available potential for change in CO_2 between 2002 and 2010 (column 10 in the tables below);
6. Estimate the actual change in CO_2 resulting from the increased utilisation of each flexibility since 2002, using:
   Actual change (given in column 11)=
   maximum change in CO_2 for given conditions (column 7, upper realistic bound)
   x the % of the maximum change in CO_2 emissions that is realistically available since 2002 (column 9)
   x the increased uptake since 2002 (column 10)

These data are given in Table 47 for the collection of coast down data, and in Table 48 for the R101 test.

Interviews with stakeholders suggest few vans use coast down data, the majority being tested using default dynamometer settings. The vans that tend to use coast down data are the car derived vans. In a separate analysis, it was estimated that around 20% of all van sales are for car derived vans. Therefore it is presumed 20% of van testing uses coast down data, and the above analysis of the use of flexibilities applies, and 80% use default dynamometer setting, with no "coast down" flexibilities applying.

For vans the assumptions are the same as for passenger cars, except for reductions in vehicle mass, where the stakeholder interviews indicated that there was no similar evidence for this occurring to the same extent as for cars.

Results for vans are presented in Table 49.

Table 47 A summary of the estimates of flexibilities available **for passenger cars** during **coast down testing**, the maximum change in CO_2 emissions, the current extent of utilisation of flexibilities for light duty vehicles, and the estimated net impact on CO_2 emissions since 2002.

Parameter	Max. ΔCO_2 from chapter 3		Circumstances for this ΔCO_2	Assumption from interviews	ΔCO_2 Realistic bounds: Lower (Note 1)	ΔCO_2 Realistic bounds: Upper (Note 2)	Level of use as % of upper realistic bound: Use of flexibility in 2002	Level of use as % of upper realistic bound: Available rel. to 2002	Level of use as % of upper realistic bound: Uptake since 2002	Actual ΔCO_2 since 2002 (Note 3)
Optimising wheel and tyre specifications	Part of 4.2% (2.0% for R101)	2.00%	Caused by increasing tyre rolling radius by 5% for a vehicle with sub-optimal gear ratios	No evidence of this flexibility being used (see comments in R101 analysis)	0.00%	0.20%	10%	90%	0%	0.00%
Tyre pressure	Part of 4.2% (Within 2% above)		Use of different specified tyre pressures in handbook	Included below in terms of tyre preparation	0.00%	0.00%	0%	0%	0%	0.00%
Brakes	0.0%		Brake adjustments to remove potential parasitic drag	Extent irrelevant if adjudged to give no change in CO_2 emissions	0.00%	0.00%	0%	100%	10%	0.00%
Preconditioning	Part of 4.2%	0.50%	Maximise temperature in bearings, gear box oil etc. for start of coast down test	All flexibility used	0.25%	0.50%	0%	100%	100%	0.50%
Running in period of test vehicle	Part of 4.2%	1.70%	Only the influence on friction loses (not engine efficiency) is relevant	For R101 test this gives overall benefit of 5%, presume power-train friction loss reduction is 1.7% of this. Also assume vehicle selected uses all this flexibility.	0.85%	1.70%	0%	100%	100%	1.70%
Ambient conditions	0.00%	0.00%	Includes temperature, humidity, pressure (corrected for) and limits on wind speed acceptable.	These “flexibilities” appear major constraint in being able to conduct a valid test. Hence, assumed max benefit is negligible	0.00%	0.00%	0%	100%	100%	0.00%
Test track design	0.30%		From using a smooth surface and a track with a permitted gradient	Assume maximum flexibility is used	0.20%	0.30%	0%	100%	100%	0.30%

				ΔCO_2 Realistic bounds		Level of use as % of upper realistic bound			
Parameter	Max. ΔCO_2 from chapter 3	Circumstances for this ΔCO_2	Assumption from interviews	Lower (Note 1)	Upper (Note 2)	Use of flexibility in 2002	Available rel. to 2002	Uptake since 2002	Actual ΔCO_2 since 2002 (Note 3)
Use of carefully prepared tyres	2%	Chapter 3 mentions how a vehicle could be fitted with very hard tyres that would have very poor handling – coast down data could be collected, but vehicle could not be driven safely on public roads. Similarly “specially prepared” tyres could be used to gather coast down data	Feedback from stakeholder consultation, and from other research undertaken by DG CLIMA indicates this is a “flexibility” that is regularly used. The CO_2 benefit is an estimate by the authors.	1.00%	2.00%	0%	100%	100%	2.00%
Other vehicle preparation not prohibited	2%	These are unspecified flexibilities, e.g. setting wheel camber and toe-in maximum permitted to provide the lowest rolling resistance, and careful adjustment of ride height.	Feedback from stakeholder consultation indicates there are a range of “flexibilities” in the vehicles’ handbooks that are regularly used, not specifically mentioned in the regulations. CO_2 reduction is an estimate.	1.00%	2.00%	0%	100%	50%	1.00%

Notes: The above data applies to virtually all passenger cars because these use coast down data.

Note 1: Lower bound = estimate of the minimum credible change in CO_2 emissions from each potential flexibility
Note 2: Upper bound = estimate of the maximum credible change in CO_2 emissions from each potential flexibility
Note 3: Actual ΔCO_2 since 2002 calculated from Upper bound (Column 7) x Uptake since 2002 (Column 10)

Table 48 A summary of the flexibilities available **for passenger cars** during the **R101 CO_2 emissions test**, estimates of maximum change in CO_2 emissions, the current extent of utilisation of flexibilities for light duty vehicles and the estimated impact on CO_2 emissions in 2010

					ΔCO_2 Realistic bounds		Level of use as % of upper realistic bound			
Parameter	Max ΔCO_2 from chapter 3		Circumstances for this ΔCO_2	Assumption from interviews	Lower (Note 1)	Upper (Note 2)	Use of flexibility in 2002	Available rel. to 2002	Uptake since 2002	Actual change in CO_2 from 2002 (Note 3)
Reduction in vehicle mass	2.50%		110 kg light-weighting, i.e. one inertia class change	One inertia class change occurs for 10% of vehicles	0.13%	0.75%	0.0%	100%	33%	0.25%
Optimising wheel and tyre specifications	2%		Caused by increasing tyre rolling radius by 5% for a vehicle with sub-optimal gear ratios	No evidence of this flexibility being used. Also manufacturers seek to optimise gear ratios. There-fore upper bound estimated to be only 10% of maximum range.	0.00%	0.20%	0.0%	100%	0%	0.00%
Reducing rolling resistance by 20%	2.80%		20% resistance in rolling resistance, e.g. through the use of very hard tyres	N/A if coast down data is used	0.00%	0.00%	0.0%	100%	0.0%	0.0%
Running in period of test vehicle	5%		Difference between fuel consumption after 15,000 km, vs 3,000 km from Ricardo vehicle testing.	Interviews suggest most vehicles start being tested with 3,000 to 5,000 on odometer. Assume this has increased by 2,400 km for 50% of vehicles, i.e. 5% of maximum benefit is being realised. (Other feedback suggests max benefit is less than 5%)	0.00%	0.50%	25%	75%	75.00%	0.38%
Implementation of laboratory instrument flexibilities	Part of 4.70%	0.30%	Comprises 0.3% ambient temperature reading error	Ambient temperature flexibilities not used	0.00%	0.30%	50%	50%	0.00%	0.00%
	Part of 4.70%	2.00%	Accuracy of CO_2 analyser ± 2.0% relative to span gas	Assume CO_2 analysers used to be set at middle of range, but are now set low to give 1.0% CO_2 advantage. Max possible estimated to be 1.5% to allow head-room for instrument inaccuracies	-0.50%	1.50%	0%	100%	66.67%	1.00%

					ΔCO_2 Realistic bounds		Level of use as % of upper realistic bound			
Parameter	Max ΔCO_2 from chapter 3		Circumstances for this ΔCO_2	Assumption from interviews	Lower (Note 1)	Upper (Note 2)	Use of flexibility in 2002	Available rel. to 2002	Uptake since 2002	Actual change in CO_2 from 2002 (Note 3)
Implementation of laboratory instrument flexibilities (cont.)	Part of 4.70%	1.20%	1.2% coast down data matching on going from -5% to +5% load setting; accuracy of actual load vs intended	Assume coast down data matching, has changed from mid-point to using an estimated 50% of the 0 to +5% range available, i.e. ¼ of whole range	0.6%	1.05%	50%	50%	66.67%	0.35%
	Part of 4.70%	1.20%	Load applied 1.2% CO_2 change on going from -5% to +5% load reading	Assume accuracy of dyno retarding forces relative to indicated load, has changed from mid-point to using an estimated 50% of the 0 to +5% range available	0.6%	1.05%	50%%	50%	66.67%	0.35%
Fuel specification flexibilities		0.00%	Found that tolerance band for fuel spec that could theoretically be used generates no CO_2 benefit	It does not matter the detailed specification of reference test fuel used	0.00%	0.00%	0%	100%	100%	0.00%
Soak temperature 30°C rather than 20°C	1.70%		The difference between soaking at 20°C and 30°C	Soak temperatures generally closer to 25°C, but testing now undertaken at top end of range. Overall increase of 1°C in soak temperature	0.17%	1.53%	50%	50%	25%	0.19%
Using cook book figures	3.00%		For vehicles with high aerodynamic drag use of cook book default figures rather than coast down data	For cars assumed very close to 100% vehicles use coast down data – hence N/A	0.00%	0.00%		N/A		
Using fully charged battery	1.00%		Change in CO_2 emissions for fully charged relative to partially discharged battery	State of battery charge is now carefully controlled, assume full advantage is taken for this flexibility – no more available	0.00%	1.00%	0%	100%	100%	1.00%

Parameter	Max ΔCO_2 from chapter 3		Circumstances for this ΔCO_2	Assumption from interviews	ΔCO_2 Realistic bounds: Lower (Note 1)	ΔCO_2 Realistic bounds: Upper (Note 2)	Level of use as % of upper realistic bound: Use of flexibility in 2002	Level of use as % of upper realistic bound: Available rel. to 2002	Level of use as % of upper realistic bound: Uptake since 2002	Actual change in CO_2 from 2002 (Note 3)
Using driving technique	1.20%		The difference between following the speed trace exactly, and following the best permitted allowed speed trace	It is presumed that previously driving had random variations relative to the precise trace. Now, systematic deviations from this towards the best permitted speed trace are driven. However, the risk of "failing" a test means that the best permitted trace cannot be followed perfectly. It is assumed that the speed trace driven generates 50% of the maximum benefit	0.30%	0.90%	0%	100%	66.67%	0.70%
Extending DPF regeneration interval (Ki factor)	0.30%		The interval is "extended" from every 550 km to 1,100 km (from 50 to 100 NEDC cycles)	Only applies to diesels, 50% of the fleet, and, on weak evidence, applies to 1/3 of vehicles	0.00%	0.15%	0%	100%	33.33%	0.05%
Declaring lower CO_2 value	4.0%		Manufacturer's judgement	On average half of this flexibility is used	1.00%	3%	0%	100%	66.67%	2.00%

Note 1: Lower bound = estimate of the minimum credible change in CO_2 emissions from each potential flexibility
Note 2: Upper bound = estimate of the maximum credible change in CO_2 emissions from each potential flexibility
Note 3: Actual ΔCO_2 since 2002 calculated from Upper bound (Column 7) x Uptake since 2002 (Column 10)

Table 49 A summary of the flexibilities available **for light commercial vehicles** during the coast down and R101 CO_2 emissions test, estimates of maximum change in CO_2 emissions, the current extent of utilisation of flexibilities for light duty vehicles and the estimated impact on CO_2 emissions in 2010

