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ABSTRACT

This ex-post evaluation covers the car and light commercial vehicles (LCV) CO₂ Regulations (respectively Regulation 433/2009 and 510/2011). Quantitative counterfactual analysis and regression analysis shows that the Regulations have been effective at reducing CO₂ emissions from new cars by 138 MtCO₂ and from new LCVs by 5 MtCO₂. The Regulations have generated net economic benefits for society with overall cost savings of €6.4 billion due to the car CO₂ Regulation and €0.9 billion due to the LCV CO₂ Regulation. Costs to manufacturers have been lower than originally anticipated. The Regulations continue to be relevant, effective, coherent, and generate EU added value today. Key weaknesses concerning the representative of the vehicle test cycle and the current exclusion of non-tailpipe emissions should be addressed in order to avoid compromising their effectiveness in future. Concerning the test cycle, there is an increasing discrepancy between real-world and test cycle emissions which has eroded a significant portion of the originally expected benefits of the Regulations. The lack of consideration of the lifecycle and embedded emissions is currently a relatively minor issue; however, as the proportion of electric vehicles is expected to increase, it will become more significant.

EXECUTIVE SUMMARY

Objectives of the study

This ex-post evaluation study covers the following two Regulations:

- **Regulation (EC) No 443/2009** of the European Parliament and of the Council of 23 April 2009, setting a fleet-wide average target of 130 gCO₂/km for new passenger cars to be met by 2015, and a target for 2021 of 95 gCO₂/km (EC, 2009a); and


These Regulations aim to reduce the carbon dioxide (CO₂) emissions from new light duty vehicles (LDVs), i.e. cars and LCVs sold on the EU market.

The purpose of this study is to conduct a formal evaluation of the passenger car CO₂ Regulation and the LCV CO₂ Regulation. This evaluation is also one of the actions for 2015 under the Commission’s regulatory fitness (or REFIT) programme. The REFIT programme is part of the Commission’s commitment to Better Regulation, and aims to ensure that legislation is fit-for-purpose and does not impose unnecessary regulatory burdens (European Commission, 2014e).

Methodology

The methodology followed the standard evaluation framework for an assessment of legislation and the key evaluation questions related to relevance, effectiveness, efficiency, coherence and EU added-value.

The main research tools used included:

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¹ ‘Light commercial vehicles’ are sometimes referred to as ‘vans’.
• Desk research and literature review. Over 230 pieces of literature were used—all of the literature is referenced throughout the report, as well as in Annex J.
• Analysis of official monitoring data collected under EU legislation, relating to CO₂ emission performance of LDVs. Official data sources included the monitoring data in accordance Article 8 of each of the LDV CO₂ Regulations and further specified in Commission Regulations (European Commission, 2010b; European Commission 2012e).
• 21 interviews with stakeholders, covering industry associations, manufacturers, suppliers, vehicle user/consumer groups and NGOs.
• Online surveys targeted at a broad range of stakeholders.

The main quantitative analytical tools were:

• **Comparative analysis with a baseline/counterfactual scenario.** The baseline was used for quantifying the effects of the intervention on costs and other key outcome indicators including CO₂ emissions, fuel expenditure, oil consumption and cost-effectiveness.

• **Regression analysis/empirical research:** It is important to stress that the presence of differences between the baseline scenario and the actual outcomes, do not, on their own, indicate direct causal relationships between the intervention and the actual outcomes. To help overcome this limitation, regression analysis was used to determine *causality.*

The quantitative techniques described above were supplemented by qualitative analysis conducted on the basis of the literature review, stakeholder engagement and collation of data from official monitoring sources.

The main limitations of the research were due to a lack of data availability. This was in part due to the limited time series of available data, since the car CO₂ Regulation was introduced in 2009 and the LCV CO₂ Regulation was introduced in 2011. Other important information, especially pertaining to the costs of manufacturing vehicles and associated investments, were not available in the public domain. In some cases, estimated or proxy data from literature could be used to supplement data. In other cases, the study team made adjustments to available data in order to reflect actual performance, for example in the case of monitored CO₂ performance data, which needed to be uplifted to better reflect real world performance.

**Main findings**

**Relevance**

The evaluation of relevance assessed the continuing relevance of the Regulations against the needs identified, and concluded that the Regulations are still valid and will remain so for the period beyond 2020, as follows:

1. **All sectors still need to contribute to the fight against climate change:** International scientific bodies, the European Commission and stakeholders generally agree that there is a need to fight climate change.

2. **The CO₂ performance of new vehicles needs to improve at a faster rate:** Since LDVs account for the majority of CO₂ emissions from transport, reductions in their emissions are required in order to contribute to overall GHG reductions.

3. **Road transport needs to use less oil.** Even if the trends towards the increasing diversification of the fuels and energy sources used by transport continued, it would still be prudent to improve the security of energy supply since the vast majority of oil used in the EU is imported.

4. **CO₂ reductions must be delivered cost-effectively without undermining either sustainable mobility or the competitiveness of the automotive industry.**
industry. The importance of maintaining sustainable mobility was emphasised in the Transport White Paper. The importance of the EU automotive sector to the EU economy is also widely recognised.

Effectiveness

The analysis suggests that the car CO₂ Regulation is likely to have accounted for 65-85% of the reductions in tailpipe emissions achieved following the introduction of the Regulation. The Regulations were found to have been more successful in reducing CO₂ emissions compared to voluntary agreements from industry, which achieved an estimated rate of annual improvement in CO₂ of 1.1 to 1.9 gCO₂/km compared to the rate achieved by the Regulations of 3.4 to 4.8 gCO₂/km.

Similarly for LCVs, the fleet wide average emissions have already exceeded the required target for 2017, and the rapid rate of CO₂ emission reductions suggests that the Regulations have played an important role in speeding up specific emission reductions.

The analysis also highlighted some key weaknesses that may need to be addressed in future policy proposals:

- **Test cycle**: The test cycle performance is not an accurate reflection of real-world emissions. This is a significant concern as the increasing discrepancy between test cycle and real-world emissions performance has eroded the benefits of the Regulations.

- **Well-to-tank emissions**: The Regulations incentivise the use of powertrains that have “zero” CO₂ emissions as measured on the test cycle, but which have higher indirect emissions associated with their production than fossil fuels. These emissions are not considered within the Regulations.

- **Embedded emissions**: The Regulations incentivise the use of vehicles that have higher GHG emissions associated with their production and disposal than more conventional vehicles, which are also not considered within the Regulations.

Other potential weaknesses (super-credits and phasing in of the targets) do not appear to have significantly weakened the targets in practice. The impact of derogations for small volume and niche manufacturers have been relatively small.

In terms of the **impact on life cycle emissions**, the analysis does not indicate that there have been environmental trade-offs to date between types of pollutants or life cycle stages. In the longer term, the potential for burden-shifting is much greater, particularly considering batteries in hybrid and electric vehicles. At the same time, technological developments in production processes, battery lifetimes and the decarbonisation of the electricity sector mean that the overall impact is still likely to be positive.

In terms of **energy security**, current impacts are relatively minor but the Regulations are expected to contribute further to energy security in future years.

Impacts on **competitiveness and innovation** also generally appear to be positive. There are promising signs that research and development of fuel-efficient technologies has ramped up, as well as clear trends towards increased market uptake of fuel efficient technologies both in cars and LCVs.

On the basis of the available information, there do not appear to be any signs of significant **competitive distortion**. However, data availability does not allow for a thorough analysis that could rule it out entirely. The analysis was mainly based on retail price changes, which were used as a proxy for technology costs faced by vehicle manufacturers. Furthermore, any impacts on competitive neutrality may not yet have emerged, since it remains to be seen how manufacturers perform against the more stringent targets in future years.
From the perspective of **social equity**, overall the impacts of the Regulations can be considered broadly positive. It is clear that the car and LCV CO\(_2\) Regulations have led to significant reductions in annual fuel costs. For new cars registered in 2013, the expected lifetime (discounted) fuel savings are €1,336 for petrol cars and €981 for diesel cars compared to the baseline counterfactual scenario. For passenger cars, it is likely that changes in the affordability of new vehicles will affect higher income consumers (as these consumers are more likely to purchase new vehicles) and in any case market data do not show increases in average retail prices for relevant vehicle segments. These more fuel efficient vehicles will eventually move into the second-hand car market, where lower income consumers are more likely to purchase them. The rapid depreciation of car values in the first few years is likely to ensure that second-hand owners can reap the fuel savings without the fuel efficiency being fully reflected in the prices they pay for used cars. Similarly for LCVs, SMEs typically only purchase used vehicles, and they will similarly benefit from the overall fuel efficiency improvements. The lifetime (discounted) fuel savings for new LCVs registered in 2013 are expected to be €1,446 for petrol LCVs and €982 for diesel LCVs compared to the baseline counterfactual scenario.

**Efficiency**

In terms of **efficiency** both of the Regulations have generated net economic benefits to society. The car CO\(_2\) Regulation has abatement costs of -€46.4 per tonne of CO\(_2\) abated, compared to central ex-ante estimates of +€32.4/tCO\(_2\) to +€38.7/tCO\(_2\). The LCV CO\(_2\) Regulation has also generated net economic benefits and emissions savings, although these are smaller than anticipated in the ex-ante Impact Assessment, primarily because the baseline emissions estimates used are likely to have been overestimated. The overall cost effectiveness of the LCV Regulations has been estimated at -€173/tCO\(_2\), which compares favourably with the ex-ante estimates of -€38.9/tCO\(_2\) to €32.6/tCO\(_2\).

**Costs to manufacturers** have been much lower than originally anticipated, because emissions abatement technologies have, in general, proved to be less costly than expected. For passenger cars, the ex-post average unit costs associated with meeting the fleet-average 130 gCO\(_2\)/km target have been estimated at €183 per car. By contrast, the ex-ante estimates of average costs to manufacturers prior to the introduction of the Regulation ranged from €430 to €984 per car.

For LCVs, the average costs to manufacturers have also been lower than originally anticipated; average ex-post costs for meeting the 175 gCO\(_2\)/km target have been estimated at €115 per vehicle, as opposed to the ex-ante estimate of €1,037 per vehicle. Part of the reason that the ex-ante costs for LCVs were so high is because the level of effort required to reduce emissions to 175 gCO\(_2\)/km is likely to have been over-estimated for the original Impact Assessment.

**Lifetime fuel expenditure savings** for cars have been lower than originally anticipated in the Impact Assessment, primarily because of the increasing divergence between test cycle and real-world emissions performance. Similarly, for LCVs, the fuel lifetime expenditure savings have also been significantly affected by this divergence from test cycle performance. Linked to these fuel expenditure savings are **losses in fuel tax revenues**. For passenger cars, fuel tax revenues are estimated to have reduced by €22 billion over the time period 2006 to 2013, whilst for LCVs, the reduction in fuel tax revenue over the period 2010 to 2013 is estimated to be €1 billion. Whilst overall, the Regulations have been cost efficient in achieving CO\(_2\) emissions reductions, a key weakness relates to the test cycle not being representative of real-world emissions. The analysis carried out for this evaluation has shown that the increasing discrepancy between test cycle and real-world emissions performance has eroded the expected emissions benefits and fuel expenditure savings of both the car and LCV CO\(_2\) Regulations.
The analysis suggests that some design elements (modalities) of the Regulations are likely to have had an impact on the efficiency of the Regulations. In particular, the use of mass as the utility parameter penalises the mass reduction as an emissions abatement option. The analysis suggests that for mass reduction options, having ‘mass’ as the utility parameter could be less than half as efficient as having ‘footprint’ would have been.

**Coherence**

It can be concluded that the two Regulations are largely coherent internally and with each other, with some important caveats as follows:

- **The derogation for niche manufacturers** potentially weakens the delivery of CO$_2$ emissions reductions. Less than one third of the manufacturers eligible actually benefit from a derogation. If all of the other manufacturers that were eligible for a niche derogation applied for it, the numbers of cars covered could increase by five times, which could have a not insignificant impact on the overall level of CO$_2$ emissions reductions achieved.

- **Super-credits** provide an additional incentive for manufacturers to develop and market low CO$_2$ emitting cars, but they potentially weaken the targets. So far, in 2013 the use of super-credits does not seem to have weakened the targets.

- **The phase-in period** for the second car target potentially weakens the Regulation and delivers little with respect to any other objective, as manufacturers will have had sufficient time to develop their cars in order to deliver the targets. This highlights the importance of setting a post 2020 target as soon as possible in order to give manufacturers sufficient time to plan to meet this target.

In relation to the coherence between the two Regulations, the main issue is the different level of stringency between the targets and the potential to move car-derived LCVs to the car CO$_2$ Regulation.

Overall, the objectives of the LDV CO$_2$ Regulations are generally coherent with objectives of other related GHG reduction policies and overarching EU policies. The main potential conflicts with other legislation were found at the interface with non-GHG polices. The issues mainly relate to specific technology choices that may have trade-offs between CO$_2$ and air pollutant emissions, noise or recyclability/recoverability. In addition, the means of improving safety may lead to increased fuel consumption in some cases. These trade-offs do not currently appear to compromise compliance with multiple Regulations at the same time. Finally, a potential conflict concerns the use of biofuels promoted under the Biofuels Directive and the Renewable Energy Directive policies, which have come under recent scrutiny over the net GHG emission savings actually achieved, particularly considering the issue of Indirect Land Use Change (ILUC).

**EU added value**

The harmonisation of the market is the most crucial aspect of added-value and it is unlikely that uncoordinated action would have been as efficient. The Regulations ensure common requirements across the EU and thus minimise costs for manufacturers, whereas on their own, Member States would represent too small a market to achieve the same level of results and therefore an EU wide approach is needed to drive industry level changes.

The automotive industry requires as much regulatory certainty as possible if it is to make the large capital investments necessary to maximise the fuel economy of new vehicles, and even more so for shifting to new primary energy sources. Performance standards can provide this certainty over a long planning horizon. In addition, there do
not appear to be any plausible alternatives to achieving the same level of CO$_2$ emission reductions in a more cost-effective manner compared to the LDV CO$_2$ Regulations.

**Recommendations**

The overall assessment of the Regulations has been largely positive. There are some aspects that could be improved and some recommendations that would ensure the Regulations remain relevant, coherent, effective and efficient.

With respect to **relevance**, a potential additional need post 2020 could be considered. Namely, that road transport needs to use less energy, in order to take account of the increasing range of fuels and energy sources that the transport is likely to be using. That is, energy efficiency will become a more important metric as the LDV fleet moves to a more diverse mix of powertrains.

Concerning **effectiveness**, the Regulations have clearly been successful in improving the specific CO$_2$ emissions of cars and LDVs. The analysis also highlighted some key weaknesses that may need to be addressed in future policy proposals:

- **The test cycle**: there is an increasing discrepancy between real-world and test cycle emissions. This issue has been recognised by policy-makers and will be addressed – at least in part – by the development of a revised test procedure, which will be part of a new worldwide harmonised test protocol (WLTP).

- **Lack of consideration of lifecycle and embedded emissions**: This is currently a minor issue due to the low penetration of electric and plug-in hybrid vehicles; however, as the proportion of electric vehicles is expected to increase, this issue will become more significant. This aspect may therefore need to be included in future legislation.

With respect to **efficiency**, whilst the Regulations have generated net economic benefits to society and have provided consumers with savings in fuel expenditure, both of these metrics have been adversely affected by the problems with the test cycle. This means that the benefits have been smaller than they would otherwise have been if the divergence between test cycle and real-world performance had not been increasing over the last few years. It is recommended that the new WLTP test cycle should address this issue, but it is important that sufficient checks are included to ensure that the new test does not in future years become subject to the problems experienced with the NEDC.

In addition, there is a need to look at how to improve the ex-ante assessment of costs associated with the Regulations. It is clear from this evaluation that the costs to manufacturers assumed prior to the introduction of the Regulations were much higher than has been the case in reality. Work is already ongoing to improve the cost assessment approach, but further assessment may be needed.

Considering the **internal coherence** of the Regulations, one recommendation could be considered with respect to the use of **super-credits** in future periods, as their use may not be needed to incentivise the uptake of low emission vehicles. If an additional incentive to develop low CO$_2$ emission vehicles is required – although the respective targets should be set to be cost-effective and therefore provide a sufficient incentive – one that does not potentially weaken the target might be explored (see, for example, Section 5.2.3).

With respect to the **coherence of the LDV CO$_2$ Regulations with other policy instruments**, it is clear that any trade-offs do not currently appear to compromise compliance with multiple Regulations at the same time. Improved coordination may be required as future targets become more stringent both for the LDV CO$_2$ Regulations and other targets such as those in the End-of-Life Vehicle Directive, Euro emission standards, noise Directives etc.
1 Introduction

1.1 Purpose of the evaluation

This evaluation study has been commissioned by DG Climate Action and focuses on the following Regulations:

- **Regulation (EC) No 443/2009** of the European Parliament and of the Council of 23 April 2009, setting emission performance standards for new passenger cars as part of the Union's integrated approach to reduce CO₂ emissions from light-duty vehicles (EC, 2009a); and


These Regulations are the cornerstones of the EU's strategy to improve the carbon dioxide (CO₂) emissions performance of new light duty vehicles (LDVs), i.e. cars and light commercial vehicles (LCVs), sold on the EU market, which are major sources of greenhouse gas emissions (GHGs). They are also referred to, respectively, as the passenger car CO₂ Regulation and the LCV CO₂ Regulation, and collectively as the LDV CO₂ Regulations.

The purpose of this evaluation is to provide insight into the actual performance of the Regulations and the overall impacts (both intended and unintended) on societal, economic and environmental issues. The evaluation report therefore aims to:

- Establish evidence-based conclusions on the actual results and impacts of the Regulations and the factors that may have resulted in the interventions being more or less successful than anticipated;

- Communicate the achievements and challenges of the Regulations; and

- Inform decisions in order to improve the design of any future Regulations.

As well as evaluating the Regulations to date, it will also provide insights as to the extent to which the Regulations and their elements can be considered to be fit for purpose beyond 2020. This evaluation is also one of the actions for 2015 under the Commission’s regulatory fitness (or REFIT) programme. The REFIT programme is part of the Commission’s commitment to Better Regulation, and aims to ensure that legislation is fit-for-purpose and does not impose unnecessary regulatory burdens (European Commission, 2014e).

The original Regulations listed above set emission reduction targets in relation to cars for 2015 and to LCVs for 2017. Both of these Regulations have subsequently been amended, by Regulation (EU) No 333/2014 and Regulation (EU) No 253/2014 respectively, in order to set additional targets for 2021 for cars and for 2020 for LCVs (European Commission, 2014a; European Commission, 2014b).

1.2 Scope of the evaluation

While the passenger car CO₂ Regulation came into force in 2009, it was preceded by voluntary agreements with various manufacturers’ associations, which were first mentioned in a Commission strategy dating from 1995 (see Section 2.2.1 for more detail). Hence, the timescale of this evaluation cover the entire period from 1995 to 2014 for passenger cars. There were no equivalent voluntary agreements for LCVs, so

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2 ‘Light commercial vehicles’ are sometimes referred to as ‘vans’.
the timescales for which an evaluation for LCVs was possible is much shorter than that for cars.

While much of the evaluation is backward looking, there is also a forward looking element that aims to identify whether the Regulations are fit for purpose for the period beyond 2020. It is appropriate to raise this question as there are a range of emerging issues that have had an impact on the effectiveness of the Regulations, some of which have the potential to have an increasing impact in the future. These issues are introduced in Section 3.3 and discussed in more detail in relation to various evaluation questions.

Geographically, the focus of the evaluation is on the implementation of the Regulations in the EU. However, the EU automotive sector is not an isolated sector: many of its manufacturers and suppliers operate globally. Also of relevance in this respect, is that similar requirements in terms of improved fuel efficiency and CO₂ reductions are being placed on manufacturers in many other major global vehicle markets. This evaluation takes account of these issues where relevant.

1.3 Structure of this report

The report is structured as follows:

- **Section 2: Background to the Regulations.** This section covers the purpose of the Regulations in more detail, their history and evolution, as well as their objectives. The Regulations are different to other pieces of emissions performance legislation, so how they work in practice and are monitored is also covered in this section. This section also includes the intervention logic for the Regulations.

- **Section 3: Expected outcomes and the current state of play.** This section sets out the expected outcomes of the Regulations, as well as the current state of play. It also discusses a number of related issues that make it challenging to isolate the impacts of the Regulations, as well as various emerging issues that affect the impact of the Regulations.

- **Section 4: Research methodology.** This section outlines the methodological approaches used in terms of data collection, analysis and engagement with stakeholders. It also discusses the limitations of the research.

- **Section 5: Analysis of the evaluation questions.** The analysis for each of the evaluation questions is covered in this section, presented under the headings of relevance, effectiveness, efficiency, coherence and EU-added value.

- **Section 6: Conclusions and recommendations.** This section sets out the conclusions for each evaluation question, followed by recommendations for future actions.
2  Background to the Regulations

2.1  Purpose of the Regulations

Both the Commission’s original 1995 strategy to reduce CO₂ emission from passenger cars (European Commission, 1995), and the review conducted in 2007 (European Commission, 2007a), make it clear that the main driver behind the strategy is the need to reduce global GHG emissions. Both Communications highlight that the high proportion of total emissions that come from the transport sector (and from cars in particular) justifies the focus on these types of vehicles (European Commission, 1995; 2007a).

The ultimate aim of the Regulations is to contribute to reductions in actual, or real-world, CO₂ emissions from one of the main sources of transport emissions. LDVs also have an important social and economic role: cars enable people to access employment, education, goods and services, while LCVs are an important part of the freight distribution network, particularly at the local level. Manufacturers of cars and LCVs in the EU also contribute to EU employment and GDP. Hence, the Regulations aim to achieve a balance between their overall environmental objectives and the needs of society and the economy.

The other challenge that the policy-makers behind the Communications faced was that in practice real-world CO₂ emissions are linked to how, and how much, vehicles are used. Directly regulating real-world total CO₂ emissions from cars and LCVs would be challenging, so the Regulations focused on a proxy measure, i.e. the average CO₂ emissions per kilometre driven that are measured when vehicles are assessed in accordance with the agreed vehicle type approval tests.

2.2  History and evolution of measures for addressing CO₂ emissions from light duty vehicles

2.2.1  Passenger cars

The origins of the Regulations date back to 1995 when the Commission published a strategy on passenger car CO₂. This responded to requests from the Council and the European Parliament for EU-level action to reduce car CO₂ emissions; these requests had suggested that an appropriate target would be to reduce average CO₂ emissions from new passenger cars to 120 gCO₂/km. The strategy to achieve this target was based on three pillars covering both supply and demand measures (European Commission, 1995):

1. Voluntary commitments from automobile manufacturers;
2. Promotion of fuel efficient vehicles through fiscal measures (taxation); and
3. Introduction of fuel economy labelling.