Parameter		Max ΔCO_2 from chapter 3		ΔCO_2 Realistic bounds: Lower (Note 1)	ΔCO_2 Realistic bounds: Upper (Note 2)	Level of use as % of upper realistic bound: Use of flexibility in 2002	Level of use as % of upper realistic bound: Available rel. to 2002	Level of use as % of upper realistic bound: Uptake since 2002	Actual change in CO_2 from 2002 (Note 3)	Comments
Reduction in vehicle mass		2.50%		0.13%	0.75%	0.0%	100%	0%	0.00%	No evidence of this occurring with vans
Optimising wheel and tyre specifications		2%		0.00%	0.20%	0.0%	100%	0%	0.00%	As for cars
Reducing rolling resistance by 20%		2.80%		0.00%	0.00%	0.0%	100%	0.0%	0.00%	As for cars
Running in period of test vehicle		5%		0.00%	0.50%	25%	75%	75%	0.38%	As for cars
Implementation of laboratory instrument flexibilities	Temperature	Part of 4.70%	0.30%	0.00%	0.30%	50%	50%	0%	0.00%	As for cars
	CO_2 analyser	Part of 4.70%	2.00%	-0.50%	1.50%	0%	100%	66.67%	1.00%	As for cars
	Coast down matching	Part of 4.70%	1.20%	0.6%	1.05%	50%	50%	66.67%	0.35%	As for cars
	Load applied	Part of 4.70%	1.20%	0.6%	1.05%	50%	50%	66.67%	0.35%	As for cars
Fuel specification flexibilities			0.00%	0.00%	0.00%	0%	100%	100%	0.00%	As for cars
Soak temperature 30°C rather than 20°C		1.70%		0.17%	1.53%	50%	50.00%	25.00%	0.19%	As for cars
Using cook book figures		3.00%		0.00%	0.00%	100%	0%	0%	0.00%	Vans have always tended to use cook book figures
Using fully charged battery		1.00%		0.00%	1.00%	0%	100%	100%	1.00%	As for cars
using a higher gear throughout the NEDC		6.00%		0.00%	0.00%	0%	100%	0%	0.00%	As for cars
Using driving technique		1.20%		0.15%	1.05%	0%	100%	66.67%	0.70%	As for cars
Extending DPF regeneration interval (Ki factor)		0.30%		0.00%	0.30%	0%	100%	33.33%	0.05%	This could apply to virtually 100% of van fleet
Declaring lower CO_2 value		4.0%		1.0%	3.0%	0%	100%	66.67%	2.00%	As for cars

Note 1: Lower bound = estimate of the minimum credible change in CO_2 emissions from each potential flexibility
Note 2: Upper bound = estimate of the maximum credible change in CO_2 emissions from each potential flexibility
Note 3: Actual ΔCO_2 since 2002 calculated from Upper bound (Column 7) x Uptake since 2002 (Column 10)

5.10 Estimation of the uncertainties in the estimates of actual change in CO_2 emissions since 2002

The preceding section estimated an average actual change in CO_2 emissions since 2002 from the use of a range of flexibilities. Table 50 tabulates estimates of the uncertainties on this “central” figure. These were derived from a combination of the range available, the positioning of the “actual change estimate” within this range, and the information from the stakeholder interviews.

Table 50 Assessment of the lower and upper limits to the estimated actual change in CO_2 emissions from **passenger cars** since 2002

Parameter		**Max. ΔCO_2 from chapter 3**		**Actual change in CO_2 from 2002**	**Lower Limit**	**Upper limit**
Reduction in vehicle mass		2.50%		0.25%	0.15%	0.50%
Optimising wheel and tyre specifications		2%		0.00%	0.00%	0.20%
Reducing rolling resistance by 20%		2.80%		0.00%	0.00%	0.28%
Running in period of test vehicle		5%		0.28%	0.15%	0.70%
Implementation of laboratory instrument flexibilities	Temperature	Part of 4.70%	0.30%	0.00%	0.00%	0.00%
	CO_2 analyser	Part of 4.70%	2.00%	1.00%	0.50%	1.50%
	Coast down matching	Part of 4.70%	1.20%	0.35%	0.20%	0.55%
	Load applied	Part of 4.70%	1.20%	0.35%	0.20%	0.55%
Fuel specification flexibilities			0.00%	0.00%	0.00%	0.00%
Soak temperature 30°C rather than 20°C		1.70%		0.19%	0.00%	0.34%
Using cook book figures		3.00%			N/A	N/A
Using fully charged battery		1.00%		1.00%	0.50%	1.00%
Using a higher gear throughout the NEDC		6.00%		0.00%	0.00%	0.00%
Using driving technique		1.20%		0.70%	0.30%	0.90%
Extending DPF regeneration interval (Ki factor)		0.30%		0.05%	0.00%	0.10%
Declaring lower CO_2 value		4.0%		2.00%	1.00%	3.00%

5.11 Combining all flexibilities

A variety of flexibilities have been identified, and to some extent quantified, in section 3. Any subsequent analysis of these flexibilities should not assume that they can be combined in a simple way. There are several factors which must be taken into account if any flexibility is being considered in conjunction with others. These factors include:

- Compounding effect of applying a percentage reduction to a value that has already been reduced by a percentage;
- Physical non-linearities in vehicle and engine characteristics; such as the shape of the engine brake specific fuel consumption (BSFC) map. When engine load is reduced there will be a reduction in fuel consumption, however that reduction will vary depending on where the engine is currently operating on the BSFC map;
- Fuel consumption requirements not related to vehicle-based drag forces, such as those associated with overcoming engine friction, which affect the relationship between percentage reduction in vehicle load, and percentage reduction in CO_2;

- Some flexibilities are mutually exclusive. For example, cookbook based load terms cannot be used at the same time as coast down based load terms; therefore any flexibilities associated with one cannot be used in combination with the other.

In order to help quantify the combined effects of flexibilities, vehicle simulation was performed using models similar to those in section 3. The CO_2 reduction from individual flexibilities that affect engine load was simulated. Subsequently two approaches for estimating the combined effect of using a range of flexibilities were compared:

1. Results for individual flexibilities were added.
2. The CO_2 reduction from those same flexibilities when used in conjunction was also simulated. This process was applied in stages in order to assess the extent to which any non-linearities may be apparent.

The results of the simulations showed that for the flexibilities that are being used, i.e. neglecting the use of a higher gear throughout the NEDC, the impact of each individual flexibility was sufficiently small so that negligible non-linearity was found. Hence it was concluded the two methods of combining flexibilities were similar at low values of total CO_2 reduction, but may diverge at higher values. Therefore it is recommended that CO_2 reduction from individual flexibilities can be combined for analysis if the total resulting percentages are relatively low, e.g. 0-10%, but should not be combined in this way where the total percentage is higher. The exact nature of each flexibility must also be considered to ensure that they are not mutually exclusive, or overlap in any way.

It is also noted that adding the estimated reductions of individual flexibilities to estimate the overall impact is not the same as applying all the flexibilities to the same vehicle. The impacts for each flexibility are a product of the impact per vehicle when applied **and** the share of vehicles to which it is applied. Many “levels of use”, given in Table 47 Table 48 and Table 49, are well below 100%. In these circumstances the average number of flexibilities applied to a single car is, in principle, smaller than the total number of identified flexibilities.

For the individual flexibilities the preceding tables have given:

- estimates of the actual change in CO_2 emissions since 2002 from the use of flexibilities for the collection of coast down data (Table 47), and for the regulation 101 test (Table 48),
- assessment of the lower and upper limits to the estimated actual change in CO_2 emissions since 2002.

The overall relative change in CO_2 emissions since 2002 from the use of **all** flexibilities was calculated using:

$$\Delta CO_2 \;/ CO_2 = 1 - \prod_{i-1}^{n} (1 - \delta_i)$$

where δ_i = the estimate of the actual change in CO_2 emissions since 2002 from the use of each individual flexibility.

A summary of the estimates of the maximum potential CO_2 impacts of flexibilities from the section 3 analysis, and the actual emissions reduction since 2002 for each flexibility is given in Table 51 for both cars and vans. The combined effect of all these flexibilities is also given.

However, the above calculation does assume that the potential CO_2 emissions reduction available from each flexibility is independent, i.e. that there are no interactions that lead to a smaller CO_2 reduction when combinations of flexibilities are used. This makes the 11.2% for cars an upper limit.

The principal differences between the two types of light duty vehicles are that:

- virtually all passenger cars use coast down data, rather than cook book (UNECE-R83 and R101 default) dynamometer settings whereas it is estimated only 20% of the CO_2 data from light commercial vehicles is collected using coast down data to derive the dynamometer load settings;
- virtually all vans have diesel engines, for which the flexibilities concerning DPF regeneration are relevant, whereas for passenger cars this flexibility is irrelevant for the petrol fuelled vehicles.

The data are shown as a series of bar graphs in Figure 19.

Table 51 A summary of the estimates of maximum potential CO_2 benefits and the current extent of utilisation of flexibilities for cars and vans

Coast down times				
		Max possible	Cars	LCVs
Optimising wheel and tyre specifications		2.0%	0.00%	As for cars but only applies to 20% of vans, others use default dynamometer setting, where there is not influence from coast down flexibilities.
Tyre pressure		0.0%	0.00%	
Brakes		0.0%	0.00%	
Preconditioning		0.5%	0.50%	
Running in period of test vehicle		1.7%	1.70%	
Ambient conditions		0.0%	0.00%	
Test track design		0.3%	0.30%	
Additional aspects of coast down times	Use of carefully prepared tyres	2.0%	2.00%	
	Other vehicle preparation not prohibited	2.0%	1.00%	
Combined CO_2 reduction effect for coast down data collection			**5.39%**	**1.08%**
Range for coast down data collection			**3.3% - 7.5%**	**0.65% - 1.5%**
Reg 101 test				
		Max possible	Cars	Vans
Reduction in vehicle mass		2.5%	0.25%	0.00%
Optimising wheel and tyre specifications		2.0%	0.00%	0.00%
Reducing rolling resistance by 20%		2.8%	0.00%	0.00%
Running in period of test vehicle		5.0%	0.38%	0.38%
Implementation of laboratory instrument flexibilities	Temperature	0.3%	0.00%	0.00%
	CO_2 analyser	2.0%	1.00%	1.00%
	Coast down matching	1.2%	0.35%	0.35%
	Load applied	1.2%	0.35%	0.35%
Fuel specification flexibilities		0.0%	0.00%	0.00%
Soak temperature 30°C rather than 20°C		1.7%	0.19%	0.19%
Using cook book figures		3.0%	0.00%	0.00%
Using fully charged battery		1.0%	1.00%	1.00%
using a higher gear throughout the NEDC		6.0%	0.00%	0.00%
Using driving technique		1.2%	0.70%	0.70%
Extending DPF		0.3%	0.05%	0.05%
Declaring lower CO_2 value		4.0%	2.00%	2.00%
Combined CO_2 reduction effect for Regulation 101 testing			**6.11%**	**5.88%**
Range for Regulation 101 testing			**3.06% - 9.24%**	**2.82% - 9.0%**
Combined effect for whole CO_2 emissions test			**11.2%**	**6.90%**
Range for whole CO_2 emissions test			**6.2% - 16.0%**	**3.5% - 10.5%**

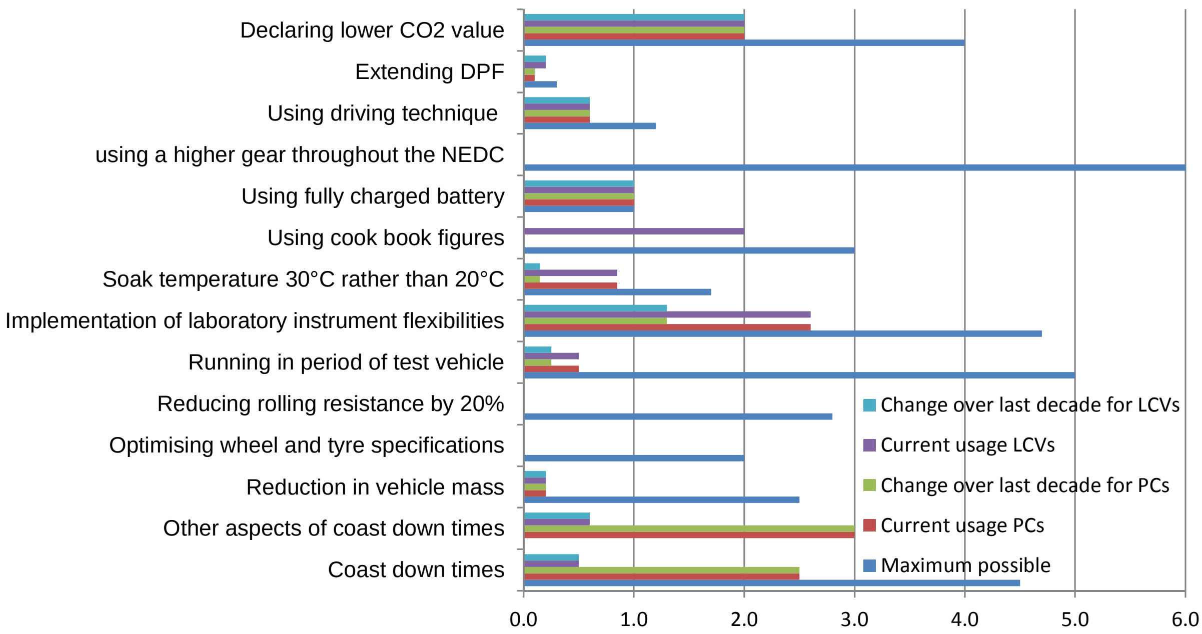

Figure 19 Bar graph of the current extent to which flexibilities reduce CO_2 emissions for light duty vehicles

The analysis thus indicates that the combined effect of utilising different flexibilities for CO_2 measurement is a reduction of 11.2% (with a range of 6.2% - 16.0%) for cars, since 2002 based on the assumptions given above, and a reduction of 6.9% (with a range of 3.5% - 10.5%) for vans.