The strategy's intention was to meet the 120 gCO₂/km target by 2012. In 1998, a voluntary agreement was reached with the European automobile manufacturers’ association (ACEA) to reduce the average CO₂ emissions of new cars to 140g/km by 2008. This was followed by similar agreements to reach identical targets – to be achieved one year later – with the Japanese and Korean car manufacturers associations (respectively, JAMA and KAMA). The taxation pillar was expected to be delivered largely through Member State action, although by 2005 few had taken any relevant action. Consequently, the Commission published a proposal for coordinated action in this respect (European Commission, 2005), but this faced opposition from some Member States and has not become law. Directive 1999/94/EC, which requires new cars to display a label showing fuel consumption and CO₂ emissions, implemented the third
pillar of the strategy. Additionally, a monitoring mechanism, Decision No 1753/2000/EC, was put in place so that the necessary data could be collated and analysed in order to assess manufacturers’ progress to meeting the targets that they had committed to in the voluntary agreements (European Commission, 2000a). This Decision was repealed by Regulation 443/2009, as the latter included the necessary monitoring requirements (see Section 2.5).

The Commission published a review of the strategy in 2007, which concluded that manufacturers’ progress in reducing the CO₂ emissions of the new EU car fleet was not sufficient to meet the targets within the voluntary agreements, or to meet the EU target for 2012. This Communication set out an ‘integrated approach’ within which a target of 130 gCO₂/km would be delivered by mandatory requirements on manufacturers, while the additional 10 gCO₂/km would be delivered by other technological improvements and by an increased used of biofuels (European Commission, 2007a). In this way, the Regulation remained part of a wider package of measures that would work together to reduce the CO₂ emissions from passenger cars.

The proposal that eventually led to the passenger car CO₂ Regulation was published at the end of 2007 and set a target for 2015 (see Section 2.4). The Regulation contained an indicative target for 2020, which was subsequently confirmed by Regulation 333/2014, although it is to be achieved in 2021, one year later than planned.

A 2010 report on the implementation of the integrated approach (European Commission, 2010a) concluded that it was unlikely that the target of the Community’s strategy, i.e. of reducing average CO₂ emissions of new cars to 120 gCO₂/km by 2012, would be met, although it expected the Regulation to achieve its target.

### 2.2.2 Light commercial vehicles

LCVs were not mentioned in the Commission’s original 1995 strategy. In the early 2000s, the European Parliament and the Council asked the Commission to assess possible approaches to extending the 1995 strategy to LCVs (TNO, LAT and IEEP, 2004). As part of the preparation of the 2007 review of the strategy, the Commission held a public consultation, which expressed strong support for the extension of the strategy to LCVs (European Commission, 2007a). Mandatory requirements on LCV manufacturers, similar to those being proposed for cars, were therefore included in the 2007 strategy (European Commission, 2007a). Further consultations and meetings with affected stakeholders were held in the following years, before the proposal for a Regulation was published in late 2009 (European Commission, 2009g). This took a similar approach to the passenger car CO₂ Regulation and contained many of the same elements. This eventually led to the publication of the LCV CO₂ Regulation in 2011, which set a target for 2017 and also included an indicative target for LCVs for 2020. This target was subsequently confirmed by Regulation 253/2014.

### 2.3 Intervention logic of the car and LCV CO₂ Regulations

The intervention logic describes, in graphical form, the links and causal relationships between the problems and/or needs, broader policy goals, the general, specific and operational objectives that the specific policy measure is designed to address, and the specific actions for addressing those problems and/or needs. The intervention logic also describes what the policy measure is expected to achieve, and how the wider policy aims are linked to the specific operational objectives and the actions undertaken to achieve the objectives by the various relevant actors. The intervention logic for the passenger car and LCV CO₂ Regulations is presented in Figure 2-1 overleaf. This is followed by a discussion of the general, specific and operational objectives of the Regulations. More detail on how the specific modalities of Regulations contribute to the main objectives of the Regulations is presented in Table 5-36 in Section 5.7.1.
Figure 2-1: Intervention logic for the passenger car CO₂ Regulation and the LCV CO₂ Regulation

**NEEDS, PROBLEMS**
- All sectors must contribute to the fight against climate change
- The CO₂ performance of new vehicles should improve at a faster rate
- Road transport needs to use less oil
- Further reductions in CO₂ must be achieved cost-effectively without undermining sustainable mobility and the competitiveness of the automotive industry

**GENERAL OBJECTIVES**
- Provide a high level of environmental protection
- Improve energy security
- Foster the competitiveness of the European automotive industry and encourage innovation in fuel efficiency technologies

**SPECIFIC OBJECTIVES**
- Reduce climate change impacts and improve fuel efficiency of cars by reaching the objective of an average emission value of 130 g CO₂/km for newly sold cars by 2015 and of 175 g CO₂/km for newly sold LCVs by 2017

**OPERATIONAL OBJECTIVES**
- Design a legislative framework to implement fleet-average CO₂ targets for new cars and new LCVs
- Ensure competitive neutrality and socially equitable and sustainable reduction targets
- Ensure the compatibility of the regulations for cars and vans

**ACTIONS**
- EU
  - Implementing legislation
  - Monitor progress
  - Implement and review modalities
- Industry
  - Compliance with Regulations
  - Participate in working groups
- Human and financial resources allocated by EU bodies (EC, EEA), industry (vehicle manufacturers, suppliers)
- Investment in R&D on fuel-efficient technologies

**IMPACTS**
- Reduction in overall CO₂ emissions and fuel consumption from LDVs
- Fuel cost savings for consumers
- Increased market penetration of fuel efficient technologies with no impacts on competitive neutrality

**RESULTS**
- Reduction in average specific CO₂ emissions of new LCVs

**OUTPUTS**
- Introduction of Regulatory targets of an average emission value of 130 g CO₂/km for newly sold cars by 2015 and of 175 g CO₂/km for newly sold LCVs by 2017
- Introduction of monitoring arrangements for CO₂ emissions from newly sold LDVs
- Introduction of Regulatory modalities to ensure implementation of targets and competitive neutrality
2.3.1 Objectives

The objectives of the car and LCV CO₂ Regulations, the Commission’s original proposals for this legislation and the Impact Assessments produced in support of these proposals were as follows (European Commission, 2007b); (European Commission, 2009g):

1. **All sectors must contribute to the fight against climate change.** The Impact Assessments justified this as the EU has an international commitment to reduce its GHG emissions under the Kyoto Protocol, and has also unilaterally committed itself to reducing GHG emissions by 20% compared to 1990 levels by 2020. The Commission considered that it was appropriate for all sectors to contribute to GHG emissions reductions to avoid distortions and “for the sake of economic and social fairness”.

2. **The CO₂ performance of new vehicles should improve at a faster rate.** The aim of the EU's legislative framework on passenger car CO₂ was to reduce CO₂ emissions from passenger cars to an average of 120 g/km by 2012. The previous mechanism that had been put in place – the voluntary agreements with manufacturers’ associations (see Section 2.2.1) – was not delivering reductions at a sufficient rate for this target to be met. As a result, the Impact Assessment for the proposed passenger car CO₂ Regulation argued that legislation to regulate the CO₂ emissions of new cars was needed. Both Impact Assessments also noted that the improvements in fuel efficiency that had taken place had been offset by increased demand and so overall road transport CO₂ emissions were still increasing.

3. **Road transport needs to use less oil.** The Impact Assessments noted the direct link between improved fuel efficiency and lower CO₂ emissions and that road transport relied heavily on oil for which the EU's import dependency was more than 80%. As road transport accounted for around 25% of final energy consumption in the EU the sector was particularly at risk from oil shocks and so would benefit from the increased security of supply that would result from lower levels of oil use.

4. **Further reductions in CO₂ emissions must be achieved cost-effectively without undermining sustainable mobility and the car industry’s competitiveness.** The Impact Assessments underlined the economic importance of the automotive sector to the EU, and the importance of mobility to individuals and to companies. As a result, it was argued that it was important that the legislative proposals should not undermine either sustainable mobility or the competitiveness of the industry.

These needs were summed up in both Impact Assessments as the following overarching problem:

"...existing policies to reduce CO₂ emissions and improve the fuel efficiency of new cars sold in the EU have not been able to deliver the progress needed for reaching the long-standing EU objective of an average new car fleet emission of 120 g CO₂/km.” (European Commission, 2007d); (European Commission, 2009b)

This overarching problem had been identified in earlier Communications, such as the 2007 review of the passenger car CO₂ strategy (European Commission, 2007a), which had also identified the criteria with which a future legislative framework should be consistent, i.e.

"...the legislative framework implementing the average new car fleet target will be designed so as to ensure competitively neutral and socially equitable and sustainable reduction targets which are equitable to the diversity of the European automobile manufacturers and avoid any unjustified distortion of competition
between automobile manufacturers. The legislative framework will be compatible with the overall objective of reaching the EU’s Kyoto targets...” (European Commission, 2007a)

For the proposed passenger car CO₂ Regulation, the specific problem identified was “how to design the legislative instrument which reflects the above criteria”, while for the proposed LCV CO₂ Regulation it was simply “how to design a legislative instrument to limit emissions of CO₂ from light commercial vehicles”.

According to the Impact Assessments, in order to address these needs and overarching problems, the proposed Regulations should pursue the various objectives set out in Table 2-1.
Table 2-1: Summary of the objectives of the Regulations, according to the respective Impact Assessments

<table>
<thead>
<tr>
<th>General policy objectives</th>
<th>Proposed passenger car CO₂ Regulation, according to European Commission (2007b)</th>
<th>Proposed LCV CO₂ Regulation, according to European Commission (2009b)</th>
<th>Proposal to define modalities for meeting respective 2020 targets, according to European Commission (2012b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>“Providing for a high level of environmental protection in the European Union and contributing to reaching the EU’s Kyoto targets,</td>
<td>“Providing for a high level of environmental protection in the European Union and contributing to reaching the EU’s climate change targets; and</td>
<td>“Provide for a high level of environmental protection in the European Union and contribute to reaching the EU’s climate change targets while reducing oil consumption, thus improving the security of energy supply in the EU, stimulating innovation and boosting competitiveness of the EU industry”</td>
</tr>
<tr>
<td></td>
<td>…Improving the EU’s energy security of supply,</td>
<td>…Reducing oil consumption and thus improving the security of energy supply in the EU.”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>…Fostering the competitiveness of the European automotive industry and encouraging research into fuel efficiency technologies.”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific objective</td>
<td>“Reducing the climate change impacts and improving the fuel efficiency of passenger cars by reaching the objective of an average emission value of 130 g CO₂/km for newly sold cars.”</td>
<td>“To reduce the climate change impacts and improve the fuel efficiency of light commercial vehicles by means of a specified emission reduction for new vehicles in line with the revised strategy COM(2007)19.”</td>
<td>“Ensure the continued and effective application of the car and van CO₂ regulations particularly in respect of the 2020 targets”</td>
</tr>
</tbody>
</table>
### Operational objectives

<table>
<thead>
<tr>
<th>Proposed passenger car CO₂ Regulation, according to European Commission (2007b)</th>
<th>Proposed LCV CO₂ Regulation, according to European Commission (2009b)</th>
<th>Proposal to define modalities for meeting respective 2020 targets, according to European Commission (2012b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Designing a legislative framework for efficiently implementing the average new car fleet target ensuring competitively neutral and socially equitable and sustainable reduction targets which are equitable to the diversity of the European automobile manufacturers and avoid any unjustified distortion of competition between automobile manufacturers. The legislative framework will be compatible with the overall objective of reaching the EU's Kyoto targets.”</td>
<td>“Designing a legislative proposal that efficiently implements the fleet average emissions target for new LCVs and prevents any regulatory gap which could undermine the effectiveness of the regulation on CO₂ and cars;</td>
<td>“Ensure that the 2020 van CO₂ target is feasible.</td>
</tr>
<tr>
<td></td>
<td>• Making the legislation compatible with the regulation on CO₂ and cars for reasons of simplification; and</td>
<td>• Ensure that the CO₂ emission targets for 2020 of 95 gCO₂/km for cars and 147 gCO₂/km for vans are achieved cost-effectively.</td>
</tr>
<tr>
<td></td>
<td>• Providing a regulatory framework that avoids any unjustified distortion of competition between automobile manufacturers.”</td>
<td>• Ensure the modalities of achieving the 2020 targets do not have unacceptable social impacts. [i.e. minimise the divergence in relative retail price increase]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Ensure the modalities of achieving the 2020 targets do not have undesired competitiveness impacts for the EU automotive sector. [i.e. avoid excessive distortion of competition between manufacturers]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Create sufficient certainty for the automotive sector with regard to future light duty vehicle CO₂ requirements.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Minimise where possible the administrative burden and costs for SMEs of the Regulations”</td>
</tr>
</tbody>
</table>
All three Impact Assessments provide similar justifications for EU level action. Without EU level action, it was argued that there was a risk of different approaches being taken in different Member States, which risked the emergence of barriers to the single market in the EU automotive sector. This would be a disadvantage to both manufacturers and their suppliers, as different national schemes could have different specifications, thus leading to different demands on the industry. As a result, economies of scale would be lost, the costs of compliance would increase and consumers would not be able to benefit from the reduced costs. Additionally, the transnational nature of climate change argued for action at the EU level, rather than the Member State level (European Commission, 2007d; 2009b; 2012b).

2.4 How the Regulations operate in practice

The Regulations set mandatory fleet-based CO₂ reduction targets for new cars and LCVs. For cars, Regulation 443/2009 sets a fleet-wide target of 130 gCO₂/km to be met by 2015, and a target for 2021 of 95 gCO₂/km. For LCVs, Regulation 510/2011 sets a target of 175 gCO₂/km by 2017 and 147 gCO₂/km for 2020.

Both Regulations use the same metric: the specific CO₂ emissions of a vehicle, measured in gCO₂/km on the vehicle emissions test cycle, which is currently the New European Drive Cycle (NEDC). The NEDC already existed prior to the Regulations, as it was used (for example) to measure the performance of new vehicles in relation to air pollutant emission limits. Consequently, vehicle CO₂ emissions as measured on the test cycle were considered to be an appropriate proxy for the vehicle’s CO₂ emissions in the real-world, and therefore a suitable focus for the Regulations. The suitability of this metric in practice is analysed in Section 3.4 and Annex A.

The Regulations are applicable to manufacturers rather than Member States, and the targets are to be met by manufacturers through improvements in vehicle technology. The approach taken in the LDV CO₂ Regulations is more complex than the approach used in EU legislation regulating air pollution from road transport vehicles, for example, as this generally sets limit values for each regulated pollutant. It was considered that a similar approach would not be practical for CO₂ emissions, as it would restrict the range of cars that could be put on the market. Hence, the Regulations set each manufacturer a different annual fleet-average CO₂ target that must be met by the fleet of new cars or LCVs that it sells each year.

In order for the targets to be able to reflect the characteristics of each manufacturer’s vehicle fleet, it was necessary to relate the targets to a measure of a vehicle’s ‘utility’. Various possible ‘utility parameters’ were considered in the studies that were undertaken in support of the legislation, but ‘mass’ (defined as the mass in running order) was chosen for both Regulations (see Section 3.3). While making the Regulation more complex compared to setting a single target value, as the emissions target is not the same for each vehicle, the utility parameter approach was considered to be competitively neutral as it took account of the diversity of manufacturers and their vehicles. It does this by directly relating manufacturers’ targets to a characteristic of their vehicles, while still requiring higher emissions reductions from manufacturers of larger (heavier) vehicles (European Commission, 2007d).

The relevant targets are calculated according to a formula set out in Annex I of the respective Regulations, which determines a manufacturer’s target as a function of the mass of its new vehicles that are registered that year. The target is therefore effectively a line: a manufacturer whose fleet is lighter than average will have a lower target than

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3 In other words, any vehicle being marketed within the EU has to have emissions that are no higher than these limit values.
a manufacturer whose fleet is heavier than average (e.g. see Figure 9-1 in Annex C). The shape and slope of the line are important to ensure that the emissions reductions required by heavier and lighter cars are appropriate (in order to ensure competitive neutrality), as well as to limit incentives for manufacturers to increase mass, rather than reduce emissions, to meet their targets. The flatter the slope, the higher the relative price increases will be for the manufacturers of heavier cars (European Commission, 2007d).

The details – or modalities – of the two Regulations are similar, although not all elements are present in both. Indeed, it was explicitly stated in the Impact Assessment supporting the proposed LCV CO₂ Regulation that there were “no obvious reasons” for the approach taken to be significantly different from that taken for cars. Hence, the approach was to design the LCV legislation to be as “similar as possible” to the one for cars, except where there was a justification for taking a different approach (European Commission, 2009b). An overview of the main modalities for both Regulations is given in Table 2-2.

**Table 2-2: Summary of the main elements of the passenger car and LCV CO₂ Regulations**

<table>
<thead>
<tr>
<th>Element of the regulations</th>
<th>Car CO₂ regulation</th>
<th>LCV CO₂ regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>First target</td>
<td>130 gCO₂/km</td>
<td>175 gCO₂/km</td>
</tr>
<tr>
<td>Phasing in of first target</td>
<td>For the purpose of determining each manufacturer’s average CO₂ emissions, 65% of registered cars are taken into account in 2012, rising to 75% (2013), 80% (2014) and 100% from 2015 to 2019.</td>
<td>For the purpose of determining each manufacturer’s average CO₂ emissions, 70% of registered LCVs are taken into account in 2014, rising to 75% (2015), 80% (2016) and 100% from 2017.</td>
</tr>
<tr>
<td>Super-credits for first target</td>
<td>Each new car with CO₂ emissions of less than 50g shall be counted as 3.5 cars in 2012 and 2013, 2.5 cars in 2014, 1.5 cars in 2015 and 1 car from 2016; there is no limit as to the number of vehicles for which a super-credit can be given.</td>
<td>Each new LCV with CO₂ emissions of less than 50g shall be counted as 3.5 LCVs in 2014 and 2015, 2.5 LCVs in 2016, 1.5 LCVs in 2017 and 1 LCV from 2018; super-credits can be applied up to a maximum of 25,000 LCVs per manufacturer over the entire period.</td>
</tr>
<tr>
<td>Second target</td>
<td>95 gCO₂/km</td>
<td>147 gCO₂/km</td>
</tr>
<tr>
<td>Phasing in of second target</td>
<td>95% of registered cars taken into account in 2020 and then 100% from 2021.</td>
<td>100% of registered LCVs from 2020.</td>
</tr>
<tr>
<td>Super-credits for second target</td>
<td>Each new car with CO₂ emissions of less than 50g shall be counted as 2 cars in 2020, 1.67 cars in 2021, 1.33 cars in 2022 and 1 car from 2023; the limit for the use of super-credits is set at a maximum of 7.5 g/km for 2020 to 2022 for each manufacturer.</td>
<td>The use of super-credits is not allowed in relation to the 2020 target.</td>
</tr>
<tr>
<td>Pooling</td>
<td>Manufacturers may form a pool to meet their specific emissions targets (except for manufacturers with a ‘small volume’ or ‘niche’ derogation; see below).</td>
<td>Manufacturers may form a pool to meet their specific emissions targets (except for manufacturers with a ‘small volume’ derogation).</td>
</tr>
</tbody>
</table>
### Element of the regulations

<table>
<thead>
<tr>
<th></th>
<th>Car CO₂ regulation</th>
<th>LCV CO₂ regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Excess emissions premium</strong></td>
<td>From 2012 (or 2014 for LCVs) to 2018, where a manufacturer’s (or pool's) CO₂ emissions exceed their target, they will have to pay an 'excess emissions premium' for each new vehicle registered that year of: €5 for the first gram over (or part thereof); €15 for the second gram over (or part thereof); €25 for the third gram over (or part thereof); and €95 for each gram thereafter. From 2019 the premium will be €95 for each gram.</td>
<td></td>
</tr>
<tr>
<td><strong>'Small volume' derogation</strong></td>
<td>Manufacturers that are responsible for fewer than 10,000 new cars (or 22,000 new LCVs) registered each year and are not part of a wider group may apply for a derogation under which the manufacturer proposes a specific CO₂ emissions reduction target consistent with its reduction potential. The application needs to be approved by the Commission.</td>
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</tr>
<tr>
<td><strong>‘Niche’ manufacturer derogation</strong></td>
<td>‘Niche’ manufacturers, i.e. those responsible for between 10,000 and 300,000 new cars registered each year, can apply for a derogation to have a reduction target for 2012 to 2019 that is 25% less than their average specific CO₂ emissions in 2007 and a reduction target from 2020 that is 45% lower than the 2007 value.</td>
<td>No equivalent provision.</td>
</tr>
<tr>
<td><strong>Eco-innovations</strong></td>
<td>Manufacturers or suppliers can apply for the CO₂ savings achieved as a result of innovative technologies to be considered, as long as these deliver verifiable CO₂ emissions reductions that are not measured under the test cycle. The 'eco-innovations' that are approved by the Commission can be used to contribute up to 7g of the manufacturer's specific emissions target.</td>
<td></td>
</tr>
<tr>
<td><strong>De minimis</strong></td>
<td>Manufacturers responsible for fewer than 1,000 new cars and LCVs registered each year do not have a specific emissions target.</td>
<td></td>
</tr>
<tr>
<td><strong>M₀ adjustment</strong></td>
<td>The average mass of the new vehicle fleet (referred to as M₀) is part of the formula used to calculate each manufacturer’s CO₂ reduction target. From 2016 (2018 for LCVs) an adjusted M₀ will be used, which will be the average mass of the new vehicle fleet from 2011 to 2013 (2013 to 2015 for LCVs). A similar adjustment will subsequently occur every 3 years.</td>
<td></td>
</tr>
</tbody>
</table>

The existence of many of these modalities adds to the complexity of the LDV CO₂ Regulations, although many of these have been included in order to improve the functioning of the Regulations for manufacturers, as is discussed below. Additionally, some of the modalities – such as super-credits, as is noted below – were not envisaged by the Commission in the original proposals, particularly in the initial proposal that led to the passenger car CO₂ Regulation, and hence no initial analysis of their impacts was undertaken.

The original proposal for the car CO₂ Regulation did not include a phase-in period; this was introduced later and justified in the preamble to the Regulation “to facilitate the transition”⁴. The original proposal for the LCV CO₂ Regulation did propose a phase-in period, which is also justified in its preamble “to facilitate the introduction” of the targets and to provide consistency with the phase-in period under the passenger car

⁴ Recital 19 of Regulation 443/2009
CO\textsubscript{2} Regulation\textsuperscript{5}. The Impact Assessment of the proposal to confirm the 2020 modalities assessed whether there was a need for a phase-in period for the 2020 targets and concluded that none was needed as manufacturers had had enough time to plan to meet the target (European Commission, 2012a).

**Super-credits** give manufacturers additional incentives to produce vehicles with low emissions by counting these as additional vehicles against their targets (see Table 2-2). Super-credits were not included in the original Commission proposal for the passenger car CO\textsubscript{2} Regulation and there is no explicit justification for their inclusion in the preamble to Regulation 443/2009. For LCVs, super-credits were included in the original proposal for the Regulation, as “a demand for inclusion of super-credits for low emitting vehicles … was made” in the course of a stakeholder consultation meeting. The preamble to the LCV Regulation explicitly links super-credits with the enhancement of the competitiveness of the European automotive industry. For both cars and LCVs, the Impact Assessment supporting the proposal to confirm the 2020 targets concluded that there should be no continuation of super-credits, as they increase CO\textsubscript{2} emissions, reduce the stringency of the target, reduce cost-effectiveness and do not respect the principle of technological neutrality (European Commission, 2012a).

The inclusion of *pooling* was considered to be an important flexibility that could improve the overall cost-effectiveness of the Regulation, as it allows manufacturers without a wide range of vehicles to create a pool with other more mainstream manufacturers. In this way, it also improves the equity and maintains the diversity of EU manufacturers (European Commission, 2007b; European Commission, 2009g). The Impact Assessment confirming the 2020 modalities did not address pooling in any detail, simply noting that it was recognised as a beneficial flexibility (European Commission, 2012a). From an administrative perspective, it is fairly straightforward for manufacturers to form a pool. A list of the required information is provided in Article 7 of each Regulation, which is replicated in short, Regulation-specific templates developed by the Commission for use by manufacturers when informing the Commission that a pool has been set up\textsuperscript{6}.

The *excess emissions premium* was included in the car CO\textsubscript{2} Regulation “to provide a sufficient incentive [to manufacturers] to take measures to reduce specific emissions of CO\textsubscript{2} from passenger cars, the premium should reflect technological costs” (European Commission, 2007b). The preamble to the LCV CO\textsubscript{2} Regulation notes that the premium for LCVs should be similar to that for cars in order to ensure consistency\textsuperscript{7}. The Impact Assessment of the proposal confirming the 2020 modalities considered that it was not necessary to change the level of the premium (European Commission, 2012a).

The inclusion of the *derogation for small volume manufacturers* was justified on the basis that such manufacturers may not find pooling, or other types of flexibility, appropriate, as their limited range of vehicles may make it costly to meet the targets set by the limit curve (European Commission, 2007b); (European Commission, 2009g). The original proposal for the passenger car CO\textsubscript{2} Regulation did not include a provision for *niche manufacturers*. For 2020, the retention of the derogation for small volume manufacturers was justified for the same reasons, as well as that it was in line with the competitive neutrality objective. Furthermore, a *de minimis* was introduced in both Regulations in order to exclude manufacturers that produce very small volumes of vehicles (i.e. those that register less than 1,000 vehicles annually), in order to reduce

\textsuperscript{5} Recital 19 of Regulation 510/2011

\textsuperscript{6} These templates can be downloaded, along with a set of FAQs, from the Commission’s website: ec.europa.eu/clima/policies/transport/vehicles/cars/documentation_en.htm; and ec.europa.eu/clima/policies/transport/vehicles/vans/documentation_en.htm

\textsuperscript{7} Recital 27 of Regulation 510/2011
burdens on SMEs (European Commission, 2012a). The information that manufacturers are required to provide in order to apply for a derogation – including a niche derogation – is set out in Article 11 of both Regulations. For each LDV CO₂ Regulation, this information is supplemented by separate Commission Regulations, which include additional definitions and more detail on what an application must cover, including a template of around three pages to be completed by each manufacturer that is applying for a derogation. The Commission is able to reject an application on the basis of incompleteness or if it concludes that the proposed specific emissions reduction target is not consistent with the reduction potential of the manufacturer concerned (European Commission, 2011e; European Commission, 2013f). While not included in the original proposal for the passenger car CO₂ Regulation, eco-innovations are justified in the preamble to the Regulation on the grounds that they result in significantly lower emissions and so contribute to the promotion of the long-term competitiveness of the European industry and the creation of more high-quality jobs. The original proposal for the LCV Regulation included provisions on eco-innovations and the preamble to the Regulation justified their inclusion for similar reasons as the passenger car CO₂ Regulation. The retention of eco-innovations for 2020 was justified on the basis that they are effective and efficient as any innovations approved would reduce CO₂ emissions and cost less than alternative options, as otherwise they would not be proposed (European Commission, 2012a). Companies must apply to the Commission in order to have a technology approved as an eco-innovation. The eco-innovation provision is not limited to manufacturers, as suppliers are also able to apply to have a technology that they have developed recognised as an eco-innovation. Indeed, as of March 2015, most of the applications for eco-innovations that had been approved had been made by suppliers rather than manufacturers. There is a separate Implementing Regulation under each LDV CO₂ Regulation that sets out the requirements for applications, including a methodology for demonstrating the associated emissions reductions and a verification report that needs to be produced by an independent, certified body to support the applicant’s claims. The Commission is to approve the application unless there are questions with respect to the eligibility of the technology or the appropriateness of the testing methodology (European Commission, 2011f; European Commission, 2014f).

A mechanism to adjust the value of the average mass of the vehicle fleet, M₀, which is used in the formula to calculate each manufacturer’s CO₂ reduction target (known as the ‘M₀ adjustment’), was included in the original proposal for the passenger car Regulation. This is important as the targets are a function of the mass (see above) and hence any changes in the average mass of the fleet would risk that the Regulation under- or over-achieves the desired CO₂ reductions (European Commission, 2007b). The formulation to adjust M₀ that is in the Regulations is simpler than that originally proposed, but still ensures that any changes in the average mass of the overall new car (or LCV) fleet are reflected in the calculation of manufacturers’ targets. Hence, if the average mass of the EU’s new car (or LCV) fleet increases, manufacturers’ targets will be adjusted to become more stringent for a given mass of vehicle, while if the average mass decreases, the targets will become less stringent (Ricardo-AEA et al, 2015). The first M₀ adjustment under the passenger car CO₂ Regulation was made for 2016 by Regulation (EU) 2015/6 (European Commission, 2015).

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8 Recital 13 of Regulation 443/2009
9 Recital 11 of Regulation 510/2011
10 See ec.europa.eu/clima/policies/transport/vehicles/cars/documentation_en.htm
2.5 Monitoring provisions

The monitoring and reporting requirements are set out in Article 8 of each of the LDV CO\textsubscript{2} Regulations and are further specified in Commission Regulations (European Commission, 2010b; European Commission 2012e). Each Member State has to monitor and report relevant data to the Commission each year based on the certificate of conformity (CoC) or type-approval documentation (TAD). At the time of registration, the vehicle owner, manufacturer/dealer or importer presents the CoC in electronic and/or paper format to the registration authority, which then incorporates the data into the national registry. The Member States transmit the relevant data for a full calendar year to the Commission at the latest by 28 February the following year using the Central Data Repository managed by the European Environment Agency. The Commission verifies the data, and may, in agreement with the Member States concerned, correct the data. At the latest by 30 June of each year the Commission makes public the aggregated provisional data and notifies each manufacturer individually of its provisional CO\textsubscript{2} average emissions and its emissions target based on the data received. After notification of the provisional data vehicle manufacturers may within three months verify the data and notify the Commission of the presence of any errors. The Commission considers any error notifications from vehicle manufacturers and either confirms or amends the provisional calculations by 31 October of each year.
3 Expected outcomes of the Regulations and current state of play

3.1 Expected outcomes

The Impact Assessment accompanying the original proposal for the passenger car CO\textsubscript{2} Regulation estimated that the implementation of the preferred option (i.e. the one that was proposed and subsequently implemented by the Regulation) would deliver well-to-wheel CO\textsubscript{2} emissions reductions of between 634 and 638 Megatonnes (Mt) of CO\textsubscript{2}eq by 2020 at a cost of between €32.4 and €39.8 per tonne of CO\textsubscript{2} abated (European Commission, 2007d). Overall, it was expected that costs to manufacturers would increase by between €620 and €1,670 per vehicle (in 2006 prices) and that the retail price of cars would increase by around 5% as a result of the Regulation. The net present value (NPV) of costs to society were estimated at between €20.5 billion and €21.7 billion for the period 2006 to 2020. The rest of the assessment was largely undertaken on the basis of a qualitative comparison of the short-listed options. The details of the preferred option – particularly the slope of the line – were chosen in order to obtain an appropriate balance between the objectives of cost-effectiveness, competitive neutrality, sustainability, social equity and maintaining the diversity of manufacturers (European Commission, 2007d).

In its Impact Assessment, the LCV CO\textsubscript{2} Regulation was estimated to deliver emissions reductions of around 60 MtCO\textsubscript{2} between 2010 and 2020, with costs to manufacturers of €1,798 per vehicle (in 2007 prices) and retail price increases per vehicle of between 5.4% and 9.9% depending on assumptions about mass increases. Other anticipated benefits included net economic benefits to vehicle operators and increases in employment as a result of the “higher added value on the vehicle” (European Commission, 2009b).

The Impact Assessment accompanying the proposal that confirmed the 2020 modalities concluded that the 2020 targets had net negative abatement costs, which means that overall society would benefit from their implementation. Compared to the ‘do nothing’ option, the Impact Assessment also concluded that the implementation of the targets would be better for the EU automotive sector, as its competitive position compared to other countries would not be weakened, while also helping to maintain the EU’s position as a frontrunner in producing low CO\textsubscript{2} vehicles (as the targets are achieved more quickly than elsewhere in the world).
way, the competitive edge of the EU’s automotive sector would be maintained. It was also concluded that the implementation of the targets would have a beneficial effect on the demand for labour (European Commission, 2012b).

### 3.2 Current state of play with respect to implementation of the Regulations

This report was drafted in the course of 2014; hence the latest year for which information on progress was available was 2013. As is clear from Table 2-2, this was only the second year for which the targets under the passenger car CO\(_2\) Regulation were applicable; furthermore, these targets were still being phased in as only 75% of new cars registered in 2013 were taken into account for the purpose of determining each manufacturer’s average CO\(_2\) emissions. For the LCV CO\(_2\) Regulation, the first year in which the targets and related provisions were applicable was 2014. Hence, the implementation of both Regulations is still in a relatively early phase. Having said that, the fact that the intention to develop both Regulations was announced in 2007 means that the Regulations could have started to have an impact several years before their targets were officially applicable (for a further discussion on this, see Section 5.2).

The most recent information published by the EEA shows that both the 2015 targets for cars and the 2017 targets for LCVs were met in 2013 (see Figure 3-1), as the respective average emissions were 126.7 gCO\(_2\)/km and 173.3 gCO\(_2\)/km. The numbers presented in Figure 3-1 represent the actual averages for the entire fleet, and so do not take account of the phase-in percentages or apply the provisions relating to super-credits or eco-innovations.

**Figure 3-1: Progress towards meeting passenger car and LCV CO\(_2\) targets since Regulations have required monitoring of average CO\(_2\) emissions**

[Graph showing CO\(_2\) emissions trends]

*Source: (EEA, 2014)*

### 3.3 Trends relevant to the CO\(_2\) emissions of LDVs

As noted in Section 2.1, the ultimate aim of the Regulations is to deliver CO\(_2\) emission reductions in the real world. While CO\(_2\) emissions as measured on the test cycle is one element of this, there are other external trends that influence CO\(_2\) emissions from the transport sector. This includes the recent decline in the amount of both passenger and
freight transport that is being undertaken and the potential reasons for this (discussed in Section 3.3.1) and the level and composition of fuel use by the transport (discussed in Section 3.3.2).

### 3.3.1 External trends relevant to the CO₂ emissions of LDVs

In recent years there has been a decline in GHG emissions from all transport modes (see Figure 3-2), including road transport where emissions decreased by 9% between 2007 and 2012 (European Commission, 2014d).

**Figure 3-2: Changes in GHG emissions by transport mode in the EU-28 (1900 to 2012; indexed to 1990)**

![Graph showing changes in GHG emissions by transport mode](image)

*Source: European Commission (2014d); figures exclude sea and air travel that departs the EU and indirect emissions, e.g. to produce the electricity used by railways.*

While policy instruments such as the LDV CO₂ Regulations may have had an impact on these figures, the fact that the declines have happened for all modes suggests that there are other factors at play. One of these factors is clearly the economic crisis of the late 2000s/early 2010s, which affected economic activity and therefore mobility. There is some debate as to the extent to which the observed reductions in GHGs are solely the result of the economic crisis or whether they represent a fundamental change to trends in the transport sector. As can be seen in Figure 3-3, the previously increasing trends in both transport and GDP growth have ceased since 2007, although the rate of increase for passenger transport had already been slowing. For both passenger transport and car use, the distance travelled peaked in 2009 and had declined by 1.6% and 3.5%, respectively, by 2012 (European Commission, 2014d).
There is some evidence that car use, at least in Western Europe, may have peaked for reasons other than the economic crisis. In a review of evidence from various countries with relatively high levels of GDP, Goodwin (2012) notes that in many of these countries there has been a long period of stable car use per head at the aggregate level and, more recently, a shorter period of declining car use per head for reasons that are not yet fully understood (see Figure 3-4).

**Figure 3-4: Passenger kilometres by passenger cars and light trucks, various countries (1990-2010; indexed to 1990)**

*Source: Goodwin (2012); based on International Transport Forum statistics*

Member States’ policies have also had a role in reducing transport’s GHG emissions in general, and in reducing those of new cars in particular. As was noted in Section 2.2, the Regulations themselves were conceived as a package of measures, with the supply-side being addressed by the Regulations and the demand-side including taxation measures, which were the responsibility of Member States. It has been demonstrated...
that the taxation measures in some Member States have played a role in the reductions that have been seen (e.g. Cambridge Econometrics, 2013; see also Section 5.2).

3.3.2 Trends relating to fuel use that may have been influenced by the Regulations

Not surprisingly, as transport’s CO₂ emissions have begun to decline, since the late 2000s, transport’s use of petroleum products has also been decreasing (see Figure 3-6). Figure 3-6 also shows that the EU’s import dependency, i.e. the proportion of crude oil from which petroleum products are refined that was originally extracted outside of the EU, increased to over 93% by 2012.

Figure 3-5: Gross EU-28 consumption and import dependency for petroleum products

The overall decline in demand for petroleum products hides different trends for different fuels. Over the last 20 years, there has been an increase in the use of diesel in the transport sector, although this has levelled off in recent years, along with a decline in the use of petrol, which has been evident since the late 1990s (see Figure 3-6).

Figure 3-6: Fuels consumption in the transport sector – 1990-2012 (ktoe)

Source: European Commission (2014d), based on figures from Eurostat

These different trends by fuel have had an impact on the extent to which the EU needs to import, or is able to export, petroleum products that are refined in the EU. Figure 3-7 demonstrates that the EU is becoming increasingly dependent on imports for diesel, i.e. it uses more diesel than is being refined in the EU and so needs to import the remainder (although recent trends are less clear), while the EU has a surplus of petrol (gasoline) that it can export.

Figure 3-7: Net imports of different petroleum products

Source: (European Commission, 2014c)

Figure 3-8 shows the EU’s trade flows in petrol and diesel for 2012, which demonstrates that the EU had to import over 26 million tonnes of diesel in 2012, including nearly 12 million tonnes from Russia, while it exported over 38 million tonnes of petrol.
This situation poses a challenge to the EU refining industry. There are limits to the degree to which processes in existing refineries can switch production from one type of fuel to another without consuming large additional amounts of energy to convert oil products (ITF, 2008). Hence, the response of a number of EU refining companies to the current market situation and future prospects has been to put refineries up for sale, halt operations and/or convert sites to terminals. Overall there has been a reduction in capacity of 1.8 million barrels/day in Europe since 2008, with more closures expected in the coming years (European Commission, 2014c).

In relation to other types of fuel and energy used by the transport sector, the main change in recent years has been a small increase in the use of biofuels for road transport (see Figure 3-9). Even though transport’s fuel use and GHG emissions have begun to decline, the sector is still a major consumer of energy. In 2012, transport consumed 32% of the EU’s final energy consumption, which was up from 28% in 1995, to make transport the largest final consumer of energy by sector (European Commission, 2014d).
3.4 Cross-cutting issues

Since the Regulations were published, a number of issues have emerged that have the potential to affect their effectiveness in relation to the delivery of actual, real-world CO₂ emissions. Furthermore, other issues have emerged that have implications for the design of the Regulations, particularly in relation to cost-effectiveness and technological neutrality. Some of these were already recognised, at least to some extent, when the Regulations were originally developed, but have become more of an issue as a result of subsequent developments and/or a better understanding of the relevant issues. Hence, these emerging issues are important in the context of the evaluation of the Regulations. These are introduced in the following sections and are discussed in more detail in the context of the appropriate evaluation questions.

3.4.1 Issues affecting the real-world CO₂ reductions of LDVs

As noted in Section 2.4, the Regulations focus on reducing the specific CO₂ emissions of vehicles, as measured on the NEDC test cycle, as this was considered to be a suitable proxy for real-world emissions. Reductions in emissions according to this measure will deliver emissions reductions in the real-world if:

- The CO₂ emissions per kilometre as measured on the test cycle are an accurate reflection of real-world emissions per kilometre;
- Any rebound effect, whereby more fuel efficient vehicles are used more intensively because average fuel costs per kilometre travelled have reduced, is less than 100% (i.e. the additional emissions associated with more intensive use do not outweigh the savings due to improved vehicle efficiency);
- Different types of vehicles are used in similar ways;
- The Regulations do not encourage the use of fuels and energy sources with higher indirect emissions compared to the fuels that they replace; and
- The Regulations do not encourage the use of vehicles with higher emissions associated with their production and disposal compared to the vehicles that they replace.
At least for cars, there is evidence that these conditions are not met in practice, i.e. in the real-world (discussed below). While the literature has paid less attention to LCVs, there are issues for these vehicles as well, or at least there is the potential for such issues to exist after 2020. More detail on each of these issues can be found in Annex A, while a summary is presented below.

First, there is evidence of an increasing divergence between real-world CO₂ emissions and those measured on the NEDC (see Figure 3-10). While the methods for collecting these data will differ, in all cases the discrepancy over time is increasing and the discrepancy appears to be increasing at similar rates (ICCT, 2014c). Similar discrepancies have been found by other authors, e.g. Fontaras and Dilara (2012) and Ntziachristos et al (2014).

Figure 3-10: Divergence between real-world fuel economy/CO₂ emissions and test-cycle fuel economy/CO₂ emissions for passenger cars

As a result, only a proportion of the emissions reductions that have been achieved on the test cycle may have been delivered in the real-world, meaning that vehicle drivers would not have received the anticipated benefit, e.g. as communicated on the label required under Directive 1999/94. This would also mean that the Regulations are not delivering the real-world reductions that they appear to be if the test cycle figures were accurate.

There are three main reasons for the discrepancies:

1. The NEDC test cycle is not representative of real-world driving;
2. Manufacturers are increasingly using flexibilities within the test cycle; and
3. The increased application and use of energy consuming devices to cars that are used in the real-world, but which are not operational when measuring emissions on the test cycle (ICCT, 2013a); (T&E, 2013d).
These issues have been recognised and some will be addressed through the development of a revised test procedure, which will be part of a new worldwide harmonised test protocol (WLTP).

Second, there are various 'rebound effects' that might occur as a result of the Regulations (see Annex A for a full explanation). The most obvious and direct of these effects is that more efficient vehicles may be driven further than the less efficient vehicles that they replace, as they are cheaper to use. This will have an adverse impact on real-world CO₂ emissions, as these will be greater than expected as a result. The existing literature does not suggest that the rebound effect is large enough to reverse energy efficiency gains (Gillingham et al, 2014); however, it does mean that the emissions savings associated with the Regulations would be lower than otherwise anticipated. The implications of these effects are explored further in Section 5.4 and in Annex A.

Third, there is increasing evidence to suggest that there is variation in the mileages that different vehicles travel. A report for the Commission showed that on average, diesel cars are driven nearly 50% further than petrol cars over their lifetime (Ricardo-AEA & TEPR, 2014). While there was no significant difference between the way in which different masses and sizes (measured in terms of their respective footprints) of diesel cars and LCVs are driven, larger and heavier petrol cars are driven further than smaller petrol cars over their lifetime (Ricardo-AEA & TEPR, 2014). Some, but not all, of these differences were taken into account in the development of the Regulations (e.g. different annual mileages were assumed for diesel and petrol vehicles). Mileage has not previously been assumed to vary with vehicle size and mass. This has a consequence for the cost-effectiveness of the Regulations (see Section 3.4.2).

Fourth, for vehicles using alternative powertrains, indirect, well-to-tank CO₂ emissions associated with the production of electricity (and hydrogen) are a significant proportion of total lifecycle emissions (Ricardo-AEA, 2013). This is important, as it suggests that some of the reductions that have been achieved according to the specific CO₂ emissions as measured on the test cycle will have been replaced by increased emissions elsewhere. For example, as measured on the test cycle, electric vehicles are considered to have zero CO₂ emissions, but this is misleading as their true 'in-use' emissions should also include the CO₂ emitted (at least in most cases) as part of the CO₂ production of the electricity. The existing literature suggests that these emissions do not fully negate the apparent reductions as measured on the test cycle (see for example, Ricardo-AEA, 2014) but it does mean that in the real-world CO₂ emissions will again not have been reduced to the extent implied by the figures reported in the context of the Regulations (see also Section 5.4.1 for a more detailed analysis of this topic).

Finally, embedded CO₂ emissions associated with electric vehicles are typically higher than the equivalent ICE emissions, largely as a result of emissions associated with the production of the battery (Ricardo-AEA, 2014). Again, these emissions are not taken account of in the Regulations as they currently stand, and so some (but by no means all) of the apparent CO₂ reductions that have been achieved will have been offset by increases in production emissions. Additionally, the use of a wider range of materials in vehicles, e.g. to make them lighter, will have knock-on effects on embedded emissions. Some alternative materials, such as aluminium, are more GHG-intensive to produce than steel, although lighter vehicles will require less energy (Ricardo-AEA, 2014). These issues all have implications for the evaluation of the effectiveness of the Regulations and so will be discussed further in Section 5.4.

3.4.2 Issues relating to the design of the Regulations
The various modalities of the Regulation were introduced in Section 2.4. Since agreement was reached on the original Regulations, various issues have come to
prominence with respect to the way in which the modalities operate, in particular whether the Regulations are as cost-effective as they might be and whether they breach the principle of technological neutrality.