In terms of the origins of these impacts for passenger cars the main flexibilities are:

- 5.4% of the overall reduction originates from aspects of the coast down data collection;
- 2.0% of the overall reduction is attributed to the declaration of a CO_2 emissions value lower than that measured;
- 1.3% of the overall reduction is attributed to the implementation of laboratory instrument flexibilities;
- 1.0% of the overall reduction is attributed to ensuring the battery is fully charged, and
- the remaining 1.5% of the overall reduction is attributed to the remaining nine areas of flexibility identified.

If it is assumed that changes in CO_2 emissions from real driving are from the technology fitted to the vehicle, then changes in the CO_2 emissions measured at homologation relative to those measured during real driving, would reflect the increase in the use of flexibilities used at homologation. Such a comparison is possible using data in a report by TÜV of the declared CO_2 values of diesel passenger cars versus those obtained from real driving as given for different time periods, see below.

This suggests that the real reduction in CO_2 emissions changed from 156 g CO_2/km in 2000 – 2002 to 143.8 g CO_2/km in 2008 – 2009, a reduction of 7.8% over 8 years. Over this same time period the declared value showed a reduction of 17.5%, suggesting that in addition to the 7.8% “real” change an additional 9.7% reduction has occurred in the type approval values. This “additional reduction” appears consistent with the estimated impact of increased utilisation of flexibilities of 11.2%, as estimated above.

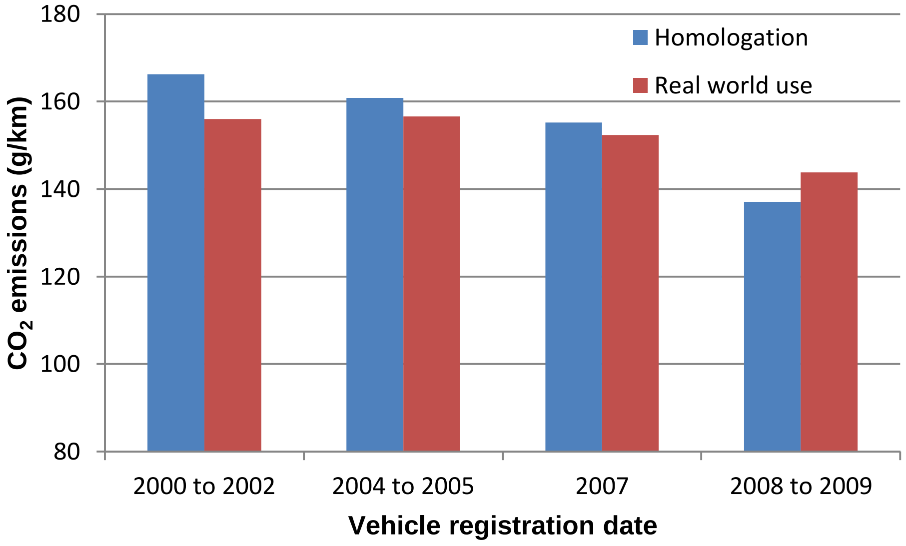

Figure 20 Average CO2 emissions from diesel vehicles at homologation and from real world use against vehicle registration year[16]

5.12 Possible flexibilities not related to bandwidths specified in the legislation

So far the quantitative analysis has focussed on flexibilities related to allowable bandwidths specified in the legislation. From the consultation of test houses and TA authorities as well as through other channels indications have been obtained that other flexibilities exist which may be utilised.

In addition to the flexibilities identified from the regulations, consultations with type approval authorities and operators of test houses indicated that there are other aspects of collecting the coast down data that are not covered in the regulations, and very probably contribute to coast down road load factors being smaller than those collected from “standard” roads. Clear quantitative data are difficult to acquire, but it is estimated that these aspects contribute a further 3% reduction in CO_2 emissions.

Also some further flexibilities exist with respect to the R101 test. Application of additional flexibilities that are not related to bandwidths specified in the legislation is possible because formally they do not exist and relate to aspects of the test that do not need to be recorded or approved by the type approval authority.

These identified additional flexibilities are listed below. Except for the last item all additional flexibilities relate to the coast down test:

1. <u>Test track surface condition (concrete or asphalt)</u>
   Road load determination is affected by the road surface properties and conditions. A smooth road surface reduces the measured road load and results in lower CO_2 emissions. Certain test tracks might have favourable road surface conditions.
2. <u>Prepared tyres (modified profile)</u>
   Tyres are meant to create some comfort and therefore they have some elasticity. This comfort conflicts with rolling resistance. Prepared tyres with modified profiles (convex surface) and treated rubber might be more stiff. This reduces the total vehicle rolling resistance.
3. <u>Increased inertia of tyres (fluid or metal)</u>
   An increase of the inertia of a wheel / tyre combination (e.g. by filling the tyre with a fluid or metal) has a positive effect on the road load curve because more kinetic energy is available

[16] Taken from Figure 3.23 of [TÜV Nord, 2010a]

for the coast down test. Another item is the diameter of the wheel rim and the rim material. The wheel inertia can be increased by increasing the diameter of the rim or by using a rim material with a high density.

4. Taping of body parts
Taping of the vehicle body (removal of gaps between body parts) might have a positive effect on air resistance and lowers the total vehicle resistance.

5. Optimized resistance of wheel bearings
Dedicated wheel bearings decrease rolling resistances and reduce the rolling resistance of a vehicle. The durability and the rolling resistance of bearings are controversial. In general a bearing with very small clearance has the lowest friction but has a shorter lifetime.

6. Optimized front cooling air inlet
Due to the very different cooling needs of an engine in summer and winter different front covers can be applied (summer and winter setting). Some modern vehicles automatically control the air inlet through the grill in response to air temperature. With a closed inlet less air flows through the engine compartment, leading to lower air drag. Performing the coast-down test with closed air inlet therefore provides a means to lower CO_2 emissions on the type approval test.

7. Optimized body position (height / ground clearance)
Optimization of the body height can reduce air resistance, even a modification of a few millimetres can have a significant impact. Therefore it makes sense to prepare the test vehicle for road load testing with an optimized body height.

8. Optimized wheel alignment
Front wheels of production vehicles are generally adjusted to have a certain degree of “toe in” as this improves driving stability. As mentioned in section 5.7.3 it appears that for coast-down testing the wheel camber and toe-in are set to the maximum permitted to provide the lowest rolling resistance. This possibility to adjust the wheel alignment therefore provides a test flexibility.
Besides that it should be noted that the situation of the driven axle during a coastdown test is not representative of real-world driving. During normal operation the driven axle experiences a driving force from the powertrain for most of the time. In a coast-down test, however, there is no driving force on the wheel, leading to a different wheel alignment –and consequently a different rolling resistance, compared to the driven mode. This may negatively affect the representativeness of the type approval CO_2 value for real-world driving.

9. Definition of a standard vehicle
The definition of a standard vehicle is to some extent covered by the test procedure. However, as there is no obligation to report the mass of the vehicle used for the coast down test, there appears to be limited control over whether the mass of that vehicle is the same as that of the vehicle used for the type I test. Whether this actually constitutes an additional flexibility is not clear, but the issue deserves further investigation.

10. Slope of the test track
Road load tests as specified in R83 require the coast down to be performed in two opposite directions, but without the criterion that this has to be on the same road. Consequently both directions of the test track might be “downhill”. Such a downhill track will have a relatively large effect at lower speeds.

11 Test modes
The engine control system of a vehicle on a chassis dynamometer with open bonnet and/or non-moving wheels of the non-driven axle might be set in a test mode which deviates from real world operation. Moreover temperature sensors and engine speed and load traces can be used to select an engine control strategy optimised to achieve low CO_2 emissions on the R101 test.

Due to lack of information on the potential impacts as well as levels of utilisation the overall impact of these additional flexibilities on measured CO_2 emissions could not be quantified.

6 Technology deployment in the current new passenger car fleet

6.1 Background

Regulation (EC) 443/2009 sets a target of 130 g/km CO_2 to be achieved by all new passenger cars registered by 2015, with a phase-in from 2012. In 2012, 65% of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75% in 2013, 80% in 2014, and 100% from 2015 onwards. For 2020 a target of 95 gCO_2/km has been set. In response to this regulation, and further promoted by fiscal policies in Member States, manufacturers have started to market vehicles with a range of new CO_2 reducing technologies. This is reflected in reductions of the average type approval CO_2 emissions of new cars sold in Europe, as observed by the Monitoring Mechanism.

Where the previous sections of this study focussed on identifying the extent to which part of the observed TA CO_2 reductions realised since 2002 may not have resulted from the implementation of CO_2 reducing technologies, but instead to the utilisation of test procedure flexibilities, it should be emphasized that the implemented technologies do account for a significant share of these reductions.

6.2 Objectives

This section aims to create insight in the extent to which technology deployment has contributed to the CO_2 reductions in new passenger cars as observed in the recent past (2002 – 2010). To this end deployment levels of various technologies are quantified and combined with the CO_2 reduction potentials as identified in previous studies ([TNO 2006] and [TNO 2011]).

The CO_2 reduction realised by deployment of technologies in LCVs will be dealt with in chapter 8, as the methodology used to determine the contribution of different factors to the 2002 – 2010 CO_2 reduction differs from the methodology used for passenger cars. This difference is a consequence of the absence of an adequate estimate for the 2002 LCV CO_2 emissions.

6.3 Methodology

The assessment presented in this chapter contains two main steps:

- Assessment of the levels of deployment of a range of CO_2 reducing technologies in 2002 and 2010;
- Estimation of the contribution of increased technology deployment levels to the reduction in TA CO_2 emissions observed in the Monitoring Mechanism between 2002 and 2010.

For the assessment of the levels of deployment of CO_2 reducing technologies, firstly a list of technologies has been constructed based on information presented in [TNO 2006] and [TNO 2011]. The market penetration of these technologies in 2002 and 2010 has subsequently been assessed using a historical Light Duty Powertrain, Production and Sales database for the EU 27. The year 2002 is used as reference year in [TNO 2006] and [TNO 2011], because it is assumed that the amount of CO_2 reducing technologies was very limited at that time since no CO_2 regulation had been defined yet. By combining the assessed technology deployment levels ($l_{deployment,i}$) with the reduction potentials (δ_i)of the identified technologies (from [TNO 2006] and [TNO 2011]), the CO_2 reduction due to increased technology deployment between 2002 and 2010 can be determined.

$$\frac{\Delta CO_2}{CO_2} = (1 - margin_{dissynergy}) \times (1 - \prod_{i=1}^{n} \left(1 - l_{deployment,i} \times \delta_i\right))$$

Since some technologies target the same energy loss in a vehicle, a “safety margin” is applied to account for the “dissynergy” occurring when such technologies are combined. This margin is 0% when no or a few technologies are applied in increases linearly to a maximum value for the case when all options are applied to their full potential. This maximum margin is set at 5% for diesel vehicles and 15% for petrol vehicles, corresponding to the safety margins used in [TNO 2011]. The penetration of technologies and resulting CO_2 reductions have been defined separately for average petrol and average diesel vehicles.

Besides technology deployment, other factors are likely to have contributed to the reduction in TA CO_2 emission reduction of passenger cars between 2002 and 2010 also. The following factors have been taken into account in this analysis:

- A sales shift between segments influences the average CO_2 emissions. For instance a shift from petrol vehicles towards comparable diesel vehicles will result in lower CO_2 emissions. The same holds for a shift in sales towards smaller vehicles. The effect of this sales shift is defined as the difference between the 2002 average CO_2 emissions and an estimate of what the 2010 average CO_2 emissions would be if they were based on the 2010 sales distribution combined with the 2002 CO_2 emissions per segment. The 2002 CO_2 emissions per segment and the sales distributions in 2002 and 2010 are taken from [TNO 2011]. [TNO 2011] distinguishes petrol and diesel vehicles for three different 'size' classes (small, medium and large), resulting in a total of six passenger cars segments.
- Effects of changes in average vehicle mass, are determined using the formula $\Delta CO_2/CO_2 = 0.65\ \Delta m/m$, as derived in [TNO 2006]. The effect of changes in mass between 2002 and 2010 is assessed separately for the six segments and is subsequently translated into an average impact by weighing the results per segment with the 2002 sales distribution.
- Also changes in the power-to-weight ratio are likely to have affected emissions between 2002 and 2010. The analysis of this effect is also based on a per segment analysis. The formulas used to determine the effect of changes in the power-to-weight ratio within each segment on the CO_2 emission for each segment are given in Annex A.
- Calibration of an increasing number of engine and powertrain parameters that can be tuned or optimised, and is likely to have contributed to lower CO_2 emissions between 2002 and 2010. This increasing number of parameters result from the increasing complexity of engines and powertrains and their control systems that is required e.g. to meet emission legislation and customer demand for driving comfort and performance.
- Moreover, it is assumed that a number of small technical improvements have been applied between 2002 and 2010, that are not identifiable as separate technologies, and these are also likely to have lowered average CO_2 emissions (see section 6.4.4).