‘Cost-effectiveness’ was one of the main principles that guided the development of the Regulations and responded inter alia to calls from different configurations of the Council of Ministers that the regulatory framework to reduce CO₂ emissions from cars should be cost-effective (European Commission, 2007d). The issue of technological neutrality has been increasingly recognised as being important in the context of the LDV CO₂ Regulations. In the Impact Assessments that accompanied the original Regulations, there was no mention of the need to ensure technological neutrality. However, in the Impact Assessment accompanying the proposal to confirm the 2020 targets, ‘technological neutrality’ was one of the criteria that was used to assess whether options for changing modalities should be considered in the context of achieving the 2020 targets (European Commission, 2012a). A summary of the relevant emerging issues is presented below, while more detail can be found in Annex C.

In relation to the design of the Regulations, the choice of utility parameter for the passenger car CO₂ Regulation has been the subject of much debate (e.g. ICCT, 2011). In the original impact assessment, ‘mass’ (defined as the mass in running order and measured in kg) and ‘footprint’ (defined as ‘wheelbase’ multiplied by ‘track width’ and is measured in m²) were the two alternative utility parameters that were considered for use in the passenger car CO₂ Regulation. Two of the original arguments in favour of the use of ‘mass’ over ‘footprint’ – that there was a lack of data to enable the calculation of ‘footprint’ and that using ‘footprint’ would not be compatible with utility parameters used in other countries around the world – are no longer valid. Furthermore, the use of footprint should theoretically and mathematically be more cost-effective for manufacturers (and therefore efficient) and be more in line with the principle of technological neutrality than ‘mass’. In engagement with industry, Ricardo-AEA et al (2015) found that many manufacturers argue that this is not the case in practice, so prefer to retain ‘mass’ as the utility parameter.

As discussed in Section 3.4.1, there is evidence suggesting that different types of vehicles travel different distances to those assumed in the Regulations. If these differences were taken account of in the passenger car CO₂ Regulation, the fleet-wide cost of achieving the same CO₂ reduction could be reduced, and so improve the cost-effectiveness and efficiency of that Regulation (Ricardo-AEA & TEPR, 2014; see Section 9.2 in Annex C). Finally, there are incentives in the Regulations for the introduction of vehicles with alternative powertrains, e.g. battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs), that means that these vehicles are incentivised more by the Regulations than would be justified on the basis of their WTW CO₂ emissions. This is due to the fact that BEVs and FCEVs have zero CO₂ emissions as measured on the test cycle and can also benefit from super-credits (see Section 2.4). The extent to which these issues are important in the context of the Regulations is addressed in Section 5.7.

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12 The relevant data to calculate ‘footprint’ are now collated as part of the monitoring requirements of both LDV CO₂ Regulations, while in the US, Canada and Mexico, ‘footprint’ is used as a utility parameter in LDV fuel efficiency legislation.
4 Research methodology

The objectives of the study and the methodological framework used to evaluate the Regulations are presented in this chapter.

4.1 Evaluation questions

The primary objective of this study has been to conduct a formal evaluation of the passenger car CO\textsubscript{2} Regulation and the light commercial vehicle (LCV) CO\textsubscript{2} Regulation. Bearing this in mind, the priorities of the study have been used to formulate a list of evaluation questions, covering the whole range of evaluation topics. These questions have been put within a conventional and well established evaluation framework that is used in standard Commission evaluation methodology.

The questions relate to the following issues of interest:

- **Relevance**: To what extent do the objectives of the Regulations still respond to the needs?

- **Effectiveness**:
  - To what degree have the Regulations contributed to achieving their targets and what are their weaknesses?
  - To what extent have the Regulations been more successful in achieving their objectives compared to the voluntary agreement on car CO\textsubscript{2} emissions?
  - How do the effects of the Regulations correspond to the objectives?

- **Efficiency**:
  - Are the costs resulting from the implementation of the Regulations proportional to the results that have been achieved?
  - What are the major sources of inefficiencies? What steps could be taken to improve the efficiency of the Regulations? Are there missing tools and/or actions to implement the Regulations more efficiently?

- **Coherence**:
  - How coherent are the Regulations' modalities with their objectives?
  - How well do the Regulations fit with other EU policy objectives?

- **EU added value**:
  - What is the EU added value of the Regulations? To what extent could the changes brought by the Regulations have been achieved by national or individuals' measures only?
  - Are there other technological, economic or administrative issues that are not covered by the existing Regulations and that could be introduced in view of their potential added value?
4.2 Methods and process used

4.2.1 Data collection

The first stage of the evaluation was to collect data, which comprised desk research, analysis of official data sources and stakeholder engagement through interviews and online surveys.

The literature review covered various relevant reports, policy documents, academic and scientific articles, databases, as well as EC consultations and own work performed previously by the evaluation study team. There is a very wide range of literature relating to the impacts of the car and LCV CO₂ Regulations, which provide detailed information on the performance of different aspects of the Regulations. Hence this evaluation was able to draw on numerous existing studies. In particular, the literature review included:

- Previous assessments of the proposals for the car and LCV CO₂ Regulations, including the impact assessments underlying the Regulations and other supporting studies;
- Studies and databases that covered issues relevant to assessing the relevance, effectiveness, efficiency and coherence of the Regulations;
- Studies providing data on the development of the automotive market, economic indicators and other data required for constructing the baseline and calculating the impact of the Regulations.

The sources were primarily selected by the study team, and supplemented by suggestions from stakeholders. Over 230 pieces of literature were used - all of the literature is referenced throughout the report, as well as in Annex J. Conclusions emerging from the desk research were supplemented by the information collected through other means.

Official data sources included the monitoring data in accordance Article 8 of each of the LDV CO₂ Regulations and further specified in Commission Regulations (European Commission, 2010b; European Commission 2012e). The most recent year for which full data were available is 2013.

- The Commission’s Decision 1753/2000 Monitoring of CO₂ emissions database from 2000-2009 provides CO₂ performance and registrations data by average mass and mass distribution in form of bins for each country by manufacturer and fuel type. The number of Member States included varies from 14 in 2001\(^{13}\) to 27 since 2007.
- Regulation No 443/2009 requires Member States to record and publish information about new passenger cars registered in Europe. The EEA makes this data available as an EU-wide database each year, providing emissions of CO₂ of each model registered along with other details: manufacturer name, type, variant, version, make, mass of the vehicle, wheel base, track width, fuel type and fuel mode, engine power and engine capacity.
- Regulation 510/2011 requires Member States to report their annual LCV registration data for the purpose of monitoring CO₂ emissions, starting from 2012. As for Regulation No 443/2009 (car registrations), several parameters are included for each model registered: manufacturer name, type, variant, version, make, mass of the vehicle, wheel base, track width, fuel type and fuel mode, engine power and engine capacity.

Since official monitoring under the passenger car CO₂ Regulation only began in 2010 and monitoring under the LCV CO₂ Regulation started two years later, a limited amount

\(^{13}\) EU15 as before the 1\(^{st}\) May 2004 expansion, excluding Portugal.
of monitoring data has been produced under the Regulations so far. For cars, a longer dataset exists that includes data collected under Decision 1753/2000. Hence, the available data for cars provides a useful basis for quantitative analysis. For LCVs, there is limited data on fleet characteristics before 2012, and the available figures are based on estimates. The stakeholder engagement activities are summarised in Table 4-1. The survey responses were complemented by telephone interviews to improve response rates and to enrich questionnaire responses. Response and completion rates were closely monitored. Missing responses were followed up by email and telephone after a suitable period of time had elapsed. Responses that were unclear were followed up and clarified by email or telephone.

**Table 4-1: Summary of stakeholder engagement**

<table>
<thead>
<tr>
<th>Type of stakeholder</th>
<th>Approached</th>
<th>Responded</th>
<th>% response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interviews</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commission officials</td>
<td>2</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>Industry associations</td>
<td>8</td>
<td>6</td>
<td>75%</td>
</tr>
<tr>
<td>Manufacturers / suppliers</td>
<td>9</td>
<td>7</td>
<td>78%</td>
</tr>
<tr>
<td>Vehicle user/consumer groups (including safety, business workers)</td>
<td>5</td>
<td>2</td>
<td>40%</td>
</tr>
<tr>
<td>NGOs/research</td>
<td>5</td>
<td>4</td>
<td>80%</td>
</tr>
<tr>
<td>Other (safety, business, workers)</td>
<td>5</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td><strong>TOTAL (interviews)</strong></td>
<td><strong>34</strong></td>
<td><strong>21</strong></td>
<td><strong>62%</strong></td>
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<table>
<thead>
<tr>
<th>Surveys</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Industry associations</td>
<td>25</td>
<td>3</td>
<td>12%</td>
</tr>
<tr>
<td>Manufacturers / suppliers</td>
<td>8</td>
<td>5</td>
<td>63%</td>
</tr>
<tr>
<td>Public authority/administration</td>
<td>28</td>
<td>14 (12)*</td>
<td>50% (43%)</td>
</tr>
<tr>
<td>Vehicle users / consumer groups</td>
<td>2</td>
<td>1</td>
<td>50%</td>
</tr>
<tr>
<td>NGOs</td>
<td>22</td>
<td>6</td>
<td>27%</td>
</tr>
<tr>
<td>Fuels/energy</td>
<td>7</td>
<td>5</td>
<td>71%</td>
</tr>
<tr>
<td>Non-EU international governments</td>
<td>5</td>
<td>3</td>
<td>60%</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td><strong>TOTAL (surveys)</strong></td>
<td><strong>99</strong></td>
<td><strong>39</strong></td>
<td><strong>39%</strong></td>
</tr>
</tbody>
</table>

Notes: *Although there were 14 completed responses for Member States, in two countries a couple of ministry departments completed the survey. Therefore only 12 Member States are represented in the responses.

Two survey questionnaires were developed and used for the consultation process; the main questionnaire focused on the EU car and LCV CO₂ Regulations and was used to gather information from all actors apart from international (non-EU) government organisations. A separate questionnaire was developed for international government organisations that focused on gathering information on legislation measures introduced in their respective countries for regulating CO₂ emissions and/or the fuel economy of light duty vehicles. This second questionnaire was sent to the relevant government representatives in the USA, Canada, Mexico, South Korea and Switzerland, but responses were only received from the last three countries from this list.

The main questionnaire includes a range of open and closed questions on the following themes:

- The relevance of the Regulations, considered today and in 2030.
• The effectiveness of the Regulations, considering their impacts on CO\textsubscript{2} emissions both during the test cycle and in real world conditions. Questions on effectiveness also covered the other objectives of the Regulations relating to improving the competitiveness of the European automotive sector, ensuring a high level of environmental protection and ensuring socially equitable targets.

• Seeking opinions and suggestions on how the effectiveness and efficiency of the Regulations could be improved.

• Identifying and providing data on cost factors such as costs to industry, public authorities or consumers.

• Identifying aspects within and between the Regulations that are not considered coherent and seeking suggestions on how this could be improved.

Further details and a summary of stakeholder responses are provided in Annex I.

The split in terms of industry and non-industry respondents, was 39% for industry respondents (vehicle manufacturers, suppliers, vehicle manufacturer/supplier associations etc.), and 61% for non-industry respondents.

Of the stakeholders that declined to participate in the study, the reasons given were typically that they lacked sufficient knowledge; they felt the Regulations were not relevant to them; that their views were already represented by their relevant associations or that they had been too involved in the development of the Regulations to be able to comment.

The preliminary results of the evaluation study, as well as a link to the online survey were presented by the study team at stakeholder conferences hosted by DG CLIMA in Brussels in May 2014 and December 2014, and the presentation slides were made available on the Commission’s website\textsuperscript{14}.

4.2.2 Comparative analysis against a baseline for assessing effectiveness and efficiency

An important aspect of any evaluation is to compare the actual outcomes of the intervention with what would have happened in the absence of the intervention. To carry out analysis of this nature, a baseline counterfactual scenario is required. The baseline represents the starting point for analysis of ex-post impacts, and can be used for quantifying the effects of the intervention on costs and other key outcome indicators. It is important to stress that the presence of differences between the baseline scenario and the actual outcomes, do not, on their own, indicate direct causal relationships between the intervention and the actual outcomes.

In the context of this study, two baselines are required: one for evaluating the passenger car CO\textsubscript{2} Regulation and one for the LCV CO\textsubscript{2} Regulation. Graphical representations of the baseline scenarios for passenger cars and LCVs compared to actual outcomes are presented in the figures below.

For passenger cars (see Figure 3-1), the baseline scenario takes as its starting point the actual CO\textsubscript{2} emissions achieved in 2006 and assumes that in the absence of the Regulation there would have been annual improvements of 0.5 gCO\textsubscript{2}/km per year until 2013. Historical evidence indicates that in the absence of regulatory measures, vehicle fuel economy remains static or can worsen (National Research Council of the National Academies, 2014; Sorenson, et al., 2011). In the case of passenger cars in the EU, the existence of the ACEA voluntary agreement on car CO\textsubscript{2} emissions immediately prior to the introduction of the Regulation complicates matters. For the purposes of this evaluation, we have assumed that investments made by manufacturers in CO\textsubscript{2} emissions would have continued as under the voluntary agreement.

\textsuperscript{14} http://ec.europa.eu/clima/events/articles/0089_en.htm
abatement technologies for meeting the voluntary agreement targets continued to have some limited impacts in the years up to 2013.

**Figure 4-1: Baseline counterfactual scenario for passenger cars**

The baseline counterfactual scenario used in this evaluation is not the same as the one used in the original Impact Assessment. This is because (a) the original Impact Assessment was based on assessing the impacts of achieving the 130 gCO₂/km target by 2012 and (b) because the Impact Assessment assumed that car manufacturers would achieve the ACEA voluntary agreement target of 140 gCO₂/km by 2008 and that there would be no change in fleet-average emissions between 2008 and 2012. In practice, the Regulation required full achievement of the target by 2015, and the voluntary agreement target was not achieved in 2008, but it is likely that it will have continued to have had impacts on fleet-average emissions beyond 2008.

For LCVs (see Figure 3-2), there was no voluntary agreement in place prior to the introduction of the Regulation and hence it has been assumed for the baseline scenario that fleet-average emissions remained static from 2009 (the year the Regulation was announced) onwards. Again, the baseline scenario used for LCVs is different to that used in the original Impact Assessment; in this case, the use of a different baseline is due to the fact that data on the pre-Regulation emissions performance of LCVs has improved over the last few years.

Prior to 2009, the quality and availability of data on CO₂ emissions from LCVs was poor; unlike for cars, at the time there was no requirement to gather and publish data on the CO₂ emissions performance of LCVs. The only data available is an estimate for new LCVs registered in 2007 of 203 gCO₂/km. No data are available for 2008 and better quality estimates are available for 2009, 2010 and 2011. The available data appear to indicate that even before the Regulations were announced, LCV emissions declined from 203 gCO₂/km in 2007 to 185 gCO₂/km in 2009 (9% reduction). Whilst it is possible that a reduction of this level actually occurred, it is likely that improvements in the robustness and availability of data on LCV CO₂ emissions performance account for much of the apparent improvement. The 2007 figure of 203 gCO₂/km is important as it was used to underpin much of the analysis of the costs and benefits of setting a regulatory target of 175 gCO₂/km undertaken as part of the original Impact Assessment. If average LCV emissions performance in 2009 was actually 185 gCO₂/km, then it is likely
that the Impact Assessment overestimated the amount of effort required to achieve the 175 gCO₂/km target. Other factors that could have contributed to any reduction in emissions prior to 2009 include shifts in the sales of LCVs across different size segments as well as spillover effects for car-derived vans from the voluntary agreement on car CO₂ emissions and the announcement of the passenger car CO2 Regulation in 2007.

Figure 4-2: Baseline counterfactual scenario for LCVs

A more comprehensive discussion of the baselines developed for this evaluation is presented in Annex B.

The baseline development was used as a starting point for assessing key indicators of the success of the Regulations, once compared with the actual outcomes. The main variables for measuring the impacts of the Regulations in terms of achieving their long term objectives were:

- Total (well-to-wheels) CO₂ emission reductions: from the sale of new cars and LCVs over the period since the introduction of the Regulations;
- Total fuel (and oil-equivalent) consumption reductions: due to improved fuel efficiency. This is relevant for assessing the impacts on energy security, in line with the general objectives of the Regulations;
- Fuel expenditure savings: relevant for assessing the social impacts of the Regulations;
- Cost effectiveness in terms of abatement costs per tonne of CO₂ emissions avoided;
- Manufacturer costs: ex-post cost estimates of the additional manufacturing costs required to reduce CO₂ emissions from new cars and LCVs.

4.2.3 Regression analysis / empirical research

The quantitative analysis conducted using the baseline/counterfactual was supplemented by further quantitative analysis using an empirical approach. Data from the EEA monitoring database has been analysed using a regression model that attempts to quantify the impact of the Regulation while controlling for other factors that may have an impact on new car emissions. Regression analysis is a statistical technique that
provides a measure of the relationship among variables. Specifically, it aims to quantify how a dependent variable changes when one of the independent variables (i.e. explanatory variable) is varied while the other independent variables are held fixed.

Full details of the methodology and underlying model for the empirical research are provided in Annex E.

### 4.3 Research limitations

There are a number of limitations that restrict the extent to which the evaluation of the car and LCV CO₂ Regulations can be fully comprehensive. Of particular importance is the timing of the evaluation. The car CO₂ Regulation was introduced in 2009 and the LCV CO₂ Regulation was introduced in 2011. Whilst in both cases, their initial emissions reductions targets for 2015 (cars) and 2017 (LCVs) have already been met (early, in both cases), the amount of data available on actual outcomes is limited. For example, in the case of LCVs, there are only two years of official monitoring data available (i.e. for 2012 and 2013) and this makes a full assessment of effectiveness and efficiency more complex. As discussed in Section 4.2.2, robust data on LCV CO₂ emissions prior to 2012 is not readily available; however, the study team supplemented the available data with estimates available from the literature for the years 2007, 2009 and 2010. Although in each case there are issues with how comprehensive the data for these earlier years are, the data used represented the best available estimates and could be considered to be sufficiently representative for the purposes of ascertaining trends. For assessing costs, emissions benefits and cost effectiveness it is necessary to construct a baseline scenario (see Section 4.2.2 and Annex B). The baseline scenario should reflect a counterfactual, business-as-usual situation. The situation is made more complex by the fact that for passenger cars, a voluntary agreement on reducing CO₂ emissions was in place immediately prior to the introduction of the car CO₂ Regulation. The voluntary agreement led to reductions in passenger car CO₂ emissions between 1998 and 2007, but it is not clear whether reductions would have continued beyond this time in the absence of a Regulation, and if so, what level of annual emissions reduction would have been achieved between 2007 and 2013. For LCVs, there is simply a lack of good quality data on emissions performance prior to 2012 and consequently, there are limitations on how robust the baseline scenario can ever be.

For the empirical research, based on regression analysis of the official monitoring data, there are several limitations that should be borne in mind. Regression analysis is a statistical technique that provides a measure of the relationship among variables. Specifically, it aims to quantify how a dependent variable changes when one of the independent variables (i.e. explanatory variable) is varied while the other independent variables are held fixed. Ideally, data would be available to allow comparisons of observations with and without treatment. This would allow the use of “difference in difference” estimation, which attempts to mimic an experimental setting by estimating the difference in the differences between treatment groups and non-treatment groups over time. In this case there is no control group because the Regulation was implemented in all Member States and therefore the analysis needs to rely on the variation in the data before and after the Regulation. As a result, the selection of appropriate control variables is important, and great care was taken when specifying the model (see Annex E for further details). Secondly, it is not possible to include year fixed effects because the treatment (i.e. Regulation) is determined in time. Inclusion of year fixed effects would not allow the estimation of the effects of all fixed effects as well as the Regulation. Instead, a time trend was introduced to control for changes in CO₂ emissions in time not explained by the control variables, i.e. autonomous improvement. Thirdly, omitted variables that are correlated both with the Regulation and the CO₂ emissions can introduce bias to the estimated effect of the Regulation. For example,
consumers’ environmental preferences and technological development are potentially omitted variables. The trend variable likely captures the technological development to an extent, although it is not a perfect proxy. Due to these limitations, the results of the regression analysis was cross-checked with other literature sources, in order to determine whether the findings were in line with other analysis.

For both Regulations, the ex-ante Impact Assessments carried out before the Regulations were introduced focused on assessing costs and benefits out to 2020, or even 2030 in the case of the LCV CO\textsubscript{2} Regulation. It is clearly not possible to carry out a full ex-post evaluation of effectiveness and efficiency for these time periods in this study, and hence the focus has to be on evaluating the impacts on the basis of what has actually happened to date. With this in mind, the evaluation has focused on the costs and benefits associated with new vehicles registered in the EU market since each of the Regulations was announced. This has taken into account the future fuel costs and emissions benefits associated with these vehicles, as once such vehicles have entered the EU’s vehicle parc, there is good knowledge on how they are likely to be used (i.e. how annual mileage changes over a vehicle’s life) and at what age they will leave the vehicle parc (i.e. due to being scrapped at the end of their useful lives). A limitation with this analysis is that estimates of future fuel prices have to be used when quantifying lifetime fuel expenditure impacts, and there is significant uncertainty when attempting to forecast fuel prices over such long period.

A further complication is that the monitoring data on car and LCV CO\textsubscript{2} emissions performance is based on the average tailpipe emissions performance of vehicles, as measured on the New European Driving Cycle (NEDC). It is widely recognised that NEDC emissions measurements are not representative of real-world performance, and in the coming years the NEDC test will be replaced (see Annex A for further discussion on the reasons why the NEDC is not representative of real-world conditions). In order to quantify the achieved emissions benefits associated with the Regulations, it is necessary to account for the real-world emissions performance of vehicles. For passenger cars, research has been carried out on the topic by the European Commission’s Joint Research Centre (EEA, 2014) and by the International Council on Clean Transportation (ICCT, 2014e). Both of these methodologies have been reviewed during this evaluation and both have strengths and weaknesses. The ICCT study identified an increasing level of divergence between test-cycle and real-world emissions performance for newer vehicles, and hence real-world uplift factors from that work have been used in this study to quantify real-world emissions performance. Whilst analysis of the divergence between real-world test-cycle emissions has been investigated in other studies for passenger cars, there is a lack of data on this topic for LCVs. Given that the emissions performance of LCVs is also certified using the NEDC, it is likely that test performance will not be representative of real-world performance. For the purposes of this evaluation, the same uplift factors to account for real-world emissions performance have been applied to both car and LCV CO\textsubscript{2} emissions, based on ICCT’s work in this area (see Annex B for further details).