Relating the effects of the technology penetration levels and the other factors that may have affected CO_2 emissions to the difference between 2002 and 2010 average CO_2 emissions for petrol and diesel as provided by the Monitoring Mechanism database (Table 6), gives an overview of the significance of the various factors and their potential contribution to the observed reductions.

6.4 Results

6.4.1 *Effect of technology deployment*

Identifying the CO_2 reduction technologies

For this purpose first a list is constituted of technologies that potentially contributed to CO_2 reductions achieved since 2002. The reduction potentials for 2002 and 2010 are taken from [Smokers 2006] and completed by information from [TNO 2011] if a certain technology was not identified in [Smokers 2006]. For consistency and comparability reasons, the list of technologies for this study is constituted in line with these previous studies. In addition, a careful review of the existing technologies enabling CO_2 reductions has been made in order to ensure that all alternatives are considered.

Segmentation of the market

In comparison to vehicle fleet data, that are subjected to volume inertia and vehicle renewal rates, the IHS Light Vehicle Sales database allows to capture the real evolution of the technological deployments across years since they are focusing on new vehicles sold and therefore on what kind of technologies OEMs bring to the market or not. This is the reason to analyse sales data (rather than vehicle fleet data) in order to have a fairer understanding of the penetration rates of CO_2 reduction technologies. Additional information has been obtained from the IHS Light Vehicle Engine

Service, which tracks the engine specifications required for this analysis and which covers all engines for passenger cars and light-duty trucks, up to 3.5 metric tons gross vehicle weight

Average penetration levels of technologies in 2002 and 2010 have been assessed for petrol and diesel passenger cars separately. Since the reduction potentials from [TNO 2006] and [TNO 2011] are given for six vehicle segments (small, medium and large for two fuel types), the average reduction potentials per fuel type are derived using the 2010 sales distribution over the 'size' classes for petrol and diesel.

Calculation of the technology penetration rates

For assessing the penetration of CO_2 reducing technologies for petrol and diesel vehicles for the years 2002 and 2010, historical data is used. In order to determine the market penetration of a technology, the adoption rate of a technology is compared to the overall numbers of vehicles in the relevant category. Therefore, all penetration rates presented in this document are within a specific vehicle category.

Calculation of CO_2 reduction due to technology deployment between 2002 and 2010

In Table 52 and Table 53 the penetration levels of various CO_2 reducing technologies are shown for 2002 and 2010 for respectively petrol and diesel passenger cars. The total effect of these technologies in 2002 and 2010 is determined by multiplying the relative emissions for all technologies in 2002 and 2010 using the method described in section 6.3. A dissynergy margin is applied to account for the overlap in the effects of technologies that target the same energy losses.

As shown in Table 52 and Table 53, the net CO_2 emission reduction between 2002 and 2010 from the deployment of technologies is 12.4% for petrol vehicles and 8.8% for diesel passenger cars.

Table 52 Penetration rates and impact on CO_2 emissions of technologies applied to passenger cars on petrol in 2002 and 2010

	Reduction Technologies	Reduction		Penetration		Relative CO2 emission	
		[%]	[%]	[%]	[%]	[%]	[%]
		2002	2010	2002	2010	2002	2010
engine options	gas-wall heat transfer reduction	3.0	3.0	5.0	50.0	99.85%	98.50%
	direct injection, homogeneous	3.0	3.0	1.2	19.0	99.96%	99.43%
	direct injection, stratified charge	3.7	3.7	0.0	5.0	100.00%	99.82%
	thermodynamic cycle imporvements e.g. split cycle, PCCI/HCCI, CAI	10.0	10.0	0.0	0.0	100.00%	100.00%
	mild downsizing (15% cylinder content reduction) between 50 - <75 Kw/l	4.5	4.5	22.7	46.8	98.99%	97.91%
	medium downsizing (30% cylinder content reduction) 75 - <95 Kw/l	9.2	9.1	1.7	7.3	99.85%	99.33%
	strong downsizing (>=45% cylinder content reduction) Above 95 Kw/l	12.0	12.0	0.0	0.4	100.00%	99.95%
	cam-phasing	4.0	4.0	14.7	47.2	99.41%	98.11%
	variable valve actuation and lift	10.0	10.0	2.3	21.4	99.77%	97.86%
	low friction design and materials	2.0	2.0	5.0	35.0	99.90%	99.30%
transmission options	optimising gearbox ratios / downspeeding (above 5)	1.2	1.2	3.8	31.8	99.95%	99.61%
	automated manual transmission	4.0	4.0	8.4	17.1	99.66%	99.32%
	dual clutch transmission	4.4	4.4	0.0	6.4	100.00%	99.72%
	continuously variable transmission	5.0	5.0	1.2	2.3	99.94%	99.88%
hybridisation	start-stop hybridisation	4.0	4.0	0.0	13.6	100.00%	99.46%
	micro hybrid - regenerative breaking	7.0	7.0	0.0	10.0	100.00%	99.30%
	mild hybrid - torque boost for downsizing	11.0	11.0	0.0	0.0	100.00%	100.00%
	full hybrid - electric drive	22.0	22.0	0.0	0.3	100.00%	99.94%
driving resistance reduction	mild weight reduction (~10% reduction on body in white)	0.9	0.9	0.0	25.6	100.00%	99.76%
	medium weight reduction (~ 25% reduction on body in white)	2.2	2.2	0.0	5.4	100.00%	99.88%
	strong weight reduction (~40% reduction on body in white)	5.6	5.6	0.0	0.9	100.00%	99.95%
	lightweight components other than BIW	1.0	1.0	0.0	25.7	100.00%	99.74%
	aerodynamics improvement	1.5	1.5	0.0	22.0	100.00%	99.67%
	tyres: low rolling resistance	2.0	2.0	4.0	44.0	99.92%	99.12%
	reduced driveline friction	0.5	0.5	0.0	9.8	100.00%	99.95%
other	thermo-electric waste heat recovery	0.0	0.0	0.0	0.0	100.00%	100.00%
	secondary heat recovery cycle	0.0	0.0	0.0	0.0	100.00%	100.00%
	auxiliary systems efficiency improvement	2.8	2.8	4.9	50.0	99.86%	98.61%
	thermal management	2.5	2.5	0.0	6.2	100.00%	99.85%
	Total result (relative to 2002 baseline)					**97.1%**	**85.1%**
	Reduction					**2.9%**	**14.9%**
	Maximum reduction					**64.5%**	**64.5%**
	Maximum dissynergy margin					**15.0%**	**15.0%**
	Reduction corrected for safety margin					**2.9%**	**14.4%**
	Reduction between 2002 and 2010 from technology deployment					**12.4%**	

Table 53 Penetration rates and impact on CO_2 emissions of technologies applied to passenger cars on diesel in 2002 and 2010

	Reduction Technologies	Reduction [%] 2002	Reduction [%] 2010	Penetration [%] 2002	Penetration [%] 2010	Relative CO2 emission [%] 2002	Relative CO2 emission [%] 2010
engine options	Combustion improvements	2.0	2.0	5.0	50.0	99.90%	99.00%
	mild downsizing (15% cylinder content reduction) between 45 - <60 Kw/l	3.0	3.0	16.0	55.0	99.52%	98.35%
	medium downsizing (30% cylinder content reduction) 60 - <75 Kw/l	5.0	5.0	0.0	8.3	100.00%	99.59%
	strong downsizing (>=45% cylinder content reduction) Above 75 Kw/l	8.7	8.7	0.0	0.2	100.00%	99.98%
	Variable valve actuation and lift	1.0	1.0	100.0	100.0	99.00%	99.00%
transmission options	optimising gearbox ratios / downspeeding (above 5)	2.7	2.7	13.2	65.0	99.64%	98.24%
	automated manual transmission	4.0	4.0	1.3	2.4	99.95%	99.90%
	dual clutch transmission	5.0	5.0	0.0	5.5	100.00%	99.73%
	continuously variable transmission	4.0	4.0	0.9	1.6	99.97%	99.94%
hybridisation	start-stop	3.0	3.0	0.0	30.0	100.00%	99.10%
	micro hybrid - regenerative breaking	6.0	6.0	0.0	5.0	100.00%	99.70%
	mild hybrid - torque boost for downsizing	10.0	10.0	0.0	0.0	100.00%	100.00%
	full hybrid - electric drive	18.0	18.0	0.0	0.0	100.00%	100.00%
driving resistance reduction	mild (~10% reduction on body in white)	1.0	1.0	0.0	32.0	100.00%	99.66%
	medium (~ 25% reduction on body in white)	2.5	2.5	0.0	10.0	100.00%	99.75%
	strong (~40% reduction on body in white)	6.2	6.2	0.0	1.5	100.00%	99.91%
	lightweight components other than BIW	1.0	1.0	0.0	38.0	100.00%	99.62%
	aerodynamics improvement	1.5	1.5	0.0	28.0	100.00%	99.58%
	tyres: low rolling resistance	2.0	2.0	2.4	32.0	99.95%	99.36%
	reduced driveline friction	0.5	0.5	0.0	20.0	100.00%	99.90%
other	thermo-electric conversion	0.2	0.2	0.0	0.0	100.00%	100.00%
	secondary heat recovery cycle	1.1	1.1	0.0	0.0	100.00%	100.00%
	Auxiliary systems improvement	2.5	2.5	6.0	50.0	99.85%	98.73%
	Thermal management	2.5	2.5	0.0	17.5	100.00%	99.56%
					Total result (relative to 2002 baseline)	**97.8%**	**89.2%**
					Reduction	**2.2%**	**10.8%**
					Maximum reduction	**57.2%**	**57.2%**
					Maximum dissynergy margin	**5.0%**	**5.0%**
					Reduction corrected for safety margin	**2.2%**	**10.7%**
					Reduction between 2002 and 2010 from technology deployment	**8.8%**	

6.4.2 *The impact of the sales shift on average CO_2 emissions*

The relative sales per segment and per fuel of passenger cars are reported in Table 54 and Figure 21. For passenger cars, 2010 sales and CO_2 data are not available in the segment definition used here. The 2010 values for the sales shares are assumed to be the same as in 2009, for which a sales database has been obtained in support of the work reported in [TNO 2011]. The 2010 CO_2 emissions per segment are estimated using the 2009 CO_2 emissions per segment and multiplying these by the ratio of the average 2010 and 2009 emissions of petrol and diesel vehicles, as available from the Monitoring Mechanism database (Table 6).

Over the period 2002-2010 the sales share of small cars has increased, while the shares of medium and large vehicles have decreased. Moreover, the petrol vehicles share has decreased approximately 3% in this eight year period. By averaging the 2002 CO_2 emissions per segment over the sales division from 2010 it is estimated that a net decrease in average CO_2 emissions of 7.4 g/km can be attributed to the shift in sales between 2002 and 2010.

Table 54 Passenger car sales per segment in 2002 and 2010 and assessment of the impact of the segment shift on CO_2 emissions.

	p,S	p,M	p,L	d,S	d,M	d,L
2002 sales share	27%	29%	3%	7%	30%	4%
2009 sales share	34%	20%	1%	12%	30%	3%
2010 sales share	34%	20%	1%	12%	30%	3%
2002 CO_2 emissions [g/km]	148.7	188.6	264.2	122.8	157.0	212.9
2009 CO_2 emissions [g/km]	134.8	165.6	247.6	118.5	148.8	201.6
2010 CO_2 emissions [g/km]	130.2	159.9	239.1	113.6	142.6	193.3
average effect [g/km]	**7.4**					

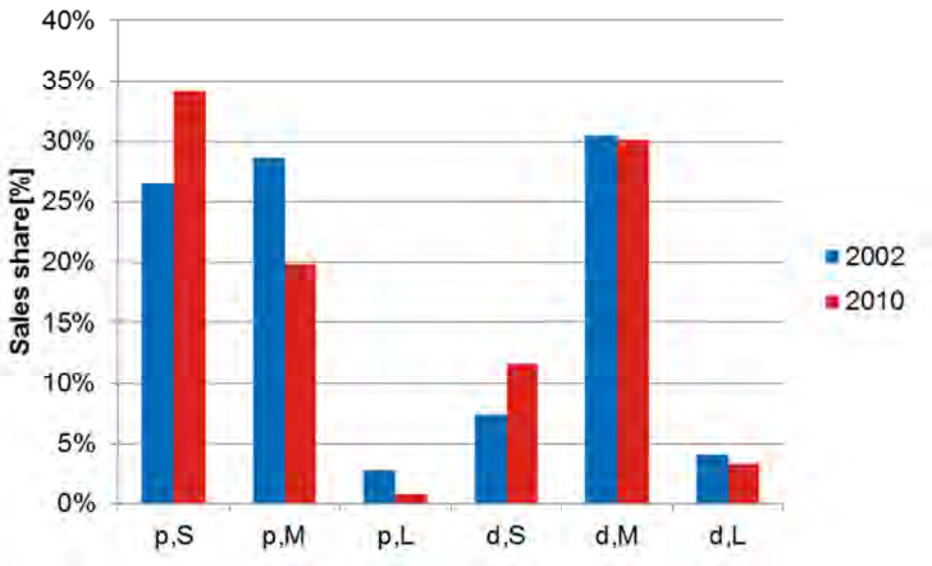

Figure 21 Relative passenger car sales per segment

6.4.3 *The impact of increased mass and power-to-weight ratio on CO_2 emissions*

As 2010 mass data per segment are not available, these values are estimated using a linear extrapolation of the 2002 and 2009 data. The effect of mass changes on CO_2 emissions is determined per segment using the formula $\Delta CO_2/CO_2 = 0.65\ \Delta m/m$, as derived in [TNO 2006]. Given the 2010 sales distribution for petrol and diesel vehicles, the effect is 10.7 g/km for petrol vehicles and 7.9 g/km for diesel vehicles. The total average effect for all segments is approximately 9.5 g/km.