Another limitation of this research is the issue of causality. The monitoring data on improvements in car and LCV CO\textsubscript{2} emissions do not only reflect the effects of the Regulations on emissions performance. There are many other factors that have also affected vehicle emissions performance including national policies and incentive schemes (e.g. CO\textsubscript{2}-based taxation measures and grants for ultra-low emission vehicles, etc) and other EU-level legislation (e.g. demand-side measures such as the Clean Vehicle Directive and the Passenger Car CO\textsubscript{2} Labelling Directive) that will all have contributed to improvements in the observed CO\textsubscript{2} emissions performance of new cars and LCVs. Furthermore, for passenger cars, the existence of the voluntary agreement on CO\textsubscript{2} emissions immediately before the introduction of the car CO\textsubscript{2} Regulation will also have had some level of influence on the outturn emissions performance, at least in the
first years after the Regulation was announced and implemented. The issues around causality are very common problems when dealing with ex-post evaluations of this nature, and this has been addressed as far as is possible through qualitative research carried out in the stakeholder engagement programme and through regression analysis to try to separate out the level of contributions to emissions reductions from the various influencing factors. It was not possible to carry out regression analysis of this nature for LCVs because of the limited availability of data. Finally, the impacts of the economic crisis of 2008/2009 were widely felt throughout the automotive sector and had many impacts that are still working through the system today. In some cases it is difficult to determine the extent to which the observed outcomes are due to short-term fluctuations caused by the recession versus longer term trends.

Another important factor is that the Regulations are likely to have had impacts on the market even before they came into force. Some manufacturers are likely to have responded quickly and placed low-CO₂ vehicles on the market in advance of the Regulations coming into force, whilst others are likely to have reacted more slowly. The issue of anticipatory effects is a common problem when evaluating legislative measures that set performance standards. In order to deal with this issue, the baseline scenario extends back to before the point at which the Regulations were announced to the market. In the case of passenger cars, the evaluation has also investigated the rate of change in vehicle emissions performance before the Regulation was announced, after it was announced and after it came into force.
5 Analysis of the evaluation questions

This section sets out in turn, analysis for each of the evaluation questions presented under the general evaluation headings of relevance, effectiveness, efficiency, coherence and EU-added value.

5.1 Relevance: To what extent do the objectives of the Regulations still respond to the needs?

The evaluation of the ‘relevance’ of the Regulations aims to identify the extent to which the objectives of the intervention are pertinent to the needs, problems and issues that needed to be addressed (European Commission, 2004). As was noted in Section 2.3, the original Commission proposals and their associated Impact Assessments defined the rationale for the Regulations consisting of four ‘needs’ (European Commission, 2007d); (European Commission, 2009b). These needs are repeated in the first column of Table 5-1, which also maps these needs to the objectives of the Regulations that were developed in the respective Impact Assessments (as introduced in Table 2-1).

Table 5-1: Mapping the needs to the objectives of the LDV CO₂ Regulations

<table>
<thead>
<tr>
<th>Need</th>
<th>General policy objective</th>
<th>Specific objective</th>
<th>Operational objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sectors must contribute to the fight against climate change</td>
<td>Providing for a high level of environmental protection in the European Union and contributing to reaching the EU’s Kyoto/ climate change targets</td>
<td>Reduce the climate change impacts and improve the fuel efficiency of LDVs in line with the revised 2007 strategy</td>
<td>Designing a legislative framework that will be compatible with the EU’s climate change targets</td>
</tr>
<tr>
<td>The CO₂ performance of new vehicles should improve at a faster rate</td>
<td>Improving the security of energy supply in the EU</td>
<td>Ensure continued and effective application of the Regulations in the context of the 2020 targets</td>
<td>Designing a legislative framework to meet the specified targets for reducing CO₂ emissions from LDVs; the 2020 modalities should ensure that the 2020 targets are feasible and can be achieved cost-effectively</td>
</tr>
<tr>
<td>Road transport needs to use less oil</td>
<td>Improving the competitiveness of the European automotive industry and stimulating innovation</td>
<td>Designing a legislative framework that is competitively neutral, socially equitable, has sustainable reduction targets that are equitable to the diversity of the European automobile manufacturers and which avoids unjustified distortion of competition between automobile manufacturers. Additionally, it should avoid any regulatory gaps between the two Regulations and the two Regulations should be compatible for reasons of simplification. The 2020 modalities should create sufficient certainty for the automotive sector and minimise administrative costs for SMEs.</td>
<td></td>
</tr>
</tbody>
</table>

15 The original Impact Assessments both referred to the ‘car industry’s competitiveness’ (including that accompanying the proposal for the LCV CO₂ Regulation). The Impact Assessment to confirm
Notes: Some of the objectives are summarised.  
Source: mapping based on (European Commission, 2007d); (European Commission, 2009b)

In addition to assessing whether the objectives of the Regulations are still pertinent to these needs, the evaluation of ‘relevance’ also assesses whether the previously-identified needs are likely to change beyond 2020 to 2030 and what the implications of this might be for the continuing pertinence of the objectives. In this respect, an additional element of the evaluation can be defined:

- Implications for the pertinence of the objectives post 2020 as a result of any evolution in the needs described above.

Each of the following sections:

- Evaluates the extent to which the identified needs remain valid with references to the literature and the views of stakeholders; and
- Evaluates the extent to which the objectives remain pertinent to the needs to 2020 and beyond.

5.1.1 All sectors must contribute to the fight against climate change

There are two elements to analyse to be able to conclude that all sectors must contribute to the fight against climate change, i.e. whether:

- There is a continuing need to tackle climate change; and
- The CO₂ emissions from cars and LCVs are a significant problem in the context of total EU CO₂ emissions.

In 2013, reports from the IPCC and UNEP underlined that there is a continuing need to tackle climate change. Contributions to the IPCC’s fifth assessment report (AR5 – which draws together all of the climate research to date) concluded that the “warming of the climate is unequivocal” and that the concentrations of GHGs seen in the atmosphere “have all increased since 1750 due to human activity”. Hence, in order to limit the impact of climate change, there was a need for “substantial and sustained reductions of greenhouse gas emissions” (IPCC, 2013). UNEP (2013) concluded that the levels of GHG emissions are “considerably higher” than the levels needed in 2020 if the world is to limit warming to below the 2°C target, and GHG emissions are still increasing.

The EU has committed itself to substantial, long-term CO₂ reductions in order to address climate change. In February 2011, the European Council reconfirmed the EU objective of reducing economy-wide GHG emissions by between 80% and 95% by 2050 compared to 1990 levels in order that the EU contributes appropriately to meeting the 2°C target. In order to provide an appropriate framework for delivering this target, the Commission published its Low Carbon Roadmap (European Commission, 2011b), which explored cost-effective reduction GHG scenarios.

At both the global and EU levels, it has been recognised that there is a need for the GHG emissions from transport generally, and from LDVs in particular, to continue to decline. IPCC (2014) argues that without “aggressive and sustained” mitigation policies, GHG emissions from transport globally will continue to increase. Amongst a range of potential GHG reduction options that are discussed in the report, the uptake of technologies to improve the performance of engines and vehicles is considered to have a high mitigation potential. The report notes that inter alia vehicle efficiency and emission standards will be needed to deliver this potential and that in order to significantly reduce GHG emissions from transport generally, and appropriately, to the automotive industry. Hence, we use this terminology here.
emissions, and counter the rapidly growing demand for vehicles globally, more stringent policies will be needed.

The EU’s Low Carbon Roadmap concluded that the EU’s transport GHG emissions in 2050 would have to be between 54% and 67% lower than 1990 (European Commission, 2011b). The Commission’s most recent Transport White Paper, which was published shortly after the Roadmap, took the midpoint of this range, i.e. 60%, as the assumed target that was needed for the transport sector in 2050, which meant that transport’s emissions had to be 20% below their 2008 level by 2030 (which would still be 8% above 1990 levels; European Commission, 2011c).

In the Impact Assessment supporting the Transport White Paper, the preferred option provides a balance between improving the efficiency of vehicles and managing mobility. Under this scenario, the average CO₂ emissions from new cars would need to be 20 gCO₂/km by 2050, while average LCV emissions would be 55 gCO₂/km (European Commission, 2011d). This compares to figures in 2013 of 126.7 gCO₂/km for cars and 173.3 gCO₂/km for LCVs (EEA, 2014; also see Section 3.2) and the targets of 95 gCO₂/km for cars for 2021 and of 147 gCO₂/km for LCVs by 2020. Hence, CO₂ emissions from both cars and LCVs would need to decrease significantly in order to contribute to the economy-wide GHG reductions that are needed according to the White Paper.

As can be seen in Annex I, stakeholders were broadly in agreement that there is, and will continue to be, a need to tackle climate change, while the majority also agreed that emissions from cars and LCVs are, and will remain, significant and so they must be reduced to meet the EU’s long-term climate goals.

In summary, according to authoritative organisations such as the IPCC and UNEP, climate change is still, and is likely to remain, a significant problem. EU leaders have confirmed their long-term commitment that the EU’s GHG emissions should be reduced by between 80% and 95% by 2050 compared to 1990 levels, while Commission analysis has demonstrated that transport will have to contribute to these reductions in the order of a 60% reduction in the same timescales. Furthermore, these reports explicitly or implicitly assume that, in order for the necessary reductions to be achieved, there will need to be significant improvements in the CO₂ emissions performance of LDVs. Hence, it can be concluded that the need - that all sectors must contribute to the fight against climate change – still exists and will continue to exist beyond 2020. Consequently, the objectives of the Regulations, i.e. that they contribute to meeting the EU’s climate change targets (see Table 5-1), are still pertinent to the need that all sectors must contribute to the fight against climate change.

5.1.2 The CO₂ performance of new vehicles should improve at a faster rate

There are a number of elements that need to be considered to determine whether it was, and will continue to be, appropriate for the CO₂ performance of new vehicles to improve at a faster rate, including:

- The rates of CO₂ reductions needed from cars and LCVs to reach long-term climate objectives; and
- Recent or anticipated increases in demand for transport or changes to vehicle size that would undermine improvements in vehicle technology without further Regulations to improve CO₂ tailpipe emissions.

Even if the average new car and LCV CO₂ emissions for 2050 implied by the preferred option of the Commission’s Transport White Paper (see Section □) are only indicative, they still suggest that higher rates of CO₂ reduction will be needed from the new car and new LCV fleets than will have been achieved by 2021. Assuming that the respective targets for 2020 and 2021 will be met, the average annual rate of reduction that will
have been achieved will be 3.5% for cars and 2.1% for LCVs, whereas achieving the numbers underlying the White Paper’s preferred option would require subsequent annual reductions of 5.2% and 3.2%, respectively.

Evidence from a report undertaken for the Commission demonstrates that unless additional action is taken to reduce CO₂ emissions from cars and LCVs, emissions from other transport modes would have to be virtually zero by 2050 if transport is to deliver the emissions reductions assumed in the Transport White Paper (AEA et al., 2012). Since this would be challenging for other modes, as well as not constituting a fair distribution of effort between modes, cars and LCVs will have to contribute their fair share to the necessary emissions reductions. Additionally, it was demonstrated that if all of the other main policy options for reducing CO₂ emissions for cars and LCVs were introduced, e.g. driver training, lower speed limits, modal shift, efficiency improvements in other modes and more tax harmonisation, the rates of decrease of emissions reductions from cars would still need to be 2.3% a year. This assumes that all of these other measures deliver to their maximum potential, which would lead to a significantly lower demand for transport and be particularly challenging for these other policy measures (AEA et al., 2012; see Annex D for more detail). Hence, annual rates of emissions reductions for new LCVs of more than 2.3%, and perhaps as much as 4% on average, are likely to be needed, which is a steeper rate than the current Regulations would deliver if they meet their 2020/2021 targets (see above).

Other reports have also highlighted the importance of introducing continually more stringent vehicle efficiency standards in order to meet long-term CO₂ reduction targets (CEPS, 2013); (ICCT, 2012a); (IEA, 2012). An analysis by engineers at Ford concluded that the EU targets for 2020 were consistent with the reduction trends needed to stabilise atmospheric concentrations of GHGs at 450ppm. This analysis foresaw further reductions between 2020 and 2050, similar to those mentioned above (Winkler et al., 2014).

The importance of legislative targets can also be demonstrated by experience from the US. The introduction of the US Corporate Average Fuel Economy (CAFE) standards for 1978 resulted in a significant improvement in car fuel economy until 1985, after which the standards were not strengthened for 15 years, during which fuel economy worsened, only to improve significantly once more when standards were strengthened (National Research Council of the National Academies, 2014; see Annex D).

The CO₂ performance of cars and LCVs is strongly correlated with the mass of the vehicle, so changes in mass will impact on CO₂ emissions. The average mass and size (e.g. as measured by a vehicle’s footprint; see Section 3.4.2) of new cars and LCVs is increasing. The EEA’s official monitoring data show that since 2004, the average mass of new cars in the EU has increased by 3.2% to 1,390kg in 2013, although there was a 1% decline in 2013 compared to 2012 (EEA, 2014). The decline in 2013 might suggest that manufacturers’ weight reduction strategies that were identified in Ricardo-AEA et al. (2015) are beginning to have an effect. The average new car footprint increased from 3.9m² to 4.0m² between 2008 and 2012. Between 2009 and 2012, the average mass of new LCVs in the EU increased by 8.8% to 1,751kg, while their average footprint is now 5.1 m², up from 4.8 m² (ICCT, 2013b).

Since the Regulations are currently related to a vehicle’s mass, the increasing trends with respect to mass would lead to increasing CO₂ emissions in the fleet. The impact of increasing mass will be addressed by the ‘M₀ adjustment’, which aims to take account of such a scenario, i.e. where the average mass of new vehicles is increasing (see Section 2.4). Hence, the trend towards increasing mass will be counteracted by a mechanism within the Regulation.

As noted in Figure 3-4, car use appears to be declining, which could suggest that CO₂ might be sufficiently reduced as a result of lower levels of use. These trends were taken
into account in the production of Figure 10-2 in Annex D, which demonstrates that further reductions in \(\text{CO}_2\) emissions from cars and LCVs are needed and that these need to be steeper beyond 2020 than the rates that will be achieved if the 2020/2021 targets are met. Hence, recent trends towards lower vehicle use are not sufficient to reduce \(\text{CO}_2\) emissions to the levels needed.

Stakeholders also recognised the importance of the Regulations in delivering \(\text{CO}_2\) reductions from cars and LCVs (see Annex I). Many believed that LDVs’ \(\text{CO}_2\) emissions per km would increase, and would continue to do so without the Regulations. Even though a similar number had the opposite view, some of these explained that the reason for their response was that vehicle efficiency may improve without the Regulations, but at a slower rate. This suggestion is consistent with the faster rate of \(\text{CO}_2\) emissions reduction observed since the introduction of the passenger car \(\text{CO}_2\) (see Figure 3-1). The majority of stakeholders believed that increases in transport demand and vehicle size would at least counteract some of the \(\text{CO}_2\) reductions achieved by the Regulations, although several of those who disagreed noted that the net effect depended on a wide range of factors and so was difficult to predict. There is some merit to this, as fuel efficiency is indeed one of many ways of reducing transport’s \(\text{CO}_2\) emissions, but as noted above many measures, including improved fuel efficiency, are necessary to meet the EU’s long-term \(\text{CO}_2\) reduction objectives. Additionally, as noted above, there is some evidence that demand for transport (and perhaps even vehicle mass) is declining (at least in the EU15), but this would have to decline significantly to deliver the necessary \(\text{CO}_2\) reductions without further improvements in vehicle efficiency. Finally, a majority of those who had an opinion did not believe that there would be any technical developments that would reduce or remove the need for the Regulations, although some who disagreed suggested that the increased uptake of vehicles with alternative powertrains could reduce the need for the Regulations in the longer-term, i.e. after 2035.

Consequently, the evidence suggests that in order to be meet long-term \(\text{CO}_2\) reduction targets (i.e. from 2020 to 2050), the \(\text{CO}_2\) emissions from new cars and LCVs will have to decrease at a faster rate than that which is necessary to deliver the 2020/2021 targets. Evidence suggests that without Regulations, average fuel consumption tends not to decline at a sufficiently fast rate – and may even increase. It is worth noting in this respect that road transport’s \(\text{CO}_2\) emissions may have peaked and have begun to decline, as might the use of cars in the EU (at least in some countries) and perhaps even vehicle mass (if the trend from 2012 to 2013 continues). These are clearly positive developments from the perspective of reducing real world \(\text{CO}_2\) emissions, although more years’ worth of data will be needed to confirm that these are all long term trends, rather than anomalies resulting from the financial crisis, for example. However, the scale of reductions needed to meet long-term \(\text{CO}_2\) reduction targets still suggests that more stringent car and LCV vehicle standards will be important.

It can be concluded the performance of new vehicles needs to improve at a faster rate beyond 2020. Hence, the relevant objectives of the Regulations, i.e. that they contribute to meeting the EU’s climate change targets and that the Regulations need to be designed to be consistent with these (see Table 5-1), remain pertinent in the context of this need.

### 5.1.3 Road transport needs to use less oil

The evaluation of whether road transport needs to use less oil is linked to the general objective of “Improving the EU energy security of supply”, which is evaluated under ‘Effectiveness’ (see Section 5.4.2). While the need as stated in the Impact Assessment is focused on oil consumption, the related general objective is focused on energy security, so it is appropriate to cover other energy resources here. Consequently, in order to evaluate whether the Regulations are still needed to encourage a shift away
from oil (and the consumption of energy more generally), it is necessary to identify the extent to which LDVs in the EU are still, and could continue to be, reliant on fossil fuels.

Given the close relationship between the amount of oil products consumed by road transport and its CO₂ emissions, it is clear that in order to reduce road transport’s emissions to the levels implied in the previous sections, road transport will have to use less oil. As was discussed in Section 3.3.2, the EU’s consumption of petroleum products has started to decrease in line with the downward trends in CO₂ emissions (see Section 3.3.1). However, in order for the CO₂ emissions from LDVs to decline at the faster rates discussed in Section 5.1.2, the use of oil by these vehicles will have to decline at similar rates. For example, under the various policy options considered in the 2011 Transport White Paper, the final consumption of oil from transport was expected to decrease by more than 70% compared to 2005 levels (European Commission, 2011c)\(^\text{16}\). The link between reducing CO₂ emissions and reducing oil consumption is also made explicitly in other reports, e.g. ICCT (2012a) and IEA (2012).

The need to use less oil in road transport has implications for the use of other fuels and energy sources that are expected to replace oil products – the likely alternatives are generally considered to be electricity, biofuels and hydrogen – as the use of these will inevitably increase. Currently, the use of these fuels and energy sources is still low (see Figure 3-9), so in the short-term, there will continue to be a close correlation between CO₂ emissions, energy use and demand for transport, particularly to 2020. In the longer-term, i.e. post 2020, the use of alternative fuels and energy sources will have to increase and the relationship between transport’s energy use and its CO₂ emissions will become more complex.

All of the main alternative fuels and energy sources have their own respective issues in relation to reducing the CO₂ emissions associated with their use in transport, particularly relating to the net impact of indirect GHG emissions associated with their production (see Section 3.4.1\(^\text{17}\)). If these issues can be resolved, these fuels and energy sources have the potential to deliver CO₂ emissions reductions from transport at the same time as reductions in the use of oil used in the transport sector. As a result, the energy used by the transport sector could effectively be decoupled from the oil used in the transport sector, as it would be possible for energy use to stabilise or even increase, while oil use and CO₂ emissions declined.

At this point, it is worth recalling that the need to use less oil is linked to the objective of “Improving the EU energy security of supply” (as noted above). Consequently, at this point it is important to explore the question of whether it would also be important for the EU to reduce road transport’s energy use, in addition to its oil use. Given the electricity sector’s commitment to decarbonise electricity supply, it might be possible that a fully electrified transport system could eventually be powered by zero (or at least very low) carbon electricity by around 2050. Similarly, if low (or zero) emissions biofuels and hydrogen could also be produced, they could also help to power a future zero (or

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\(^\text{16}\) This was actually about 70% lower for Policy Options 2, 3 and 4 compared to Policy Option 1, under which oil consumption would be marginally less than 2005 levels; see paragraph 232

\(^\text{17}\) Biofuels were not covered in Section 3.4.1 and the respective Annex as their use is not directly incentivised by the Regulations and their increased use has no impact on the effectiveness of the Regulations. However, biofuels were one of the additional policy measures that were expected to contribute to the delivery of the additional 10g of CO₂ emissions reduction that were needed to reach the overall Community target of 120 gCO₂/km (see Section 2.2.1). As with electricity and hydrogen, it has become clear that biofuels also have issues with respect to their indirect GHG emissions. Many of these are linked to concerns about land use, including increased demand for land in the EU and elsewhere resulting in previously uncultivated land being taken for biofuel crop production, or for food crop production that had been displaced by biofuel crop (EEA, 2013d).
low) carbon transport sector. While such a transport-system would be low (or zero) carbon, it would not necessarily be – or have to be – a low energy transport system. As is evident from the Commission’s Low Carbon Roadmap (European Commission, 2011b), the transition to a low carbon economy will require significant levels of sustained investment over the next 35 years. Given the scale of the decarbonisation challenge, in particular the challenges associated with decarbonising the energy system, and levels of investment needed, it would seem to be sensible to ensure that all low (or zero) carbon energy that is produced is used as efficiently as possible.

A majority of stakeholders agreed that the LDV CO₂ Regulations are, and will continue to be, needed to encourage a reduction in the energy consumed by the LDV sector (see Annex I). It was noted by some stakeholders that as the Regulations focus on CO₂ and not energy, they would not necessarily lead to reduced consumption of energy, while others noted that energy reduction would have been delivered by the market in the absence of the Regulations. These points are valid to some extent. As noted above, without the Regulations, there could have been improvements in the fuel efficiency of vehicles, but probably not as fast as has been the case with the Regulations in place (although other evidence indicates that in the absence of regulatory measures, fuel efficiency tends to stabilise, or even get worse; see Section 5.1.2). It is also correct to say that the Regulations do not focus on energy, but on CO₂ emissions. In the short-term, as the vast majority of vehicles covered by the LDV CO₂ Regulations use fossil fuels, this distinction is not necessarily important, as a focus on reducing CO₂ emissions for vehicles using diesel and petrol will reduce their energy consumption. As the proportion of electricity (and potentially hydrogen) used by the LDV fleet increases, the energy used by transport indirectly, i.e. in the course of electricity production, will increasingly become an issue, as discussed above.

In summary, in order to be consistent with long-term CO₂ reduction targets, the road transport sector needs to use less oil. As the vast majority of oil used in the EU is imported, the respective general objective of the Regulations, i.e. to improve the security of energy supply in the EU (see Table 5-1), is pertinent in this respect. Even if the fuels and energy sources used by the transport sector continue to diversify, it would still be prudent to improve the security of energy supply in relation to these fuels and energy sources. This means that the general objective would remain pertinent even if transport did use significantly fewer fossil fuels. These conclusions are valid both up to and beyond 2020.

Beyond 2020, the fuels and energy sources used by the transport sector are expected to diversify and could, in principle, deliver a low or zero carbon transport system at high levels of energy use. This raises the additional question as to whether road transport also needs to use less energy. As noted above, a low (or zero) carbon transport system that uses significantly less oil need not necessarily be a low energy transport system. Given the challenges and the sustained investment needed to deliver the transition to a low carbon economy and considerations about energy security, it would still be prudent – not least as it would be the most efficient use of private and public money – to ensure that the energy consumed by the transport sector is used as efficiently as possible. Hence, the following additions might be considered for any post 2020 legislation:

- Additional need: Road transport should use less energy.
- Additional general policy objective: Improving the energy efficiency of road transport.

The potential utility in considering this additional need and policy objective for the post 2020 period does not necessarily imply that their lack of consideration for the first two targets under the two Regulations was an oversight. For the period to 2020 the focus on oil was appropriate, as it predominated as the fuel used in the road transport sector.
5.1.4 Further reductions in CO\textsubscript{2} emissions must be achieved cost-effectively without undermining sustainable mobility and the automotive industry’s competitiveness

In order to evaluate whether it was, and will continue to be, appropriate that further reductions in CO\textsubscript{2} emissions should be achieved cost-effectively and without undermining either sustainable mobility or the competitiveness of the automotive industry, it is necessary to evaluate the extent to which the following are still relevant:

- Cost effectiveness is an important consideration in CO\textsubscript{2} emissions reductions policy; and
- Maintaining sustainable mobility and the competitiveness of the automotive industry are still important considerations.

This section does not explore whether the Regulations achieved these aims (this is addressed in Section 5.2), only whether these principles were appropriate and whether they should remain as overarching needs to guide the development of the Regulations. That both of the above statements were, and remain, valid is largely self-evident.

The need for cost-effective policies is an underlying principle of EU policy-making, in order to ensure that public and private money is spent well to achieve the desired objectives of any policy, and the best outcome for society, at least cost (European Commission, 2009h). The need for the benefits of EU legislation to be achieved at the lowest cost has also been highlighted by the REFIT Programme (of which this evaluation is a part, see Section 1.1; European Commission 2014). Hence, it is important that Regulations were, and will continue to be, developed to achieve CO\textsubscript{2} reductions from LDVs as cost-effectively as possible.

The importance of maintaining sustainable mobility is clear and was emphasised in the Transport White Paper. Mobility is an important enabler of economic activity, as well as being fundamental to maintaining the quality of life of the EU’s citizens (as noted in Section 2.1). It is now also widely recognised that mobility should be sustainable, i.e. that it delivers its economic and social benefits while minimising the associated adverse environmental and social impacts. This means that it was correct for the Regulations to ensure that sustainable mobility was not undermined, and it will be important that this continues to be the case for any future revisions to the Regulations.

The importance of the EU automotive sector to the EU economy is also widely recognised, both in terms of the direct and indirect jobs it creates and the contribution it makes to the EU economy. It is also a global industry, so the EU automotive industry faces intense competition globally both in terms of sales to other markets, but also increasingly from non-EU manufacturers within the EU market. Since the start of the financial crisis in the late 2000s, the industry has been facing an even more challenging situation, to which the Commission and industry have responded with a series of measures to improve the competitiveness of the industry (European Commission, 2012c). Within this wider context, the Regulations should have been developed in a way that does not undermine the competitiveness of the industry, and that any future Regulations should be developed with this in mind, as well.

A majority of stakeholders believed that encouraging the development of low CO\textsubscript{2} LDVs is, and will continue to be, beneficial for EU competitiveness (see Annex I). In this respect, the Regulations could be seen to increase competitiveness as they force the development of new technologies and models. There was, however, a note of caution in that if the pace of change that was required was too fast, it might have a detrimental impact on the competitiveness of EU industry. It was also argued that it was too simplistic to conclude that the Regulations were beneficial for the competitiveness of the EU automotive industry, as they were only one of many factors that have an impact on this.
It can be concluded that the need for reductions in CO\textsubscript{2} emissions to be achieved cost-effectively without undermining either sustainable mobility or the competitiveness of the automotive industry was, and remains, valid. The associated objective – to improve the competitiveness of the European automotive industry and to stimulate innovation – also remains a valid objective.

5.1.5 Conclusions

The evaluation of relevance has concluded that the four needs that were the basis of the Regulations (see Table 5-1) were valid and will remain so for the period beyond 2020. All sectors needed, and still need, to contribute to the fight against climate change, while the CO\textsubscript{2} performance of new vehicles needed, and still needs, to improve at a faster rate; road transport also needed to, and will continue to need to, use less oil. Ensuring that CO\textsubscript{2} reductions are delivered cost-effectively without undermining either sustainable mobility or the competitiveness of the automotive industry will also be as valid post 2020 as it was in 2007 when the passenger car CO\textsubscript{2} Regulation was first proposed. A potential additional need post 2020 that might be considered is that road transport needs to use less energy to take account of the increasing range of fuels and energy sources that the transport is likely to be using.

The objectives of the Regulations were, and also remain, pertinent to the identified needs. Providing for a high level of environmental protection, while improving energy security and the competitiveness of the EU automotive industry were and will remain valid objectives for the Regulation. One additional general policy objective that might be considered post 2020 is linked to the potential additional need mentioned above is to improve the energy efficiency of road transport.
5.2 Effectiveness: To what degree have the Regulations contributed to achieving their targets and what are their weaknesses?

One of the key evaluation questions is the effectiveness of the Regulations in reducing CO\textsubscript{2} emissions from vehicles. An important aspect of this is to analyse the achievement of the specific emission targets and the extent to which these are attributable to the Regulations. A further aspect is to consider the extent to which reductions in specific emissions translate into reductions in real world CO\textsubscript{2}. Therefore, this section considers the following issues:

- The extent to which LDV specific (tailpipe) emissions decreased, and whether manufacturers appear to be on track to achieve their targets by the 2015/2017 deadline;
- The extent to which the Regulations have contributed to any changes in specific (tailpipe) emissions;
- The potential weaknesses in the Regulations; namely, aspects where:
  - The intended targets are weakened (as measured on the test cycle); and/or that
  - Real-world emissions might not be reduced to the same degree as test cycle emissions.

In addition, wider impacts related to effectiveness are explored elsewhere in this report. These include analysis of the impact of the Regulations on the competitiveness of the automotive industry and social equity, which are considered in further detail in Section 5.4.

5.2.1 The extent to which LDV specific emissions have decreased and manufacturers are on track to meet their targets by the 2015/2017 deadline

Evolution in fleet average emissions to date

The specific objective for the car and LCV CO\textsubscript{2} Regulations are expressed in terms of the specific (tailpipe) CO\textsubscript{2} emissions reductions achieved. Monitoring data from the EEA (2014) suggests that the average fleet emissions of both cars and LCVs in 2013 have (for the first time) over-achieved against their Regulatory requirements:

- **Passenger cars**: The average specific emissions of the new European car fleet in 2013, as measured under the NEDC was 126.7 gCO\textsubscript{2}/km, a reduction of 4.1% compared to 2012. This means the legal target of 130 gCO\textsubscript{2}/km set for 2015 has been met two years early (EEA, 2014).
- **LCVs**: The average emissions for new European LCV fleet in 2013 (also measured using the NEDC) was 173.3 gCO\textsubscript{2}/km, a reduction of 3.8% compared to 2012. The LCV target in 2017 is 175 gCO\textsubscript{2}/km (EEA, 2014).

A more detailed assessment of progress for passenger car manufacturers shows that in 2013, 55 manufacturers out of 84 (representing 99% of total European registrations) met their specific emissions target for 2013 (including derogations). Taking into account the pools, 72 manufacturers out of 84 met their specific emissions targets for 2013 (EEA, 2014). A number of small volume manufacturers (less than 10,000 registrations per year) did not achieve their targets. A number of these manufacturers have either ceased production since 2013, or would fall within the scope of the proposed *de minimis* threshold, according to which manufacturers with less than 1,000 registrations per year
will be exempt from achieving a specific emissions target. In 2013, two manufacturers responsible for more than 1,000 vehicles did not meet their respective target and were required to pay the excess emissions premium for missing their targets (EEA, 2014).

For LCVs, 12 out of 13 larger manufacturers (registering more than 10,000 vehicles per year and representing 95% of total European registrations) achieved their indicative targets for the year 2013 (as they do not have a binding target). Only Jaguar Land Rover did not meet its indicative target; however as from 2014 this manufacturer was granted a derogation that will allow it to respect its binding target from that year (EEA, 2014).

**Whether manufacturers are on track to meet future targets**

According to official monitoring data, for passenger cars all of the 21 large manufacturers\(^\text{18}\) achieved their 2013 and 2014 targets, while 15 already comply with their 2015 targets (EEA, 2014). In 2013, six manufacturers already had average emissions below 120 gCO\(_2\)/km (EEA, 2014). All of the large manufacturers appear to be on track to meet their 2015 targets given current pooling arrangements, although further pooling could also occur before the deadline.

For the largest manufacturers (registering more than 500,000 vehicles per year), the rate of progress required from 2014 until 2021 is generally lower than the rate that has been achieved over the last four years (see Figure 5-1). There are only three of the largest manufacturers for which the reduction rate required is slightly faster.

**Figure 5-1: Comparison of past and future progress for meeting the 2021 target for manufacturers registering more than 500,000 vehicles per year**

\(^{18}\) i.e. those that registered more than 100,000 vehicles in 2013. In total, these manufacturers sold around 11.1 million vehicles in the EU-27 in 2013, equivalent to 93.7% of the total new registrations.
For LCVs, there are only two years of official monitoring data, therefore discerning trends in the progress of manufacturers is more challenging; this data shows on average the new LCV fleet has already met the 2017 targets. The average emissions for new European LCV fleet in 2013 were 173.3 gCO₂/km. Assuming that the estimated CO₂ emissions in 2010 were accurate, there has been a reduction of 8.2 gCO₂/km between 2010 and 2013, of which the majority (6.9 gCO₂/km) occurred between 2012 and 2013. As mentioned in Section 4.2.2, there is significant uncertainty with respect to recent historical trends (i.e. prior to the availability of official monitoring figures for 2012) in LCV CO₂ emissions due to a lack of robust data. It should also be noted that the original Impact Assessment of proposals for the LCV CO₂ Regulation assumed that emissions would need to reduce from 203 gCO₂/km to 175 gCO₂/km. Given that the best estimate for emissions performance in 2009 (i.e. the year the Regulation was announced) is now 185 gCO₂/km, it seems likely that the Impact Assessment overestimated the likely impacts of the Regulation on emissions reductions.

It is also worth noting that the Regulatory target of 147 gCO₂/km in 2020 is only three years after the 175 gCO₂/km target, and hence it may be this more stringent target that is driving the reductions currently observed. A continuation of the trend between 2012 and 2013 would lead to LCVs exceeding their target by 2020 (see Figure 5-2). A slower rate of reductions based on the best fit line through 2010, 2012 and 2013 shows that LCVs would not meet the target in 2020, whereas the actual emission reductions rate needed to meet the targets is between these two projections.

**Figure 5-2: Fleet average LCV emissions**

![Average CO₂ emissions for new LCV registrations](image)

**Notes:** 2010 emissions are estimated.

**Source:** (EEA, 2014) and (TNO, 2012)

Five manufacturers, representing almost 48% of the European new LCV fleet, already had average emissions lower than 175 gCO₂/km: Dacia, Renault, Automobiles Citroen, Automobiles Peugeot and Fiat group. These are the manufacturers with the lower average mass in the group (EEA, 2014). In addition, the percentage of newly registered LCVs with emissions lower than 140 gCO₂/km has increased, accounting for almost 32% of newly registered vehicles in 2013, compared to 27% in 2012.

All of these trends indicate significant progress and suggest that LCV manufacturers are on track to meet their 2020 targets.
5.2.2 The extent to which the Regulations have contributed to the changes in specific (tailpipe) emissions

This section explores the extent to which these reductions in CO₂ emissions can be attributed to the impact of the Regulations, as opposed to other potential factors.

Following the adoption and implementation of the car CO₂ Regulations, there was a striking increase in the rate of reduction of CO₂ emissions from passenger cars. Figure 5-3 shows the annual change compared to the previous year and the average reduction rate for the time periods given.

Figure 5-3: Percentage reduction in average gCO₂/km compared to previous year

![Graph showing percentage reduction in average gCO₂/km](image)

Notes: Numbers in brackets indicate the average annual reduction in emissions over the relevant time periods: 2001-2006; 2007-2008 and 2009-2013.
Source: Adapted from (EEA, 2014)

This high-level data suggests that the Regulations have been effective in achieving reductions in CO₂ emissions compared to previous years where the voluntary agreement was in place. However, there are many other factors that may also have had an important effect on the observed trends in fleet average CO₂ emissions over this same time period, which could have contributed to these reductions. These issues require further analysis before concluding on the effectiveness of the Regulations.

The most recently available monitoring data was analysed using a regression model that attempts to quantify the impact of the Regulation while controlling for other factors that may have an impact on new car emissions.

Regression analysis is a statistical technique that provides a measure of the relationship among variables. Specifically, it aims to quantify how a dependent variable changes when one of the independent variables (i.e. an explanatory variable) is varied while the other independent variables are held fixed. Full details of the model specification and results are provided in Annex E.

The results of the regression analysis suggest that it is highly likely that the Regulations have contributed to the CO₂ reductions observed. The findings suggest that the
Regulations were responsible for at least two-thirds of the reductions in test-cycle emissions observed since 2009.

The results should be taken as an indication that there is likely to be a positive effect due to the Regulations, in terms of reducing CO₂ emissions. Nevertheless, there were significant limitations to the quality and availability of the data that mean these quantitative results should be interpreted with caution. Therefore, a wider discussion of the effectiveness of the Regulations is provided below.

Ideally, data would be available to allow comparisons of observations with and without treatment. This would allow the use of “difference in difference” estimation, which attempts to mimic an experimental setting by estimating the difference in the differences between treatment groups and non-treatment groups over time. In this case there is no control group because the Regulation was implemented in all Member States¹⁹ and therefore the analysis needs to rely on the variation in the data before and after the Regulation.

The factors responsible for the remaining part of the emissions reductions observed are likely to include national policy measures, residual impacts from the voluntary agreement, shifting consumer preferences and autonomous improvements. These have not been quantified in the regression analysis as this would have required much more detailed datasets than those that are publicly available. Since such analysis is beyond the scope of the current study, these aspects are explored qualitatively below by synthesising findings from the literature.

Other factors driving emission reductions from the data and a literature review were thus examined in this Section, as summarised in Table 5-2. Further details are provided in Annex E. The impact of the voluntary agreement and autonomous technical improvements were estimated together to be 1.6 g/km per year. These were further split out into an assumed autonomous improvement rate of 0.5 g/km (based on time trends observed prior to the voluntary agreement) and 1.1 g/km due to the voluntary agreement.

Table 5-2: Overview of mechanisms of CO₂ reductions in passenger cars

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
<th>Estimated “most likely” contribution to CO₂ reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical analysis - Direct change due to Regulation</td>
<td></td>
<td>65%-85% of the observed reductions -3.4 to 4.8 gCO₂/km per year (reduction)</td>
</tr>
<tr>
<td>Car CO₂ Regulation</td>
<td>Mandatory requirement to reduce average fleet emissions. Additional impact over and above the impact of voluntary agreement (had it continued) and autonomous technical improvements. The lower estimate is based on the regression analysis and includes the continuation of the voluntary agreement in the absence of the Regulations, while the higher estimate assumes the discontinuation of the voluntary agreement.</td>
<td></td>
</tr>
</tbody>
</table>

¹⁹ Neighbouring countries such as Belarus or Ukraine could potentially act as a control group. However, sufficiently detailed data was not available for these countries.
### Factor Description

**Estimated “most likely” contribution to CO\textsubscript{2} reductions**

#### Other drivers of CO\textsubscript{2} emission reductions included in the regression

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
<th>Estimated “most likely” contribution to CO\textsubscript{2} reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voluntary agreement and autonomous technical improvements</strong></td>
<td>Improvements in emissions performance which would have occurred without the presence of the car CO\textsubscript{2} Regulation, given general improvements to knowledge, technologies, and manufacturing techniques not attributable to particular policies or circumstances. Since the time period for which data were available also included the impact of the voluntary agreement, this effect also includes the voluntary agreement. The impacts have been estimated separately based on taking the average rate of reduction between 1990 and 1996 and assuming this represents autonomous improvement.</td>
<td><strong>33%</strong> -1.6g per year (reduction) based on empirical regression analysis</td>
</tr>
<tr>
<td>Diesel share</td>
<td>Between 2006 and 2013 the diesel share grew by 2 percentage points</td>
<td><strong>2%</strong> -0.7gCO\textsubscript{2}/km (reduction) between 2006 and 2013</td>
</tr>
<tr>
<td>Number of new registrations</td>
<td>In 2013 new registrations were almost 25% below the peak of 2007; however, there is no significant effect on the fleet average emissions of new vehicles.</td>
<td><strong>0%</strong></td>
</tr>
</tbody>
</table>

**Potential drivers of CO\textsubscript{2} emission reductions not controlled for in the Regression**

*These may have been captured in the above figures for ‘Car CO\textsubscript{2} Regulation’ and/or ‘Voluntary agreement and autonomous technical improvements’ – hence overall contributions from all factors will add up to more than 100%*

| Changes in vehicle mass | Changes in vehicle mass – impact estimated according to \( \Delta \text{CO}_2/\text{CO}_2 = 0.65 \Delta \text{m} / \text{m} \). Impact was small, estimated at approximately 1 gCO\textsubscript{2}/km overall | Overall +1 gCO\textsubscript{2}/km (increase) |
| Changes in vehicle segment share | Shifts in vehicle segment. It was found that changes to the market share of different vehicle segments between 2006 and 2012 will have reduced emissions by less than 1 gCO\textsubscript{2}/km and may have even led to increased emissions (due to increased SUV share). | Overall +2 gCO\textsubscript{2}/km (increase) to -1 gCO\textsubscript{2}/kmCO\textsubscript{2} (reduction) |
A similar empirical analysis for LCVs was not possible given the short timescales of the available data, which do not provide an adequate time series for the multiple regression. Nevertheless, substantial improvements have been observed: in 2013, the average new LCV in Europe emitted 6.9 gCO₂/km less than the average newly registered vehicle in 2012 (EEA, 2014). Improvements in CO₂ emissions from all fuel types have been seen (Figure 5-4), with average CO₂ emissions from diesel LCVs (which represent 96.5% of sales) reaching 175.2 g/km in 2013.
Prior to 2007, there was thought to be limited pressure on lowering CO₂ emissions due to a lack of legislation as well as of fiscal incentives, while between 2007 and 2010 some technological improvements were expected to have contributed to CO₂ reductions, especially due to crossover of technologies from passenger cars (TNO, 2012). On the other hand, without regulatory pressure to improve CO₂ emissions, these fuel efficiency improvements may have been offset by increases in other vehicle attributes such as footprint/mass or engine power. Thus it is possible to argue that autonomous improvement in the absence of the Regulations would be either positive (decreasing CO₂) or negative (increasing CO₂). Overall, a baseline that assumes no autonomous improvement appears to be a sensible compromise, as was used in the Impact Assessment underlying the proposals for the 2020 modalities (TNO, 2012).

Data for years prior to the official monitoring are based on estimates – the estimated average LCV emissions performance in 2010 was 181.5 gCO₂/km, which is much lower than the estimate of 203 gCO₂/km in 2007. Part of the reason for the large difference is likely to be due to the lack of complete and robust data for 2007; however, it is also possible that the rapid reduction was due to shifts in the sales mix (8.5 gCO₂/km), mass changes (0.7 gCO₂/km) and increased utilisation of test cycle flexibilities (5 to 6 g/km) (TNO, 2012). The remaining 7 gCO₂/km was not attributed to specific causes, but could be considered reasonable for the application of technological improvements over the period – particularly considering cross-over of technologies from cars to LCVs (TNO, 2012).

Since 2009, the LCV market appears to have been shifting towards higher classes (the majority of new LCVs are Class III vehicles), and therefore heavier vehicles (Ricardo-AEA et al, 2015). Hence, the impact on CO₂ emissions, all else being equal, will be to increase CO₂ emissions due to increased vehicle mass. Sales weighted average mass increased by 16% between 2009 and 2012, an increase of over 250 kg. Increases in mass are likely to be due to a combination of factors including a shift on sales towards LCVs with larger load capacities, additional safety and comfort features being fitted as standard, and the emergence of new market segments (Ricardo-AEA et al, 2015).
Table 5-3 provides a qualitative assessment of the factors contributing to the trends in fleet average CO₂ emissions from LCVs, although the magnitude is less certain due to the lack of consistent data (since official monitoring data are only available from 2012) as well as uncertainty over the extent to which the changes in fleet characteristics are long-term trends as opposed to short-term fluctuations caused by the economic crisis. Further details are provided in Annex E.

Table 5-3: Qualitative assessment of contributions to LCV fleet average CO₂ trends

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
<th>Qualitative estimate of contribution to CO₂ reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total emission reductions occurring between 2010 and 2013 of 8.2g/km</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCV CO₂ Regulation</td>
<td>Mandatory requirement to reduce average fleet emissions.</td>
<td>Expected to have a large contribution to CO₂ reduction trends</td>
</tr>
<tr>
<td>Autonomous technical improvements</td>
<td>Overall, a baseline that assumes no autonomous improvement appears to be a sensible compromise, as was used in the Impact Assessment underlying the proposals for the 2020 modalities (TNO, 2012).</td>
<td>Negligible</td>
</tr>
<tr>
<td>Diesel share</td>
<td>Between 2009 and 2013, the diesel share of LCVs has remained at over 96%</td>
<td>Negligible</td>
</tr>
<tr>
<td>Changes in mass</td>
<td>Between 2013 and 2013, mass changes are estimated to have had a minor impact on average CO₂ emissions.</td>
<td>Small contribution CO₂ -0.7g/km (reduction) to +3.5g/km (increase) between 2010 and 2013</td>
</tr>
<tr>
<td>Changes in sales mix</td>
<td>Impacts due to changes in sales mix, estimated by calculating effective fleet average emissions if sales mix had remained at 2010 levels, while CO₂ emission reductions occurred as observed from 2010-2013.</td>
<td>Contributions to increase in CO₂ emissions +10g/km between 2010 and 2013 (increase)</td>
</tr>
<tr>
<td>Economic crisis</td>
<td>The number of new registrations has been significantly affected following the recession; however the impact is not clear as there have been significant changes in vehicle mass and sales mix at the same time, which may be due to the recession or due to more enduring trends.</td>
<td>Unclear, but largely included in estimate above</td>
</tr>
</tbody>
</table>
While it is difficult to draw conclusions based on only a few years of data, this suggests that the rate of emission reductions from the LCV fleet has increased since the introduction of the Regulations and therefore that the Regulations have been effective, at least in part, in stimulating higher emission reductions than would otherwise have been seen, as well as leading to emission reductions despite shifts to larger/heavier LCVs.