Table 55 2002, 2009 and estimated 2010 vehicle masses per segment and the resulting impact on CO_2 emissions

	p,S	p,M	p,L	d,S	d,M	d,L
2002 vehicle mass [kg]	947.4	1276.2	1683.6	1048.6	1404.5	1826.9
2009 vehicle mass [kg]	1052.0	1349.1	1829.0	1152.8	1490.5	1947.9
2010 vehicle mass [kg]	1066.9	1359.5	1849.8	1167.7	1502.8	1965.2
ΔCO_2 emissions (2002 - 2010) [g/km]	12.2	8.0	16.9	9.1	7.1	10.5
average effect based on 2010 sales distribution [g/km]	**10.7**			**7.9**		
	9.5					

As 2010 power data are not available, 2010 values are derived using a linear extrapolation on the basis of 2002 and 2009 data. In Annex A, the effect of a change in power-to-weight ratio (P/m) on the CO_2 emissions is analysed. This can be described by the following relations:

Petrol vehicles: $\Delta CO_2/CO_{2_0} = 0.63 * \Delta\left(\frac{P}{m}\right) / \left(\frac{P_0}{m_0}\right)$

Diesel vehicles: $\Delta CO_2/CO_{2_0} = 0.42 * \Delta\left(\frac{P}{m}\right) / \left(\frac{P_0}{m_0}\right)$

As shown in Table 56, despite the significant change in power-to-weight ratio in the large petrol segment, changes in the power-to-weight ratio of all petrol vehicles between 2002 and 2010 have resulted in a CO_2 decrease of approximately 0.3 g/km. For diesel vehicles, the power-to-weight ratio has increased in every segment, resulting in a CO_2 increase of approximately 5.9 g/km. The overall effect is approximately 2.5 g/km.

Table 56 2002, 2009 and estimated 2010 power-to-weight ratios per segment and the resulting impact on CO_2 emissions

	p,S	p,M	p,L	d,S	d,M	d,L
2002 power [kW]	51.3	88.5	181.9	51.5	83.6	121.3
2009 power [kW]	57.0	92.0	238.4	59.3	95.0	157.4
2010 power [kW]	57.8	92.5	246.5	60.4	96.6	162.6
2002 power-to-weight [kW/kg]	0.054	0.069	0.108	0.049	0.060	0.066
2009 power-to-weight [kW/kg]	0.054	0.068	0.130	0.051	0.064	0.081
2010 power-to-weight [kW/kg]	0.054	0.068	0.133	0.052	0.064	0.083
power-to-weight ratio increase [%]	0.0%	-1.9%	23.3%	5.4%	8.0%	24.6%
ΔCO_2 emissions (2002 - 2010) [g/km]	0.0	-2.3	38.8	2.8	5.2	22.0
average effect based on 2010 sales distribution [g/km]	**-0.3**			**5.9**		
	2.5					

6.4.4 *Calibrations and small improvements*

Another factor that may have contributed to the total change in average type approval CO_2 values between 2002 and 2010 is optimisation of powertrain calibration. The main changes that have taken place during this period are related to legislation for criteria emissions, which has driven much of the developments in calibration, and is dealt with separately in this report. However, there are also other effects which are discussed here.

During this period two key changes have occurred. Firstly, the process of calibrating engine control systems has improved. This is due to changes in testing technology, engine modelling techniques, and more advanced engine control systems allowing more precise control of key parameters. Secondly, the calibration optimisation objectives have changed during this period. For example certain engine attributes, such as CO_2 emissions, have taken a higher priority in 2010, compared to

2002. For example combustion noise quality may be sacrificed slightly in order to reduce CO_2 emissions in 2010, whereas in 2002 there was reduced focus on CO_2 as an optimisation objective, so the change in combustion noise may not have been considered acceptable.

A range of calibration experts have been consulted in order to estimate the potential reduction in average type approval CO_2 values between 2002 and 2010 due to calibration changes alone. This value is very difficult to quantify precisely, due to the changes in emissions legislation that also occurred during that period. However, the reduction available relative to a typical vehicle from 2002 is unlikely to be over 5%, unless the baseline calibration was particularly poorly optimised for CO_2. For vehicles that were very well optimised for CO_2, and had low CO_2 as a high priority in 2002 the reduction potential may be close to zero.

Diesel and gasoline vehicles will differ in calibration approach for reduced CO_2. Some gasoline vehicles may have had a larger criteria emissions margin in 2002, which could be traded off for lower CO_2. For example less aggressive catalyst heating strategies at the start of the NEDC would improve CO_2 at the expense of other emissions. Diesel vehicles may have a smaller margin in criteria emissions to trade off during this period. However, as diesel technologies such as common rail fuel systems were relatively new in 2002, it is anticipated that understanding of calibrating these systems has increased during this time period, leading to further reductions in CO_2.

Overall, the reduction in average type approval CO_2 values between 2002 and 2010 due to calibration changes alone is estimated to be in the range 2 - 4%. This figure also depends on the mix of vehicles under consideration, gasoline, diesel, small, medium and large passenger car, and light commercial vehicles. In the remainder of this study, a value of 2% is used for the improvement of fuel efficiency resulting from calibration.

Moreover, small technical improvements, that are not in the list of CO_2 reduction options as developed in previous studies and for which the application is difficult to identify based on available vehicle specs, are also likely to have lowered average CO_2 emissions between 2002 and 2010. Possible items which improve engine fuel consumption are:

- faster engine warm-up strategy
- improved configuration of the cooling and lubricant system
- improved mixing of air and fuel
- increased performance of engine management systems with more sensors and actuators
- improved efficiency of auxiliaries (alternator and power steering)

For these small improvements a 1% CO_2 emission reduction is assumed between 2002 and 2010.

6.4.5 *Combining the impacts of all factors affecting CO_2*

In Table 57 and Figure 22 the contributions of various factors, that have contributed to the net change in CO_2 emission of new passenger cars between 2002 and 2010, are combined.

According to the methodology used in this study, it is estimated that approximately 22.3 g/km was reduced between 2002 and 2010 by deploying technologies on passenger cars (including small improvements and calibration).

If the 2002 average CO_2 emissions are corrected for the segment shift, mass increase and power-to-weight ratio increase, it can be concluded that up to two thirds of the net CO_2 emission reduction in passenger cars between 2002 and 2010 may have resulted from technology deployment.

A gap of 9.1 g/km remains between the actual 2010 EU average CO_2 emission of passenger cars and the value estimated on the basis of the net impact of technology deployment and a range of additional factors related to changes in vehicle characteristics and sales.

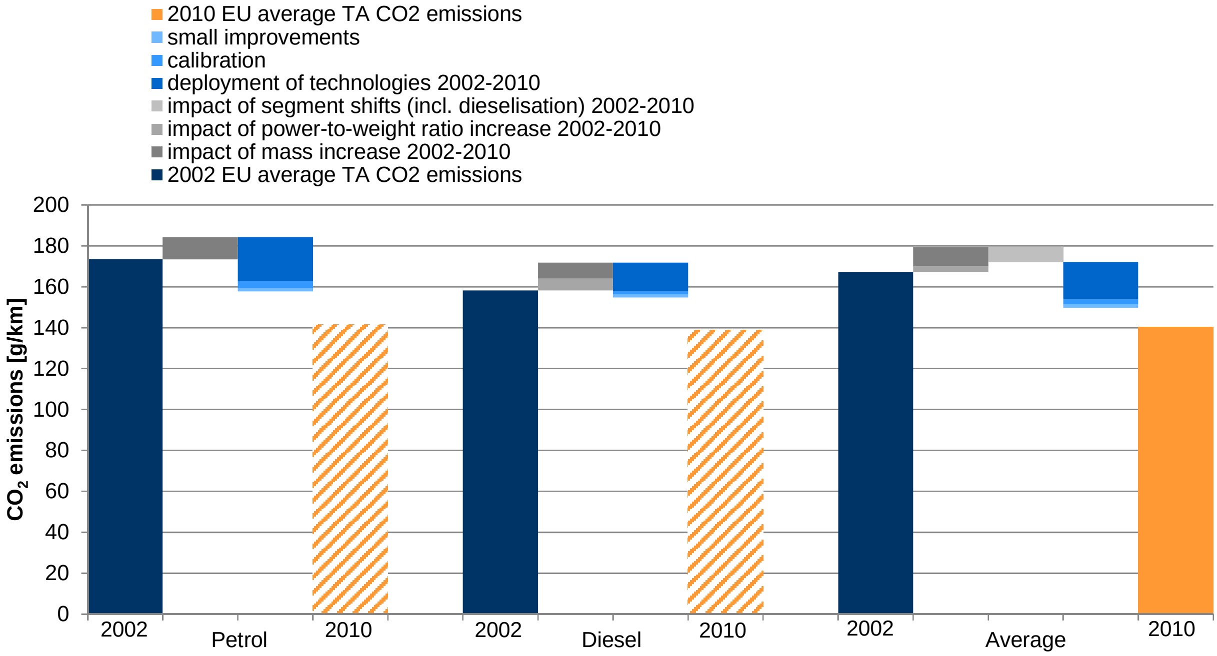

Figure 22 Estimation of the net CO_2 reduction resulting from technology deployment in passenger cars between 2002 and 2010.

Table 57 Overview of the estimated contributions from technology deployment and a range of additional factors related to changes in vehicle characteristics and sales to the net reduction of CO_2 emissions between 2002 and 2010 for passenger cars

Item	CO_2 [g/km]
2002 EU average TA CO_2 emissions	167.2
impact of mass increase 2002-2010	9.5
impact of power-to-weight ratio increase 2002-2010	2.5
impact of segment shifts (incl. dieselisation) 2002-2010	-7.4
deployment of technologies 2002-2010	-18.1
calibration	-2.6
small improvements	-1.7
estimated 2010 EU average TA CO_2 emissions	149.4
gap	9.1
actual 2010 EU average TA CO_2 emissions	140.4

7 Contributions from utilisation of flexibilities and technology deployment to CO_2 reductions between 2002 and 2010 for passenger cars

7.1 Introduction

This chapter confronts the results from the previous chapters to analyse the extent to which the combined estimates for the impacts of increased utilisation of test flexibilities, technology deployment and a range of additional factors related to changes in vehicle characteristics and sales, can account for the reductions in CO_2 emissions of passenger cars between 2002 and 2010, as observed in the Monitoring Mechanism.

In chapter 6 the possible impact of technology deployment has been estimated in what can be called a **top-down approach** (see section 1.4). Starting from the 2002 average CO_2 emission value an estimate has been made of the 2010 new fleet average, if changes were only resulting from the identified levels of technology deployment. In this assessment account was taken of a number of other factors, related to observed changes in vehicle characteristics and sales, that would have led to a change in emissions between 2002 and 2010 even in the absence of contributions of technology deployment or increased utilisation of flexibilities.

Starting from the actual 2010 average CO_2 emissions for passenger cars, the assessments presented in chapters 2 to 5 have been used, in what can be called a **bottom-up approach** (see section 1.4), to estimate what the 2010 average CO_2 emissions could have been in the absence of the estimated impact of increased utilisation of test flexibilities.
Given the uncertainties in all possible contributions to the observed CO_2 reduction it is expected that the combination of the two approaches will not give an accurate match, as indicated in Figure 5 in section 1.4.