### 5.2.3 Weaknesses of the Regulations

Since the evaluation questions refer to ‘weaknesses’ in the context of the Regulations meeting their targets, an issue relating to the Regulations might be considered to be a weakness if it **undermines the Regulations’ ability to reduce real world CO₂ emissions.** Consequently, ‘weaknesses’ of the Regulations might be considered to be issues that mean that:

- The intended targets are weakened (as measured on the test cycle); and/or that
- Real-world emissions might not be reduced to the same degree as test cycle emissions.

In this respect, many of the emerging issues discussed in Section 3.4 are relevant. Furthermore, ‘weaknesses’ are both actual – where a target was weakened or real-world emissions were not reduced – or theoretical, i.e. where there is/was the potential for a weakening of a target or a failure to reduce real-world emissions. The latter are important, as these will have implications as to whether the respective elements are ‘fit-for-purpose’ for the post 2020 period.
5.2.3.1 Possible weakening of the targets
In relation to the first type of weakness, the following issues can be identified:

- **Phasing in** of both targets for cars (2015 and 2021) and of the first target for LCVs (2017);
- The potential to use **super-credits**, again for both targets for cars and for the first target for LCVs;
- **Derogations for small volume manufacturers** of cars and LCVs, niche car manufacturers and the **de minimis** that has been introduced in both Regulations.

As discussed in Section 2.4 each of the modalities, including the ones listed above, was introduced in the Regulations for a particular reason, either by the Commission in the original proposal or by the Council and Parliament in the course of the co-decision process. The evaluation in this section focuses on the extent to which these modalities might be considered to be a weakness; whether, taken together, they provide a coherent framework within the Regulation will be evaluated in Section 5.7. More detail is provided on the extent of each of these weaknesses in Annex F.

At this point, it is worth mentioning that modalities can also directly address what would otherwise have been a weakness in the Regulations. Such an example is the ‘M₀ adjustment’, which adjusts the formula with which manufacturers’ targets are calculated to take account of any underlying changes to the mass of the new car and LCV fleets. Without this adjustment, if the average mass of the new fleet increased, the CO₂ reductions delivered by the Regulations would be reduced (as the targets are a function of the mass; see Section 2.4).

5.2.3.2 Factors that may influence the real-world emission reductions
In relation to the second type of weakness, i.e. issues that mean that observed test cycle emissions might not be replicated in the real world, the following weaknesses can be identified:

- **Test cycle**: The CO₂ emissions per kilometre as measured on the test cycle are not an accurate reflection of real-world emissions per kilometre, which is at least partially caused by the impact and use of more energy consuming devices to vehicles that are used in the real-world, but not measured on the test cycle (see Section 7.1 of Annex A);
- **Well-to-tank emissions**: The Regulations incentivise the use of energy sources that have zero CO₂ emissions as measured on the test cycle, but which have higher indirect emissions associated with their production than fossil fuels. These emissions are not considered within the Regulations; and
- **Embedded emissions**: The Regulations incentivise the use of vehicles that have higher GHG emissions associated with their production and disposal than more conventional vehicles, which are also not considered within the Regulations.

The above issues have already been introduced in Section 3.4 and further discussed in Annex A. A ‘weakness’ might also be interpreted as being broader than the definition used in this section, e.g. elements of the Regulations that result in inefficiencies, or an inequitable treatment of manufacturers or of different groups of drivers. These issues are not covered here, as they are more appropriately addressed under the evaluation questions that deal more directly with these issues, e.g. in Section 5.6 for inefficiencies and Section 5.4.5 for social equity.

From the discussions in Section 3.4.1 and the relevant sections of the associated Annexes (i.e. Annex A and Annex F), it is clear that the most significant weakness
associated with the Regulations is the test cycle. According to various data sources, there is an increasing discrepancy between real-world and test cycle emissions (see Figure 3-10), which means that the impact of the Regulations on emissions reductions might be between 20% and 50% less than appears to be the case when considering emissions reductions as measured on the test cycle. Addressing this weakness is, out of the scope of the Regulation, as the procedures are developed and defined within other technical and policy processes. As noted in Section 3.4.1, the increasing discrepancy has been recognised by policy-makers and will be addressed – at least in part – by the development of a revised test procedure, which will be part of a new worldwide harmonised test protocol (WLTP).

The analysis carried out for this evaluation has examined the effects of the Regulations on (a) total lifetime real-world emissions and (b) total lifetime NEDC test cycle emissions for all new cars registered between 2006 and 2013 and for all new LCVs registered between 2010 and 2013. In this way, the effectiveness of the Regulations in reducing CO₂ can be quantified and the effects of the increasing divergence between test cycle and real-world emissions can also be assessed. For the purposes of this assessment, data on the divergence between test cycle and real-world emissions was taken from (ICCT, 2014e). For actual outturn emissions, the monitored NEDC values were uplifted by the individual percentage divergence factors for private cars from the ICCT analysis for each year from 2006 to 2013. This work estimated that the level of divergence was 11% in 2006 and 31% in 2013. For the baseline scenario, it was assumed that the level of divergence did not increase as rapidly, because without regulatory pressure to cut CO₂ emissions, it is likely that manufacturers would not need to use all of the test-cycle flexibilities available to them. Hence, under the baseline, the divergence for the years 2006 to 2013 was extrapolated from the observed 2004-2007 trend for private cars identified by ICCT. This resulted in real-world emissions diverging from test cycle performance by 11% in 2006 and rising to 15% in 2013.

The data in Table 5-4 and Table 5-5 show that the Regulations have reduced CO₂ emissions from both cars and LCVs despite the above-mentioned weaknesses. It is clear that the increasing divergence between test-cycle and real-world emissions performance has significantly reduced the effectiveness of the Regulations. The ex-post estimate of the lifetime real-world well-to-wheels CO₂ savings for new cars registered between 2006 and 2013 are 138 MtCO₂ and lifetime real-world CO₂ savings for new LCVs registered between 2010 and 2013 are 2.0 MtCO₂. By contrast, if the emissions savings are estimated on the basis of NEDC performance, the savings would be significantly greater for both cars and vans. For passenger cars, real-world emissions savings are estimated to be 48% lower than indicated by the improvements in official NEDC test-cycle performance. For LCVs, real-world emissions savings are estimated to be 73% lower than the savings calculated based on improvements in test-cycle emissions performance. These figures indicate that the increasing discrepancy between test cycle and real-world emissions performance is very significantly weakening the effectiveness of the Regulations.

It should also be noted that the impacts on emissions savings are very sensitive to assumptions made on the levels of divergence between test cycle and real-world emissions performance. For LCVs, there is no robust empirical data on the levels of divergence and how this has changed over time. For the purposes of this analysis, it has been assumed that in the baseline scenario, the level of divergence remains static at 11% between 2009 and 2013. By contrast, for the actual outturn results, the level of divergence is assumed to increase from 11% in 2009 to 15% in 2013. This more conservative set of assumptions compared to the figures used for passenger cars

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20 Only the data for private cars was used as the dataset for company cars is understood to be less robust.
reflects the lack of robust data in this area for LCVs. If the same assumptions used for cars on test-cycle divergence are used for LCVs, then the analysis indicates that there have been no emissions reductions due to the LCV CO$_2$ Regulation – by contrast, emissions would actually be higher than under the baseline scenario.

These findings are very significant and highlight a major weakness of the Regulations that needs to be addressed prior to implementing future regulatory targets.

**Table 5-4: Lifetime CO$_2$ savings from new cars registered between 2006 and 2013**

<table>
<thead>
<tr>
<th>Passenger cars</th>
<th>Lifetime emissions savings</th>
<th>Based on NEDC test cycle</th>
<th>Based on real-world uplift applied to test cycle emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tank-to-wheels emissions</td>
<td></td>
<td>208 MtCO$_2$</td>
<td>108 MtCO$_2$</td>
</tr>
<tr>
<td>Well-to-wheels emissions</td>
<td></td>
<td>266 MtCO$_2$</td>
<td>138 MtCO$_2$</td>
</tr>
</tbody>
</table>

**Table 5-5: Lifetime CO$_2$ savings from new LCVs registered between 2010 and 2013**

<table>
<thead>
<tr>
<th>LCVs</th>
<th>Lifetime emissions savings</th>
<th>Based on NEDC test cycle</th>
<th>Based on real-world uplift applied to test cycle emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tank-to-wheels emissions</td>
<td></td>
<td>5.7 MtCO$_2$</td>
<td>4.0 MtCO$_2$</td>
</tr>
<tr>
<td>Well-to-wheels emissions</td>
<td></td>
<td>7.4 MtCO$_2$</td>
<td>5.2 MtCO$_2$</td>
</tr>
</tbody>
</table>

Notes: Test cycle uplift factors for passenger cars derived from ICCT (2014e) and for LCVs derived from analysis of databases real-world LCV fuel consumption

Source: baseline calculations, see Section 5.5 and Annex B

Super-credits – at least potentially – are the second most significant source of weakness, at least in the early years of the first targets of both Regulations (see Section 5.4.4.5 and Figure 12-2 in Annex F). However, as both targets have now been met, super-credits have not yet been needed and so have not resulted in any practical weakening of the Regulatory targets. Similarly, while the phasing-in of the first targets in each Regulation has the potential to weaken the Regulations by a few percentage points (see Figure 12-1 in Annex F), in practice the only weakening was by 1.7% in 2012 for cars as the actual emissions that year were 132.2 gCO$_2$/km instead of 130 gCO$_2$/km. This of course assumes that the average fleet-wide CO$_2$ emissions continue to decline.

The impacts of the derogations for small volume car and LCV manufacturers and for niche car manufacturers are relatively small. Even assuming that those small volume manufacturers benefiting from the derogation were 50 gCO$_2$/km over the target that would have been implied by the Regulation, the resulting weakening would only be a small fraction of 1%. A similar result is found in relation to the ‘de minimis’ that now excludes the very small manufacturers. Under the same assumptions, the comparative impact of the niche manufacturer derogation is more significant, i.e. nearly fifty times as high (taking into account the manufacturers that have benefitted from this derogation), which suggests that this derogation is potentially a greater source of
weakness than the small volume derogation and ‘de minimis’ (see Figure 12-3 in Annex F).

The lack of consideration of the lifecycle and embedded emissions of vehicles is currently a relatively minor issue due to the small numbers of electric and plug-in vehicles that are currently being put in the market. For example, whereas according to its tailpipe emissions an electric car would reduce its CO$_2$ emissions compared to a comparable sized petrol car by 100%, in practice – once lifecycle fuel and embedded emissions have been taken into account – the emissions reduction might be no more than 30% (see Annex A). If electric cars made up 10% of new car sales, this would deliver a 10% reduction in total CO$_2$ emissions as measured on the test cycle, whereas taking account of all lifecycle and embedded emissions the reduction might only be 3%. In 2013, when only 0.20% of the new cars registered were electric cars – and an additional 0.26% were plug-in hybrids were registered (EEA, 2014) – the discrepancy might be around 0.14%$^{21}$. As the proportion of electric vehicles is expected to increase, this issue will become more significant.

The issues discussed here are similar to those identified by stakeholders as being most detrimental to the effectiveness of the Regulation (see Section 15.3 in Annex I). Additionally, an issue that was mentioned by a stakeholder that might be considered to be a weakness – or at least if it was addressed would ensure consistent CO$_2$ reductions – was the frequency of the targets. The fact that there are effectively eight years between the first two targets for cars and six years between the respective LCV targets (ignoring the relevant phase-in periods) means that theoretically manufacturers need not take any action between these targets. In practice, it seems more likely that action will be taken in order to ensure that the next target is met rather than leaving all CO$_2$ emissions reductions to the target year. Setting a clear reduction pathway to the next target would give more confidence that the target is on course to be met and would also facilitate the introduction of other potential mechanisms (see Section 5.10).

**5.2.4 Conclusions**

The analysis suggests that the car CO$_2$ Regulation is highly likely to have had a positive impact in terms of contributing to the CO$_2$ emission reductions achieved following the introduction of the Regulation. Monitoring results from 2014 indicate that the fleet wide average targets have been met two years early in 2013, and that the largest manufacturers appear to be on track to meet their future targets. The regression analysis suggests that two-thirds of the observed reductions in test cycle emissions may have been due to the Regulation. This might be an over-estimate as some other factors could not be included in the regression (such as fuel price increases, the economic crisis and Member State policies). These other factors may have together contributed up to 20% or more to the observed reductions, reducing the magnitude of the Regulation’s impact accordingly. However, the Regulation may have indirectly supported the implementation of some of these other measures (especially national policies).

It is also conceivable that the CO$_2$ Regulation in fact accounts for more than two thirds of the observed reductions (up to 85%), as the contribution of the voluntary agreement and autonomous improvement are derived from past trends. It could be assumed that the announcement of the Regulation would supersede the voluntary agreements, and hence further reductions over autonomous improvement could be attributed to the Regulation rather than the voluntary agreement.

Similarly for LCVs, monitoring data shows that the fleet wide average emissions have already exceeded the required target for 2017, and place manufacturers in a strong

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$^{21}$ I.e. instead of a 0.2% reduction in total emissions resulting from electric cars, the emissions reductions might only be 0.06% (i.e. 30% of 0.2%), thus delivering a discrepancy of 0.14%.
position to meet their 2020 targets. The rapid rate of CO$_2$ emission reductions seen in recent years suggests that the Regulations have played an important role in speeding up specific emission reductions from LCVs.

Nevertheless, both Regulations have inherent weaknesses related to their modalities that reduce their effectiveness. The most significant of these appears to be the test cycle: there is an increasing discrepancy between real-world and test cycle emissions. This issue has been recognised by policy-makers and will be addressed – at least in part – by the development of a revised test procedure, which will be part of a new worldwide harmonised test protocol (WLTP). Other potential weaknesses (super-credits and phasing in of the targets) do not appear to result in significant weakening of the targets in practice. The impact of derogations for small volume and niche manufacturers have been relatively small.

The lack of consideration of the lifecycle and embedded emissions of vehicles is currently a relatively minor issue due to the low penetration of electric and plug-in hybrid vehicles; as the proportion of electric vehicles is expected to increase, this issue will become more significant. This aspect may therefore need to be included in future legislation.
5.3 Effectiveness: To what extent have the Regulations been more successful in achieving their objectives compared to the voluntary agreement on car CO₂ emissions?

The aim of this question is to compare the effectiveness in terms of the achieved CO₂ emission reductions under the Regulation with those achieved under the voluntary agreement reached with car manufacturers before the Regulations.

In 1998 the European Automobile Manufacturers Association (ACEA) made a voluntary commitment to reduce average emissions from new cars sold in the European Union to 140 gCO₂/km by 2008. The Japan Automobile Manufacturers Association (JAMA) and the Korean Automobile Manufacturers Association (KAMA) made similar commitments in 1999. By 2005, it became apparent that the manufacturers were very unlikely to meet the 2008/2009 standards under the voluntary agreement and hence the Regulations were needed.

This section considers:

- Whether the average CO₂ reductions under the Regulations have been faster than those seen under the voluntary agreement;
- Whether the achievement of targets has been more successful under the Regulations compared to the voluntary agreement.

5.3.1 Comparison between the CO₂ reductions under the CO₂ Regulation and voluntary agreement for passenger cars

Over the period between 1995 and 2008, emissions from new passenger cars fell on average by 2.4 gCO₂/km per year. Between 2007 (when the Regulation was published) and 2013, emissions fell on average by 5.3 gCO₂/km. This is already indicative of a higher effectiveness of the Regulation compared to the voluntary agreement.

AEA et al. (2009) used the ASTRA model to assess the impact of the voluntary agreement. The approach aimed to control for the effects of dieselisation, size, energy prices, taxation, autonomous improvement and variation in data sources. Autonomous improvement was found to be the single most important factor. Over the period of the voluntary agreement, between 1998 and 2008, emissions fell on average by some 2.4 gCO₂/km per year. In the sensitivity analysis, the autonomous improvement was changed from the default assumption of 0.5 gCO₂/km per year (based on taking the average rate of reduction between 1990 and 1996) to 1.3 gCO₂/km per year (1992-1996 average). As a result, the savings attributable to the voluntary agreement are halved: for the year 2007 they were found to be around 30 MtCO₂ in the EU-27 under the default assumption, and only 15 MtCO₂ if the higher 1992-1996 rate of autonomous improvement is assumed (AEA et al., 2009). This suggests that annual improvement in CO₂ emissions attributed to the voluntary agreement was between 1.1 and 1.9 gCO₂/km.

As noted previously, assumptions on the rate of autonomous improvement have dramatic effects on the conclusions about effectiveness – hence a range of possible scenarios is explored here:

- In the original Impact Assessment of the passenger car Regulation (as well as the upper bound assumptions used in the baseline calculations), an autonomous improvement of 1.5 gCO₂/km per year was assumed, reflecting the average

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22 Note that this differs from the estimate in the previous section because it applies to a different time period, i.e. prior to the Regulations
annual improvement in the period 2002-2006\textsuperscript{23}. Hence, the annual improvement attributable to the Regulation would be \textbf{3.8 gCO\textsubscript{2}/km}.

- The results of the regression analysis of Annex E are similar to the previous result, finding an annual reduction of \textbf{3.4 gCO\textsubscript{2}/km} attributable to the Regulation.

- Alternatively, assuming autonomous improvement of \(0.5 \text{ gCO}_2/\text{km}\) per year (based on taking the average rate of reduction between 1990 and 1996) and the discontinuation of the voluntary agreement (consistent with the baseline) suggests that the annual reduction due to the Regulation increases to \textbf{4.8 gCO\textsubscript{2}/km}.

In conclusion, the assumptions used on the rate of autonomous improvement are clearly very important when attributing impacts. Under all assumptions the effect of the Regulations on CO\textsubscript{2} emission reductions was found to be greater than under the voluntary agreement.

Overall therefore, it is likely that the Regulations have led to greater fleet average emission improvements than the voluntary agreements. However, the difficulty of reliably attributing emission reductions to a single intervention (whether the voluntary agreement or the Regulation) is evident.

5.3.2 \textbf{Whether manufacturers met their targets under the CO\textsubscript{2} Regulations and/or the voluntary agreement}

Another relevant benchmark for comparison is whether the manufacturers met their targets in practice, as shown in Figure 5-5. ACEA reached an average of 152.3 gCO\textsubscript{2}/km in 2008, missing their target for that year by 12.3 gCO\textsubscript{2}/km, whereas JAMA and KAMA reached 142.6 gCO\textsubscript{2}/km and 141.8 gCO\textsubscript{2}/km respectively in 2009\textsuperscript{24}, missing their targets by 2.6 gCO\textsubscript{2}/km and 1.8 gCO\textsubscript{2}/km (European Commission, 2010a).

By contrast, the Regulation’s 2015 target of 130 gCO\textsubscript{2}/km has already been exceeded in 2013 and manufacturers are on track for meeting the 2020 target of 95 gCO\textsubscript{2} by 2020 if current trends are maintained. The significant financial penalties associated with the failure to meet the Regulation’s targets are likely to have acted as an incentive to manufactures for meeting their targets which was absent during the voluntary agreement period.

It should be noted that the voluntary agreement was in place during the 2002-2006 reference period, so it is conceivable that CO\textsubscript{2} reductions in absence of the voluntary agreement would have been even lower. Reductions between 2002 and 2006 merely averaged 1.5g, around 1g less than the average over the entire period of the voluntary agreement.

\textsuperscript{24} The target year under the voluntary agreement for JAMA and KAMA members to reach the 140 gCO\textsubscript{2}/km target was 2009, as opposed to 2008 for ACEA members.
This suggests that the car CO\textsubscript{2} Regulation has been more successful at achieving its objectives than the voluntary agreements.

There is no directly equivalent evaluation question for LCVs as there was no voluntary agreement with industry prior to the LCV CO\textsubscript{2} Regulation. Even so, the average emissions for new European LCV fleet in 2013 were 173.3 gCO\textsubscript{2}/km – a substantial reduction of 6.9 gCO\textsubscript{2}/km compared to 2012 (EEA, 2014). This rapid rate of CO\textsubscript{2} emission reductions from the fleet average emissions in recent years, along with the fact that industry has achieved the Regulatory targets four years ahead of schedule, suggests that the Regulations have been more effective than voluntary targets would have been.

### 5.3.3 Conclusions

The analysis indicates that the passenger car Regulation has been more successful in reducing emissions than the voluntary agreement that was previously in place. While the targets of the voluntary agreement in 2008/2009 were missed, the 2015 target under the Regulation has already been exceeded in 2013, and manufacturers are on track for meeting the 2020 target if current trends are maintained. Furthermore, the rate of CO\textsubscript{2} emission reductions seen under the Regulation (estimated to be between 3.4 and 4.8 gCO\textsubscript{2}/km) were higher than those seen under the voluntary agreement (estimated to be between 1.1 and 1.9 gCO\textsubscript{2}/km).

For LCVs, there were no equivalent voluntary agreements, but the rate of recent CO\textsubscript{2} emission reductions and the fact that the fleet average emission targets have been met four years early suggests that the Regulations are more effective than voluntary targets would otherwise have been.
5.4 Effectiveness: How do the effects of the Regulations correspond to the objectives?
This section compares the achieved results with the objectives of the Regulations, namely in terms of:

- **General objectives:**
  - Providing for a high level of environmental protection in the European Union;
  - Improving the EU’s security of energy supply;
  - Fostering the competitiveness of the European automotive industry and encouraging innovation in fuel efficiency technologies.

- **Operational objectives:**
  - Ensuring competitively neutral targets; and
  - Ensuring socially equitable targets.

The specific objectives have been discussed previously in Section 4.2, which explored the degree to which the Regulations have contributed to achieving the CO₂ emission reduction targets – i.e. the specific objectives of the Regulations are:

- **Cars:** Reducing the climate change impacts and improving the fuel efficiency of passenger cars by reaching the objective of an average emission value of 130 g CO₂/km for newly sold cars in 2015.
- **LCVs:** To reduce the climate change impacts and improve the fuel efficiency of light commercial vehicles by means of a specified emission reduction for new vehicles in line with the revised strategy COM(2007)19 – i.e. a reduction target of 175 gCO₂/km in 2017.

5.4.1 Providing for a high level of environmental protection in the European Union
It has already been seen that the Regulations have been effective in reducing direct CO₂ emissions from both cars and LCVs. Ensuring that a high level of environmental protection has been provided must also encompass other non-GHG emissions, as well as other lifecycle stages. The focus here is on broader impacts that are outside the specific focus of the Regulations, including:

- Embedded emissions.
- Well-to-wheel emissions and lifecycle emissions.
- Consideration of the possible rebound effect.
- Impacts on emissions of other pollutants.