7.2 Bottom-up analysis of the impact of test flexibilities

7.2.1 *Origin of values used*

The impact of increased utilisation of flexibilities, that can be applied in the type approval test, has been determined for average passenger cars in section 5.9. In order to determine the significance of the effect of these flexibilities on the development of CO_2 emissions between 2002 and 2010, it is related to the 2002 and 2010 average CO_2 emissions as provided by the Monitoring Mechanism database (Table 6). Also the effects of other factors, i.e. changes in vehicle mass, power-to-weight ratio and segment distributions are taken into account. The effects of these parameters on the CO_2 emissions were determined in sections 6.4.2 and 6.4.3.

7.2.2 *Results*

Figure 23 and Table 58 report the results of the assessment of the impact of increased utilisation of test flexibilities which could be estimated in the context of this study. The estimated CO_2 reduction over the 2002-2010 period that may be attributed to the increased utilisation of test flexibilities is 11.2%. Given the average 2010 emissions of 140.4 g/km (Table 6), the effect of flexibilities is estimated to be approximately 15.7 g/km. As can be seen from Figure 23, this is a significant part of the total observed reduction over that period. It should be emphasized that this is an estimate for the average impact across the total new passenger cars sales in the EU. This study does not make any claims concerning the utilisation of test flexibilities by individual manufacturers.

Given the 2002 average of 167.2 g/km (Table 6), in the absence of contributions from technology deployment or test flexibilities, changes in vehicle characteristics and sales between 2002 and 2010 would have resulted in a 2010 average CO_2 emission of 172.0 g/km. Corrected for the estimated average impact of increased utilisation of test flexibilities the observed 2010 average of 140.4 g/km would have been 156.1. A gap of 16.0 g/km remains between the two estimates for the 2010 average, which cannot be explained without a finite contribution from deployment of CO_2 reducing technologies.

Table 58 EU27 average CO2 emissions registered for 2002 and 2010 and the estimated impact of increased application of test flexibilities on CO_2 emissions

Item	CO_2 [g/km]
2002 TA average CO_2 emissions	167.2
impact of mass increase 2002-2010	9.5
impact of power-to-weight ratio increase 2002-2010	2.8
impact of segment shifts (incl. dieselisation) 2002-2010	-7.4
estimated 2010 average TA CO_2 emissions without technology deployment	172.0
gap	16.0
2010 average TA CO_2 emissions corrected for estimated effect of utilisation of flexibilities	156.1
increased utilisation of flexibilities 2002-2010	15.7
2010 EU average TA CO_2 emissions	140.4

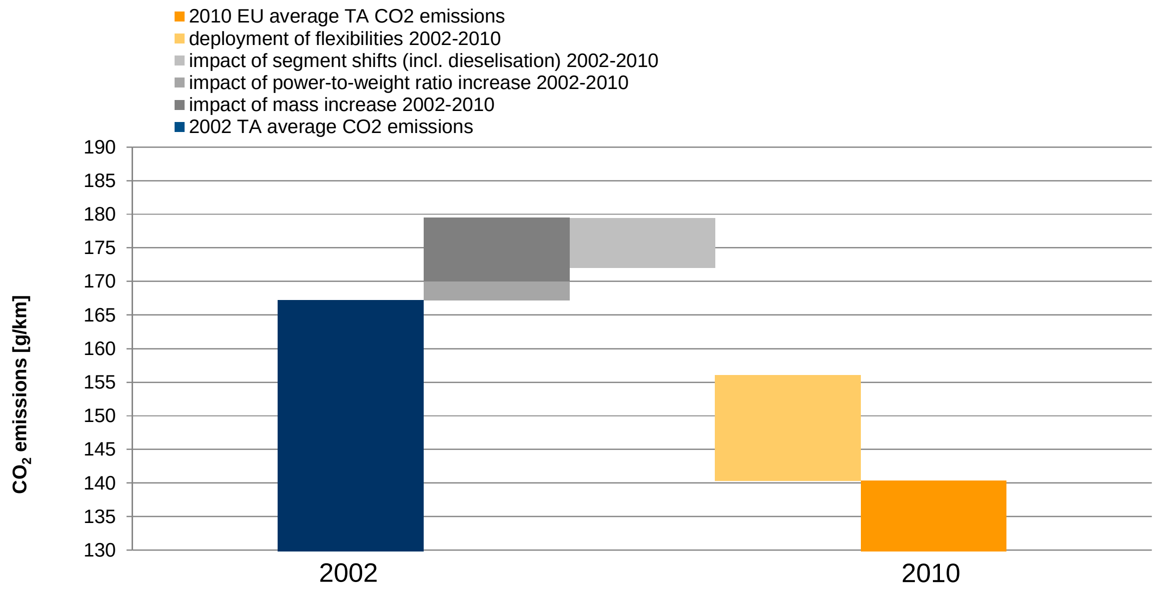

Figure 23 Result of the bottom-up analysis with respect to the possible contribution of increased utilisation of test flexibilities to the observed reduction of CO_2 emissions from passenger cars between 2002 and 2010

7.2.3 *Further potential use for utilising flexibilities*

Based on a numerical combination of the potentials of individual flexibilities the total potential would be of the order of 25%. However, it is unlikely that all flexibilities can be combined and that each flexibility can be utilised to its full potential. Moreover, the CO_2 impacts are not expected to be simply additive.

The estimation of past and present use of flexibilities in chapters 4 and 5 indicates that many of the identified flexibilities are currently not utilised to their full potential. A further reduction of type approval CO_2 emissions due to a further increase in the utilisation of flexibilities beyond 2010 levels can therefore not be excluded. Taking account of the mentioned fact that the potentials of individual flexibilities are not fully additive and that there may be reasons why various flexibilities can or will not be utilised to their full potential, it seems possible that a further reduction potential of the order of 5 to 10 g/km could still be available between 2010 and 2020. This conclusion, however, is indicative and deserves further investigation.

In addition to the above, the utilisation of flexibilities outside allowable bandwidths, or related to test conditions which are not or not clearly defined in the test procedure, deserves more attention and is not included in the above estimates.

7.3 Combining the top-down and bottom-up analysis

The results of the top-down analysis in Figure 22 and Table 57 of section 6.4.5 and the results of the bottom-up analysis in presented in Figure 23 and Table 58 are combined in Figure 24 and Table 59.

Table 59 Summary of the top-down and bottom-up analysis for the contributions of technology deployment and test cycle flexibilities to the reduction of passenger car CO_2 emissions observed between 2002-2010

Item	CO_2 [g/km]
2002 TA average CO_2 emissions of passenger cars	167.2
impact of mass increase 2002-2010	9.5
impact of power-to-weight ratio increase 2002-2010	2.8
impact of segment shifts (incl. dieselisation) 2002-2010	-7.4
improved calibration	-2.6
small technical improvements	-1.7
deployment of technologies 2002-2010	-18.1
estimated 2010 EU average TA CO_2 based on 2002 value and impact of technology deployment and of changes in vehicle characteristics and sales between 2002 and 2010	149.7
overlap	6.4
estimated 2010 EU average TA CO_2 after correcting actual value for estimated impact of increased utilisation of flexibilities between 2002 and 2010	156.1
deployment of flexibilities 2002-2010	15.7
actual 2010 EU average TA CO_2 emissions of passenger cars	140.4

Combining the estimated impacts resulting from deploying CO_2 reduction technologies and increased utilisation of test flexibilities leads to an overlap in the sense that the sum of the two effects is somewhat larger than the net reduction that is to be accounted for. The fact that the two effects do not exactly match the observed reduction may be caused by uncertainties in various elements of the assessment:

- estimate of the impact of observed mass increase;
- estimate of the impact of the observed power-to-weight ratio increase;
- assessment of the average extent to which flexibilities are exploited and their actual impact on CO_2;
- assessment of the average deployment level of technologies and their actual impact on CO_2.

However, the overlap is limited compared to the estimated size of the effects of technology deployment and utilisation of test flexibilities.

Figure 24 and Table 59 clearly indicate that neither technology deployment nor increased utilisation of test flexibilities can alone explain the observed reduction in CO_2 emissions of passenger cars between 2002 and 2010. This is a convincing indication that both factors have contributed to this reduction.

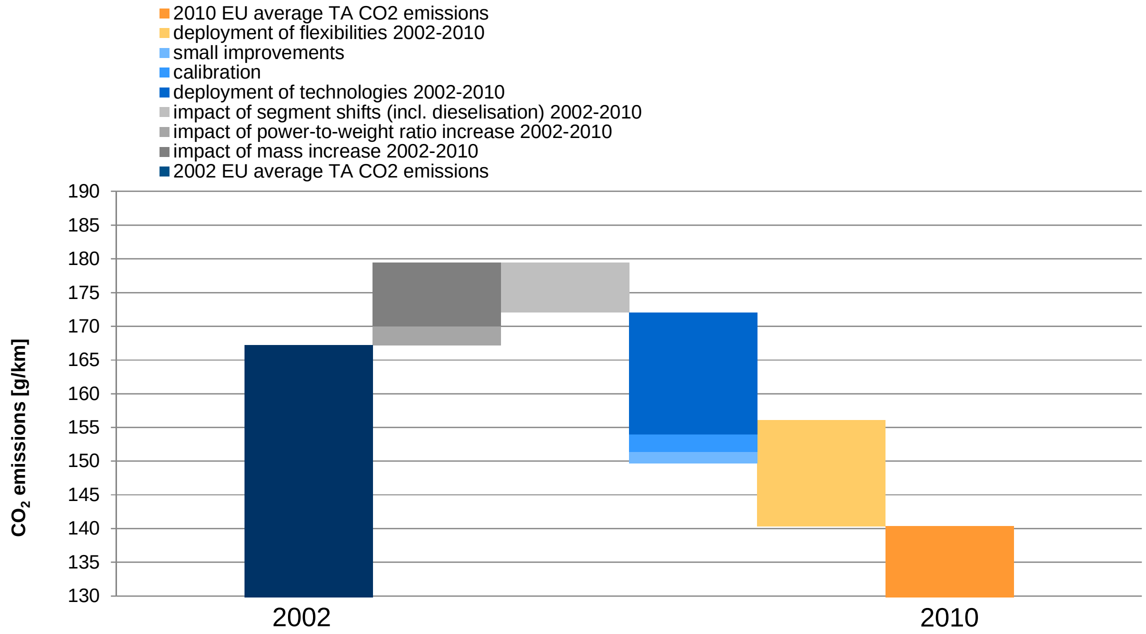

Figure 24 Graphical summary of the top-down and bottom-up analysis of the contributions of technology deployment resp. test cycle flexibilities to the reduction of passenger car CO_2 emissions observed between 2002-2010

It is very important to repeat that the estimates presented are average impacts. Every manufacturer will have its own considerations for application of flexibilities and application of technologies. The estimated levels of utilisation of flexibilities and technology deployment are not representative for individual manufacturers.

8 Combined effect of test flexibilities and technology deployment for LCVs

8.1 Introduction

In follow-up to the legislation for passenger cars, Regulation (EU) No 510/2011 was adopted for light commercial vehicles in 2011. This regulation sets a target of 175 gCO_2/km for the EU fleet average in 2017. Similar to the procedure for implementation of the target for passenger cars, this target for LCVs will be phased in. In 2014 an average of 70% of each manufacturer's newly registered vans must comply with the manufacturer-specific target determined using the limit value curve set by the legislation. This proportion will rise to 75% in 2015, 80% in 2016, and 100% from 2017 onwards. For 2020 a target of 147 gCO_2/km has been proposed.

Because monitoring of CO_2 data for LCV sales in Member States, as obliged by Regulation (EU) No 510/2011 (Annex II), has only commenced in 2012, no official 2002 or 2010 average for LCVs is available. For 2010 an average can be estimated on the basis of commercially available sales databases. For 2002 this is not possible. Older LCV sales databases hardly contain CO_2 data, as these were not required to be reported on the type approval certificate back then. As a consequence of this lack of CO_2 data, the bottom-up analysis for LCVs of the contribution of test flexibilities relative to the observed 2010 average for LCVs, as reported in section 5.11, cannot be confronted with a top-down analysis of the contribution of technology deployment relative to 2002 in the same way as was done for passenger cars in chapter 7.

This chapter therefore provides a separate presentation of the results for LCVs with respect to test flexibilities and technology deployment and the extent to which it can be considered likely that both these effects have contributed to reduction of type approval CO_2 emissions of LCVs in the past decade.

8.2 Methodology

The methodology used to decompose the 2002 – 2010 CO_2 reduction for LCVs is to a large extent similar to the methodology used for passenger cars. However, because of the lacking 2002 CO_2 emissions data, the CO_2 emission reduction resulting from the deployment of technologies cannot be determined relative to the 2002 emissions, as it was done for passenger cars in chapter 6. Also some other steps in the analysis have to be done more indicatively for LCVs as a result of the lack of 2002 data.

Therefore the following steps are followed to break down the CO_2 reduction in LCVs between 2002 and 2010 into the different contributing factors as identified in sections 6.4.2 to 6.4.4:

- First the contribution of test flexibilities is determined in the same way as it was done for passenger cars in section 7.2.2. The absolute reduction resulting from flexibilities is determined by applying the estimated relative impact to the 2010 average CO_2 emissions.
- The effect of the changes in average vehicles mass between 2002 and 2010 is determined similarly as was done for passenger cars in section 6.4.3. As no 2002 mass data is available for LCVs, the change in mass between 2002 and 2010 is estimated by linear extrapolation of available 2007 and 2010 mass data from respectively [AEA 2009] and [TNO 2012]. The impact of this mass change is then "backcasted" relative to the 2010 average, rather than "forecasted" relative to the 2002 average, as was done for passenger cars.
- Since no power data is available for LCVs, an analysis of the possible impacts of changes in power-to-weight ratio is not performed for LCVs. The effect is expected to be significantly less for LCVs than for passenger cars.
- In a next step the impact of the segment sales shift is indicatively determined. As there is no sales distribution available for 2002, they are assumed equal to the distribution in 2007 and taken from [Smokers 2006].
- The CO_2 reduction from calibrations and small improvements is calculated relative to the 2010 average CO_2 emissions, corrected for the impact of test flexibilities and the indicative effect of shifts in sales.

- Finally the CO_2 reduction resulting from the deployment of technologies between 2002 and 2010 is indicatively determined using penetration levels and reduction potentials of CO_2 reduction technologies for LCVs in 2002 and 2010. The absolute reduction resulting from technologies is determined relative to the an adjusted 2010 average CO_2 emissions, which is corrected for the estimated impact of test flexibilities, the effect of the a sales shift and the effect of calibration and small improvements.
- By combining the contributions of all factors, and their impact relative to the 2010 average, a backcasted estimation of the 2002 average CO_2 emissions for LCVs is determined.

Due to the lack of a 2002 reference, or more generally of information on the development of type approval CO_2 emissions from LCVs over the last decade, it is not possible to draw conclusions on whether the estimated impacts of technology deployment and test flexibilities together are too large, sufficient, or too small to explain the reduction of type approval CO_2 emissions in LCVs. The credibility of both estimates can only be judged indicatively by evaluating the likeliness of the estimation of the 2002 average CO_2 emissions, backcasted using the methodology described above.

Since the database used to determine the penetration of technologies in 2002 and 2010 does not distinguish LCV classes and fuel types, the analysis in this chapter is done for diesel LCVs only. In [TNO 2012] it was already determined that the share of petrol LCVs is very small.

8.3 Contribution of the various factors affecting LCV CO_2 emissions between 2002 and 2010

8.3.1 *Increased utilisation of test flexibilities*

For LCVs it was concluded in section 5.11, that approximately 6.9% of the CO_2 reduction observed between 2002 and 2010 may be attributed to increased utilisation of flexibilities. Given a 2010 average of 181.4 gCO_2/km, the contribution of flexibilities is 12.5 g/km.

8.3.2 *Effect of mass increase*

As 2002 mass data are not available, these values are estimated using a linear extrapolation based on 2007 and 2010 mass data. As shown in Table 60 the average vehicle masses of the three segments have changed by respectively 30.4, -76.5 and 102.5 kg. Using the formula $\Delta CO_2/CO_2 = 0.65\ \Delta m/m$ as derived in [TNO 2006] to assess the impact per segment, and combining the impacts per segment using the 2010 sales distribution, this results in an overall CO_2 emission increase of 2.2 g/km for LCVs in the 2002-2010 period.

Table 60 LCV masses per segment in 2002, 2007 and 2010, and impact of mass changes on CO_2 emissions

	Class I	**Class II**	**Class III**
estimated 2002 vehicle mass [kg]	1166.5	1602.3	1910.9
2007 vehicle mass [kg]	1185.5	1554.5	1974.9
2010 vehicle mass [kg]	1196.9	1525.8	2013.4
average effect based on 2010 sales distribution [g/km]	**2.1**	**-5.0**	**7.8**
	2.2		

8.3.3 *Impact of sales shifts*

As shown in Table 61, the relative sales of Class I and especially Class II LCVs has increased at the expense of Class III vehicles between 2007 and 2010. For the purpose of this assessment it is assumed that the 2002 sales distribution equals the 2007 distribution. In case the sales in 2010 would have been divided over the segments in similarly as in 2002 / 2007, the 2010 average CO_2 emissions would have been 8.6 g/km lower.

Table 61 LCV sales per segment in 2002 and 2010

	Class I	Class II	Class III
2002 sales share [%]	18%	25%	57%
2007 sales share [%]	18%	25%	57%
2010 sales share [%]	21%	34%	45%
2010 CO_2 emissions [g/km]	**122.8**	**161.6**	**223.2**
average effect [g/km]	**8.6**		

8.3.4 *Calibrations and small improvements*

Assuming the same relative reductions resulting from calibrations and other small improvements as were assumed for passenger cars, i.e. respectively 2% and 1%, these factors may have contributed respectively 2.0 g/km and 3.9 g/km to the change in LCV CO_2 emissions between 2002 and 2010.

8.3.5 *Deployment of technologies*

Table 62 shows the penetration rates, reduction percentages and estimated impacts on LCV CO_2 emissions of a range of technologies applicable to (diesel) LCVs. This table was developed similarly as Table 52**and** Table 53 for passenger cars.

Taking account of the reduction potential that is needed to overcome the negative effect of the mass increase on CO_2 emissions (section 8.3.2), the increased penetration of CO_2 reducing technologies in LCVs is estimated to have resulted in a net emission reduction of approximately 10.7 g/km.

Table 62 Penetration, reduction percentages and relative CO_2 emissions of technologies of (diesel) LCVs

Reduction Technologies		Reduction [%] 2002	Reduction [%] 2010	Penetration [%] 2002	Penetration [%] 2010	Relative CO2 emission [%] 2002	Relative CO2 emission [%] 2010
engine options	Combustion improvements	3.0	3.0	5.0	50.0	99.85%	98.50%
	mild downsizing (15% cylinder content reduction) between 45 - <60 Kw/l	2.0	2.0	1.9	23.5	99.96%	99.53%
	medium downsizing (30% cylinder content reduction) 60 - <75 Kw/l	4.0	4.0	0.0	1.1	100.00%	99.96%
	strong downsizing (>=45% cylinder content reduction) Above 75 Kw/l	1.5	1.5	0.0	0.0	100.00%	100.00%
	Variable valve actuation and lift	0.8	0.8	100.0	100.0	99.17%	99.17%
transmission options	optimising gearbox ratios / downspeeding (above 5)	1.0	1.0	10.9	48.6	99.89%	99.51%
	automated manual transmission	6.0	6.0	2.4	1.9	99.86%	99.89%
	dual clutch transmission	1.9	1.9	0.0	1.7	100.00%	99.97%
	continuously variable transmission	0.0	0.0	0.0	0.0	100.00%	100.00%
hybridisation	start-stop	3.0	3.0	0.0	9.2	100.00%	99.72%
	micro hybrid - regenerative breaking	6.0	6.0	0.0	8.4	100.00%	99.50%
	mild hybrid - torque boost for downsizing	10.0	10.0	0.0	0.0	100.00%	100.00%
	full hybrid - electric drive	18.0	18.0	0.0	0.0	100.00%	100.00%
driving resistance reduction	mild (~10% reduction on body in white)	1.0	1.0	0.0	32.0	100.00%	99.68%
	medium (~ 25% reduction on body in white)	2.4	2.4	0.0	0.0	100.00%	100.00%
	strong (~40% reduction on body in white)	6.0	6.0	0.0	0.0	100.00%	100.00%
	lightweight components other than BIW	1.1	1.1	0.0	12.0	100.00%	99.87%
	aerodynamics improvement	1.5	1.5	0.0	7.0	100.00%	99.90%
	tyres: low rolling resistance	2.0	2.0	0.0	10.0	100.00%	99.80%
	reduced driveline friction	1.0	1.0	0.0	10.0	100.00%	99.90%
other	thermo-electric conversion	3.0	3.0	0.0	0.0	100.00%	100.00%
	secondary heat recovery cycle	3.9	3.9	0.0	0.0	100.00%	100.00%
	Auxiliary systems improvement	2.5	2.5	4.0	50.0	99.90%	98.75%
	Thermal management	2.3	2.3	0.0	10.0	100.00%	99.77%
					Total result (relative to 2002 baseline)	**98.6%**	**93.6%**
					Reduction	**1.4%**	**6.4%**
					Maximum reduction	**46.6%**	**46.6%**
					Maximum dissynergy margin	**5.0%**	**5.0%**
					Reduction corrected for safety margin	**1.4%**	**6.4%**
					Reduction between 2002 and 2010 from technology deployment	**5.1%**	

8.4 Result

As can be seen in Figure 25 and Table 63, adding the CO_2 impacts of all factors assessed in the previous sections to the 2010 average CO_2 emissions for LCVs leads to a "backcasted" estimate for the average 2002 LCV CO_2 emissions of 216.9 g/km.

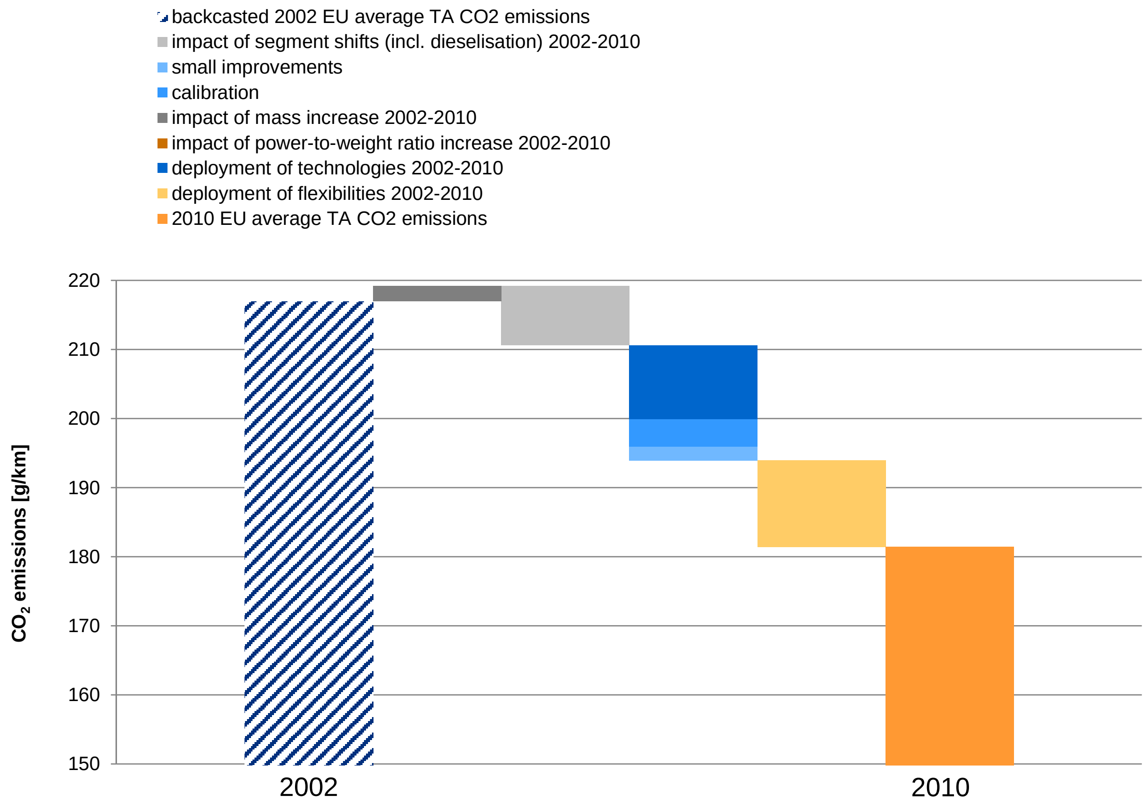

Figure 25 Contribution of various factors that have affected LCV CO_2 emissions between 2002 and 2010

Table 63 Breakdown of factors that have affected the LCV CO_2 emissions between 2002 and 2010

Item	CO_2 [g/km]
2010 TA average CO_2 emissions	181.4
deployment of flexibilities 2002-2010	12.5
impact of mass increase 2002-2010	-2.2
impact of segment shifts (incl. dieselisation) 2002-2010	8.6
calibration	4.0
small improvements	2.0
deployment of technologies 2002-2010	10.7
indicative estimate of 2002 emissions	216.9

8.5 Backcasted average 2002 LCV CO_2 emissions compared to 2002 emissions estimated in previous studies

As explained in section 8.1, reliable 2002 emissions data are not available for LCVs. Therefore a 2002 value was backcasted in section 8.4. A value of 216.9 g/km was derived for LCVs in 2002.

In previous studies, attempts were also made to derive 2002 average emissions for LCVs. In [AEA 2009] a 2007 LCV database was analysed. This database lacked CO_2 information for a large share of its entries, which was corrected by using estimates (averages or based on linear fits) derived from CO_2 data available for vehicles from the same model range that were available in the database. As discussed in [TNO 2012c], this involved a significant degree of uncertainty in the end result, so that the 2007 average CO_2 emission from this study should be considered indicative. The 2002 average that was derived in [AEA 2009] by backcasting the 2007 average, assuming an annual CO_2 emission reduction of 0.5% between 2002 and 2007, is therefore also likely to have deviated from the actual 2002 average.

The final average 2002 LCV CO_2 emissions in [AEA 2009] was 208.2 g/km, which is some 4% lower than the 2002 estimate derived in section 8.4 (216.9 g/km).

In section 7.3, an overlap was observed in the estimated impacts of factors that have contributed to the reduction of CO_2 emissions of passenger cars. The fact that the effects of these factors did not exactly match the observed 2002 – 2010 reduction, was attributed to uncertainties in various elements of the assessment.

As a consequence of the methodology applied to determine the impact of the various factors that may have contributed to the 2002 – 2010 CO_2 reduction for LCVs, such an overlap does not become apparent in the LCV analysis. However, also in the case of LCVs it is likely that the combined estimated impacts of increased utilisation of test flexibilities and of technology deployment are larger than the actual reduction in CO_2 emissions. This may explain why the backcasted 2002 LCV CO_2 emissions in this study are higher than for example in [AEA, 2009]. However, the difference between both backcasted 2002 LCV CO_2 emissions is limited compared to the estimated size of the effects of technology deployment and utilisation of test flexibilities. This indicates that the actual 2002 average is likely to have been close to the estimated values in this study and to what was derived in [AEA 2009].

9 Discussion and conclusion

9.1 Industry consultation

On June 19th 2012 an industry consultation meeting was held in Brussels. On this occasion draft results of the work presented in this report have been presented to and discussed with representatives from automotive manufacturer and supplier associations as well as from individual car manufacturers and component suppliers. Participants were also given the opportunity to provide feedback in writing after the meeting.

Feedback from the industry representatives has been very useful for fine-tuning various details of the assessments presented in this report, as well as for improving the clarity of presentation of the results and the accuracy of the wording of conclusions. Industry comments did not lead to major changes in the applied methodology nor in the overall results of the work.

9.2 Discussion and conclusions

The study identified a number of potential flexibilities allowable within the type approval procedure, the use of which may contribute to a reduction of CO_2 emissions as measured on the type approval test. From literature review and information obtained from TA authorities and test houses it is clear that flexibilities are increasingly being used to lower CO_2 emissions of new vehicles on the TA test.

For passenger cars it is estimated that the potential reduction in average type approval CO_2 emissions between 2002 and 2010 due to increased use of flexibilities is around 11% (with a range of +/- 5%). For LCV a value of around 7% (with a range of +/- 3.5%) is estimated.

There is uncertainty with respect to the degree to which the flexibilities identified as potentially being utilised in 2010 may be used in combination. The CO_2 impacts are unlikely to be simply additive. Without more detailed investigation into the interactions between factors the potential cumulative effect of combined flexibilities may only be quantified as a range.

The utilisation of allowable flexibilities in the type approval procedure may vary from vehicle model to vehicle model and OEM to OEM and there is no clear picture of how they are implemented in specific cases.

All estimates are for the current test procedures based on the NEDC. The adoption of the WLTP drive cycle and accompanying new test procedures may affect the number of available test flexibilities as well their impact on type approval CO_2 emissions. In the WLTP process attention is paid to reducing test cycle flexibilities, but available information indicates that also under WLTP flexibilities may still have a finite reduction potential.

The study also identified the level of deployment of CO_2 reducing technologies, their potential CO_2 benefit, as well as the impacts of improved calibration and took into account the counter effects of increased mass and power-to-weight ratio for the period 2002 and 2010.

Of the net reduction observed between 2002 and 2010 in passenger cars up to two thirds appears to have been realised by deployment of CO_2 reducing technologies, including small optimisations / improved calibration. About half of the net reduction can be explained by the estimated impact of increased utilisation of test flexibilities. The combined impact of the estimated reductions from technologies and flexibilities is more than the net reduction to be explained, also when taking into account impacts of increases in vehicle mass and power-to-weight ratio and segment shifts. This overlap is likely to have been caused by uncertainties in various elements of the assessment:

- estimate of the impact of observed mass increase;
- estimate of the impact of the observed power-to-weight ratio increase;
- estimation of the average extent to which flexibilities are exploited and their actual impact on CO_2;
- assessment of the average deployment level of technologies and their actual impact on CO_2.

However, the overlap is limited compared to the estimated size of the effects of technology deployment and utilisation of test flexibilities, and of the same order of magnitude as the uncertainty in the estimated impact of the increased utilisation of test flexibilities.

Also for LCVs the estimated impact of technology deployment on CO_2 reductions between 2002 and 2010 is larger than the estimated impact of increased utilisation of test flexibilities. Segment shifts may also have contributed significantly to reductions between 2002 and 2010. Due to the lack of 2002 data, however, it is more difficult to judge to what extent the estimated impacts of different factors over- or underestimate the net reduction between 2002 and 2010. However, as the 2002 LCV CO_2 emissions back-casted in this study are only marginally higher than the 2002 average estimated in a previous study, it appears likely that the combined effects of technology deployment and test flexibilities, as assessed for LCVs in this study, only slightly overestimates the net reduction to be explained.

The estimation of past and present use of flexibilities indicates that many of the identified flexibilities are currently not utilised to their full potential. A further reduction of type approval CO_2 emissions due to a further increase in the utilisation of flexibilities beyond 2010 levels can therefore not be excluded. Taking account of the fact that the potentials of individual flexibilities are not fully additive and that there may be reasons why various flexibilities can or will not be utilised to their full potential, it seems possible that a further reduction potential of the order of 5 to 10 g/km could still be available between 2010 and 2020. This conclusion, however, is indicative and deserves further investigation.

In addition a number of other elements have been identified that are not fully specified in the test procedure and that can also contribute to changes in the type approval test result.

Overall the conclusion is that this study has generated convincingly strong indications that the reductions in CO_2 emissions of light duty vehicles, as observed over the last decade, can be attributed to a combination of deployment of CO_2 reducing technologies, increased utilisation of test flexibilities and a range of smaller factors, including changes in vehicle characteristics which affect CO_2 emissions and shifts in sales between different size classes.

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A Effect of changes in the power-to-weight ratio on the CO_2 emissions

Introduction

An increase of the power-to-weight ratio generally results in lower TA CO_2 emissions. This is the results of a lower average engine load over the type approval cycle. Especially for petrol engines this lower load will lower the engine efficiency and therefore increase fuel consumption (and CO_2 emissions).

Methodology

In order to derive a relation between the power-to-weight ratio and the CO_2 emissions, firstly a number of vehicle models is selected. Of these vehicle models the power-to-weight ratios and CO_2 emissions of different models are selected from a 2009 sales database. Next, the CO_2 emissions of the model versions with more power-to-weight than the 'base version' are corrected for the mass difference compared to the base version, using the $\Delta CO_2/CO_2 = 0.65\ \Delta m/m$ relationships as used in [TNO 2006].

In order to derive one formula from all vehicle models assessed, the power-to-weight ratio and (mass corrected) CO_2 emissions are normalised using the base version. This base version is the one with the lowest power-to-weight ratio. This way data of all vehicle models is equivalent and can be used to derive a single relation.

The 2009 sales database contains vehicles with different emission standards. Since the same vehicle models complying with different emissions standards are likely to have different engine versions, only vehicles are selected that comply with the Euro 4 emission standard.

Vehicle models assessed

The vehicle models assessed are the VW Polo, VW Golf, VW Passat, Opel Corsa, Opel Astra, Opel Insignia, Peugeot 207, Peugeot 308, Peugeot 407, Peugeot 607, Citroen C3, Citroen C4, Citroen C5, Citroen C6, Toyota Yaris, Audi A3, Audi A4, Audi A6, Renault Clio, Renault Laguna, Renault Megane, Renault Scenic and Renault Twingo.

Result

Results of the analysis are plotted in Figure 26. As can be seen, quite a number of vehicles have a normalised CO_2 value lower than that of the base version. In Figure 26 these vehicles are located below the x-axis. This indicates that there a model versions with higher power-to-weight ratio than the base version, but lower CO_2 emissions. These vehicles are generally lighter than the base versions, and therefore lower CO_2 emissions, but have more power than the base version.

Moreover it can be concluded that an increased power-to-weight ratio has a larger effect on the CO_2 emissions of petrol vehicles, than on the CO_2 emissions of diesel vehicles.

The relation between the power-to-weight ratio and the CO_2 emissions are as follows:

Petrol vehicles: $\Delta CO_2/CO_{2_0} = 0.63 * \Delta\left(\frac{P}{m}\right)/\left(\frac{P_0}{m_0}\right)$

Diesel vehicles: $\Delta CO_2/CO_{2_0} = 0.42 * \Delta\left(\frac{P}{m}\right)/\left(\frac{P_0}{m_0}\right)$

in which:

P = power
P_0 = power of base version
m = mass

m_0 = mass of base version
CO_2 = CO_2 emissions
CO_{2_0} = CO_2 emissions of base version

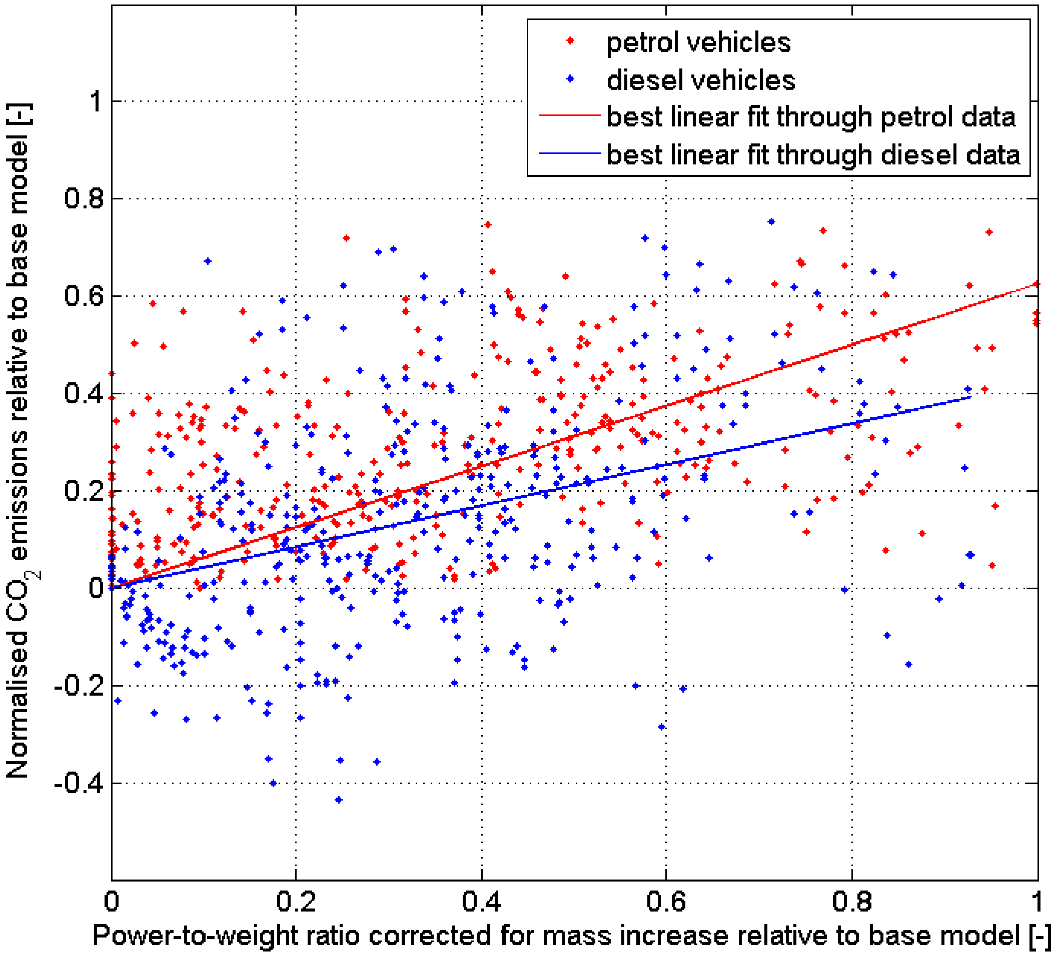

Figure 26 Relation between the power-to-weight ratio and the CO_2 emissions for passenger cars on petrol and diesel