5.4.1.1 Embedded emissions
The impact of near-term conventional fuel efficient technologies on production emissions is limited, since:

- Most technologies influence vehicle mass in only a very limited way, apart from weight reduction, hybridisation and electrification.
- Furthermore, conventional materials are used generally for the technologies with limited impact. That is, the CO₂ savings during vehicle use by far outweigh the additional production emissions in all cases (TNO et al, 2011).
- Hybrid vehicles have slightly higher production emissions, but these are small compared to their reduced fuel consumption (TNO et al, 2011).
Finally, lifecycle studies typically show that the reductions in energy use and GHG emissions during the use stage of vehicles due to aluminium and high-strength steel material substitution (for **light weighting**) exceed the increased energy use and GHG emissions needed to manufacture these lightweight materials at the vehicle production stage (NHTSA, 2012). However, the magnitude of lifecycle GHG-emission and energy-use savings are influenced by the amount of recycled material used in automobile components, the materials recycling rates at end of life, the lifetime of vehicles in use, and the location of production (NHTSA, 2012). In parallel, many OEMs have voluntary targets to reduce production emissions\(^{25}\) that are likely to keep manufacturing emissions stable or lead to reductions over time.

Finally, end-of-life disposal and recycling do not generally make a significant contribution to life cycle CO\(_2\) emissions, with estimates of the order of a few percent at most (Ricardo, 2011; Ricardo-AEA, 2013). The situation changes with an increasing proportion of vehicles using alternative powertrains entering the market, as for electric vehicles, emissions associated with production increase the more the vehicle relies on the use of electricity, mainly due to emissions associated with the battery production. However, analysis for the UK Committee on Climate Change (Ricardo-AEA, 2013) has shown that the significance of batteries in the overall footprint of BEVs should be anticipated to decrease very significantly in the long term under the base case, due primarily to the following factors:

- The anticipated increase in battery gravimetric energy density (kWh/kg), reducing the materials use per kWh of battery storage;
- Reduced GHG intensity of the energy and materials used in battery manufacture;
- Improved overall vehicle efficiencies (i.e. reducing the size of the battery needed for a given operational range);
- Improved recycling processes, facilitating reuse of battery component materials;
- More localised manufacture of batteries (i.e. same region as vehicle manufacture itself) as electric vehicles become more mainstream. Currently batteries are predominantly manufactured in SE Asia, which has higher energy GHG intensity.

An additional consideration is also the battery lifetime. Battery replacement may not be required, since even with current technologies for light duty vehicles, the batteries are designed/anticipated to last the life of the vehicle under typical operating conditions. In addition, it is generally the calendar life of the battery, rather than the number of charge-discharge cycles that is the key limiting factor due to degradation of the battery chemistries currently used. Future battery systems are anticipated to improve on both the number of charge-discharge cycles, calendar lifetime durability, and resilience to frequent rapid charging (Ricardo-AEA, 2014).

Figure 5-6 provides an illustration of the projected change in significance of the battery to the lifecycle GHG footprint of a BEV car currently and projected to 2050. The figure shows that the lifecycle emissions are expected to significantly reduce in future years – mostly due to decarbonisation of electricity production, but also due to reduced emissions from battery production over time (due to reduced battery weight, decarbonisation of manufacturing energy, improved recycled and reduced GHG intensity of the materials used) (Ricardo-AEA, 2014).

\(^{25}\) Such as under EMAS (EU Eco-management and audit scheme) or ISO 14001
Figure 5-6: Estimated breakdown of GHG emissions from the lifecycle of a battery electric car (excluding operational electricity consumption), projected to 2050

In summary, the exclusion of embedded emissions from the scope of the Regulations to date is highly unlikely to have had a significant impact on the overall effectiveness in terms of reducing CO₂ emissions to date, due to the currently low penetration rates of BEVs. Consideration of embedded emissions in the future as the penetration of alternative powertrains increases could be required in some form in the future, in order to properly recognise the shifting of emissions to production. Further discussion of this issue is provided in Section 7.5 of Annex A.

5.4.1.2 Well-to-wheel emissions and lifecycle emissions

From the perspective of well-to-tank CO₂ emissions, the use of the specific CO₂ emissions of a vehicle as the metric in the Regulations has largely been appropriate to date. This is because as the vast majority of cars that are currently on the market are internal combustion engine vehicles (ICEVs), the focus of the Regulations on tailpipe emissions is not currently a significant issue. However, an increasing (though still small) proportion of vehicles on the market now use alternative powertrains, such as electric vehicles (EVs), and this proportion will continue to increase if the regulatory regime tightens beyond 2020. In the longer-term, therefore, it will be important to consider how best to take account of Well-to-Tank (WTT) as well as Tank-to-Wheel (TTW) CO₂ emissions. Otherwise there is a risk the effectiveness of the Regulations in reducing CO₂
emissions could be questioned if it delivered reductions in TTW CO₂ emissions, while at the same time increasing WTT CO₂ emissions and perhaps even WTW CO₂ emissions. Further discussion of this issue is provided in Section 7.4 of Annex A.

Figure 5-7 presents a comparison of results from the literature for different car powertrain types with respect to GHG emissions per km. The vast majority of LCA studies have focused on the assessment of car powertrain/fuel technologies. The LCA approach includes the well-to-wheels aspect of fuel production, as well as the embedded emissions discussed in the previous section.

**Figure 5-7: Comparison of car lifecycle GHG emissions estimates from the literature for different powertrain types**

<table>
<thead>
<tr>
<th>Car Type</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>Patterson et al. 2011 [UK]</td>
</tr>
<tr>
<td>HEV</td>
<td>Samaras &amp; Meisterling 2008 [USA]</td>
</tr>
<tr>
<td>PHEV</td>
<td>Hawkins et al. 2012 [USA]</td>
</tr>
<tr>
<td>REEV</td>
<td>Ma et al. 2012 [UK]</td>
</tr>
<tr>
<td>BEV</td>
<td>Lucas et al. 2012 [Portugal]</td>
</tr>
<tr>
<td>FCEV</td>
<td>Helms et al, 2010 [Germany]</td>
</tr>
<tr>
<td></td>
<td>Zamel &amp; Li 2006 [Canada]</td>
</tr>
<tr>
<td></td>
<td>Burnham et al. 2006 [USA]</td>
</tr>
<tr>
<td></td>
<td>[TfL LEV Study, 2014] [UK]</td>
</tr>
</tbody>
</table>

Notes: Estimates for the whole lifecycle emissions (LCA analysis) including all lifecycle stages, but excluding refuelling infrastructure

Source: (Ricardo-AEA, 2014)

The figures show that there is reasonable agreement with these literature sources for GHGs, although it is quite common to find a reasonable range of values for the ‘same’ vehicle and powertrain/fuel type in the literature. The main reasons for these differences are due to a combination of the following key factors (which can vary significantly between studies):

- Lifetime km (affects the importance/share of the use-phase emissions relative to vehicle production and disposal);
- Vehicle size/efficiency (in particular the relative efficiency of different technologies);
- Lifecycle stages covered and general boundary conditions (e.g. most studies don’t include refuelling infrastructure);
- (Grid) electricity or hydrogen production GHG intensity (the impact for other fuels is less significant, except where higher biofuel blends are also assessed);
- Batteries (i.e. size/weight/kWh capacity, GHG intensity of production, recycling, etc.)
Overall, HEVs, PHEVs, REEVs, BEVs and FCEVs are all expected to have lower lifecycle GHGs compared to ICE vehicles. In general, the differential in lifecycle GHG emissions between BEVs and FCEVs and other powertrain types is anticipated to significantly increase over time, with these vehicle types having the lowest GHG emissions. This is mostly due to decarbonisation of electricity and hydrogen production, but also due to reduced emissions from battery and fuel cell/hydrogen storage production over time (Ricardo-AEA, 2014).

Figure 5-8 compares passenger car powertrain/fuel variants assessed with a breakdown by lifecycle area for 2020 and the trend of the overall total lifecycle GHG to 2050. On a lifecycle basis by 2020 new BEV cars are expected to save 64% GHG compared to an equivalent petrol ICEV (and 51% vs a diesel ICEV) based on current projections for grid carbon intensity (in the UK). Savings increase up to 85% vs petrol ICEVs by 2050, despite significant remaining potential for improvements in ICEV efficiency in the medium-longer term. Savings for PHEVs and FCEVs are anticipated to be similar (43-46%) at this time point in the baseline assumptions for hydrogen production (i.e. ~60% hydrogen still produced from natural gas, the rest from electrolysis of water in 2020, decreasing to 50% by 2030).

**Figure 5-8: Estimated GHG emissions of different powertrain technologies for new cars**

![Diagram showing GHG emissions for different powertrain technologies](image)

*Notes: Includes vehicle cycle (production, use, recycling/disposal), fuel use, fuel production, fuel infrastructure and indirect land use change (ILUC), with reference to the UK.*

*Source: Ricardo-AEA (2014)*

The vast majority of LCA studies have focused on the assessment of car powertrain/fuel technologies and hence there are limited published estimates for LCVs; however we have been able to identify a limited number of studies that have also considered LCVs as shown in Figure 5-9. The comparisons between similar powertrain/fuel options is broadly similar for different vehicle categories, with the differentials between vehicles fuelled by electricity or hydrogen increasing in the future. Based on this, it can be concluded that the trends for LCVs will also be similar. For LCVs, dual-fuel diesel-natural gas technology options perform favourably compared to conventional diesel vehicles; the use of biomethane instead of natural gas further enhances their performance, with significant life-cycle emissions benefits for vehicles operating solely on biomethane compared to all other technologies.
5.4.1.3 Consideration of the rebound effect

First-order rebound impacts would suggest that consumers may increase their mileage in response to greater fuel efficiency (thereby leading to higher CO$_2$ emissions). The possibility of a rebound effect was considered in the Impact Assessment underlying the proposal for the legislation for 2020, estimated the first-order effects to be 25% (short term) to 60% (long term) based on an extensive literature review (TNO et al., 2011). A review of more recent literature indicates that the magnitude of the rebound effect is still uncertain, but sources generally produce estimates within this range.

For example, based on 17 studies in OECD countries, the “best guess” direct rebound effect for personal automotive transport is estimated to be between 10-30% (Maxwell et al., 2011). However, the findings show a very wide variation (between 5% and 87%) and depend on the model specifications applied, as well as variation in the quality of data and varying definitions (Gillingham et al, 2014). Furthermore, studies with greater credibility (based on the robustness of techniques used such as panel data methods, experimental designs, and quasi-experimental approaches) tend to provide estimates of the rebound effect that lie toward the lower end of the range (between 5 and 40 per cent), although these refer to short- or medium-run effects (Gillingham et al, 2014). Even so, the highest estimates found in the literature are typically less than 100%; hence even in the worst case the rebound effects cannot negate the overall improvement in emissions. The rebound effect is also unlikely therefore to negate the improvement in air quality emissions (due to reduced fuel consumption).

It is also worth noting that this first order rebound effect would suggest that distances driven should be increasing, which does not appear to be the case in practice (see Section 3.3). More recently, the possibility of second-order rebound effects has also...
been considered, which may counteract the first-order impacts and lead to increases in overall effectiveness as summarised in Table 5-6.

Table 5-6: Effects of changes in vehicle purchase and usage costs

<table>
<thead>
<tr>
<th>Type of effect</th>
<th>Mechanism and impact on effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect from higher purchase price</td>
<td>Reduced vehicle sales (reduced demand for vehicles) and shifts to smaller vehicles, which increases GHG savings.</td>
</tr>
<tr>
<td>Effect from lower fuel costs per km</td>
<td>Increased vehicle use, which decreases GHG savings.</td>
</tr>
<tr>
<td>Effect from net decrease in total cost of ownership (TCO)</td>
<td>Lower TCO may stimulate a shift to larger vehicles if payback is short, leading to decreased GHG savings, although the savings would have to be significant and have a short payback period. May also increase demand for vehicles and increase vehicle use, leading to decreased GHG savings. However, the effect strongly depends on the fuel price and in general payback times of more than 4-5 years are not expected to lead to rebound effects.</td>
</tr>
</tbody>
</table>
| Net overall effect | For 130 g/km target for 2015 a small decrease in overall effectiveness is expected (small increase in overall GHG emissions when taking these factors into account). For the 95 g/km target:  
  - A small increase in overall effectiveness is expected if technology costs are as anticipated in TNO et al (2011).  
  - A small decrease in overall effectiveness is expected if costs are lower (as indicated in more recent literature). |

Source: (AEA et al, 2012a)

Additionally, there are other potential rebound effects associated with substitution and income effects for other goods. Namely, this takes into consideration that consumers may spend the fuel cost savings on other goods and services, which may have energy consumption associated with them. The findings in the literature vary, but most recent work tends to find an estimate on the order of 5 - 15% (Gillingham et al, 2014).

A further method of assessing rebound effects is to consider the macroeconomic price effects. That is, when an energy efficiency improvement shifts the market demand curve for energy in, consumers and producers will adjust until a new equilibrium is reached. Quantifying this effect is very difficult, and there is very little empirical evidence on supply-side elasticities. Based on the available evidence Gillingham et al (2014) estimate that a total macroeconomic price effect of 20 - 30% is likely. Regardless of the actual supply-side elasticities, the macroeconomic price effect is certain to be less than 100% due to the downward sloping demand curve and upward sloping supply curve (Gillingham et al, 2014). Overall, although the mechanism of the rebound effect is widely accepted, the precise magnitude is still highly contested (Frodel et al, 2011). Nevertheless, the existing literature does not suggest that the rebound effect is large enough to reverse energy efficiency gains (Gillingham et al, 2014), while modelling the inclusion of second-order effects indicates that the overall rebound effect could be smaller than originally anticipated.

Moreover, Gillingham (2014) emphasises that, while rebound effects may reduce the emission-saving impacts of policies, rebound occurs from consumers responding to changes in relative prices – so by revealed preference it provides welfare benefits. It
follows that a net welfare decrease would only be possible if the external costs associated with these adjustments outweigh the private gains (which is possible in theory, but would require externalities that are so large they would outweigh the increased consumer surplus).

For LCVs, the rebound effects have been studied less intensively, and typically one must infer the values from studies of heavy goods vehicles (HGVs). Based on analysis carried out in TNO (2012), the total rebound effects of a change in the average new LCV CO$_2$ emissions from 175 g/km to 147 g/km (i.e. a 16% reduction) in terms of vehicle kilometres is roughly 0.8 – 1.6%. In terms of fuel consumption the rebound effect is roughly estimated at 1.6 – 2.6%. This is further supported by modelling carried out for the Impact Assessment underlying the 2020 modalities, which estimated that a very slight overall increase of transport demand would occur as a result of the fuel cost savings (TNO et al., 2012). By comparison, the reduction required between 2010 emission levels and the 2017 target of 175g/km is far lower (a reduction of 4%), hence the rebound effects based on the same elasticities would be very minor.

5.4.1.4 Impacts on emissions of other pollutants

This Section considers potential increases in other emissions due to fuel efficiency improvements, as follows:

- Due to improvements in ICE technologies;
- Due to hybridisation; and
- Due to electrification.

Impacts on air pollutant emissions may result from the choice of technologies that are used to meet the CO$_2$ reduction targets, as engine-related measures may improve or reduce the effectiveness of certain exhaust aftertreatment equipment and other emission reduction technologies (AEA et al, 2012a). If measures to reduce CO$_2$ emissions lead to decreased effectiveness of exhaust emission reduction technologies, these technologies will be adjusted to make sure that on the type approval test the applicable Euro emissions standards are still met. Overall, the impact on real-world emissions depends on the interplay between applied technologies in relation to the real-world driving loads (AEA et al, 2012a).

One specific concern has been that shifts to diesel vehicles may increase emissions of oxides of nitrogen (NO$_x$). Light-duty diesel vehicles are allowed slightly higher NO$_x$ emissions than petrol vehicles (180 mg/km under Euro 5 and 80 mg/km under Euro 6; the standard for petrol vehicles is 60mg/km under both Euro 5 and 6). Moreover, in contrast to petrol vehicles, diesel vehicles tend to far exceed the NO$_x$ limit values under real world driving conditions. For example, TNO (2013) tested a sample of Euro 6 diesel vehicles, finding that on average, real-world NO$_x$ emissions exceed test cycle limit values by around a factor of six$^{26}$. However, there is no conclusive evidence that the Regulations have increased the uptake of diesel vehicles in Europe to date (as discussed in more detail below in Section 5.4.2.2).

Another challenge is managing NO$_x$ emissions in the hybridisation of diesel vehicles, which is likely to be a key step to meet the emission targets set in the LCV Regulation. Fonseca et al. (2011) found that equipping a diesel vehicle with a start-stop system increased NO$_x$ emissions in urban driving conditions by around 20%, while reducing CO$_2$

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$^{26}$ From 2017/18 standards for ‘real driving emissions’ (‘Euro 6c’) are expected, although the modalities of the procedure have not been finalised yet (TU Graz, 2013). This should greatly reduce the observed gap between petrol and diesel NO$_x$ emissions and consequently trade-offs between CO$_2$ and NO$_x$ emissions.
emissions. Increased NO\textsubscript{x} emissions have also been found in trials of diesel hybrid LCVs (NREL, 2009). These increases are likely to be due to an interruption of the exhaust gas recirculation (EGR) cycle (Hofmann, 2010). EGR is the main means by which Euro 4 and 5 diesel engines control NO\textsubscript{x} emissions. Moreover, selective catalytic reduction (SCR) and lean NO\textsubscript{x} trap (LNT) aftertreatment systems which manufacturers use to meet Euro 6 standards operate within certain temperature bands. An interruption of the exhaust stream and a resulting cooling down of the system is also likely to lead to NO\textsubscript{x} peaks. However, potentials for decreases in NO\textsubscript{x} emissions through hybridisation have also been identified, primarily through easing the requirement of a rapid change in engine load (Hofmann, 2010).

For electric vehicles, there are clearly significant benefits to local air quality as there are no associated tailpipe emissions. Any pollutant emissions from their manufacture and electricity supply (if powered by the EU average electricity mix) are likely to have far lower health impacts than an equivalent quantity of emissions from the tailpipe, since vehicle production and power plant emissions mainly occur outside of urban areas. Although significant levels of NO\textsubscript{x}, sulphur dioxide (SO\textsubscript{2}) and particulate matter (PM) may be emitted upstream at power stations (especially when using coal), this effect is likely to diminish with the changing electricity generation mix, and emission reductions will be stimulated by legislation including the Large Combustion Plant Directive (LCPD 2001/80/EC), the Industrial Emissions Directive (2010/75/EU) and the Renewable Energy Directive (2009/28/EC).

Data on real world air pollutant emissions performance of hybrid and plug-in hybrid vehicles is more limited. However, improvements over a standard petrol vehicle can be expected. Based on a literature review Ricardo-AEA (2013a) suggests 50% improvements over standard petrol vehicles for hybrids in urban driving, and 90% for PHEVs. An important benefit of PHEVs is that when using the all-electric mode, all pollutants are shifted from the tailpipe to a small number of large power plants in less-populated areas.

Figure 5-10 presents a comparison between literature estimates of lifecycle NO\textsubscript{x} and PM\textsubscript{10} emissions. It shows that the same studies typically find lower lifecycle emissions of NO\textsubscript{x} and PM\textsubscript{10} from HEVs, PHEVs and FCEVs compared to ICEs. The lifecycle emissions from BEVs may be higher or lower depending on the assumptions made about the electricity generation mix (see Annex A for further discussion), although as noted previously the health impacts are typically lower due to the location of these emissions away from sensitive urban areas.
5.4.1.5 Overall assessment

A general conclusion from the above analysis is that in most cases the technologies and fuels with the greatest potential reductions in lifecycle GHG emissions, typically also have the greatest potential to reduce NOx and PM emissions. However, it should be noted that in general that the reverse is not usually true – i.e. technologies primarily

aimed at reducing NOₓ and PM emissions (e.g. engine-based measures or exhaust aftertreatment systems) generally have a negative impact on (i.e. increase) CO₂ emissions from vehicles (Ricardo-AEA, 2014). In addition, the differential in lifecycle GHG emissions between BEVs and FCEVs and other powertrain types is anticipated to significantly increase over time, with these vehicle types having the lowest GHG emissions. This is mostly due to decarbonisation of electricity and hydrogen, but also due to reduced emissions from battery and fuel cell/hydrogen storage production over time (Ricardo-AEA, 2014).

This assessment includes the impact of non-tailpipe emissions (embedded emissions and well-to-wheel emissions), which are not currently included in the scope of the Regulation, and the conclusions apply both to cars and LCVs. In addition, consideration of a potential rebound effect shows that the impacts on overall effectiveness are likely to be very minor, again both for cars and LCVs, when second-order effects are taken into account.

5.4.2 Improving the EU’s security of energy supply

In the context of the Regulations, improvements in car and LCV fuel efficiency were expected to reduce European oil imports, which in turn would reduce the risks caused by potential sudden disruptions in supply, as well as diversifying fuel consumption. That is, energy security was assessed in terms of:

- Impacts on imports of oil;
- Impacts on the relative balance of petrol and diesel; and
- Impacts on the diversity of transport fuel consumption.

5.4.2.1 Impacts on imports of oil

There has been a small increase in the share of road transport in total consumption of oil products, rising from around 51% in 2006 to 53% in 2012, although absolute oil consumption in the road transport sector has fallen (Eurostat, 2014a). Overall, gross consumption and the absolute level of imports for petroleum products have declined, which is positive in terms of energy security (Figure 3.5). The EU-28’s gross consumption of petroleum products in 2007 was around 655 Mtoe, falling to around 570 Mtoe in 2012. On the other hand, import dependency has increased somewhat from 91.2% in 2007 to 93.4% in 2012, which is clearly negative from an energy security perspective. It is expected that Europe’s oil import dependency will continue to rise as domestic stocks are depleted. This trend, along with the increasing importance of road transport in total oil consumption, means that fuel efficiency is likely to become more important from an energy security perspective.

This suggests that LDV fuel consumption and oil-related aspects of energy security are closely interlinked.

The calculations of oil consumption under the Regulations compared to the baseline show that lifetime reductions in oil-based road transport fuel consumption for new vehicles registered since the introduction of the Regulations have been achieved (see Table 5-7). For future years these savings are likely to grow further as the number of vehicles affected by the Regulation increases.
Table 5-7: Lifetime oil-equivalent savings from new cars and LCVs (real-world performance)

<table>
<thead>
<tr>
<th></th>
<th>New cars registered between 2006 to 2013</th>
<th>New LCVs registered between 2010 and 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption savings</td>
<td>35.9 Mtoe</td>
<td>1.4 Mtoe</td>
</tr>
<tr>
<td>% saving</td>
<td>3.6%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Notes: Test cycle uplift factor for cars derived from ICCT (2014e) and for LCVs derived from databases of real-world fuel economy
Source: baseline calculations, see Section 5.5 and Annex B

5.4.2.2 Impacts on the relative balance of petrol and diesel

The trend towards increased diesel use in the transport sector has implications for energy security. An imbalance within the demand for refined oil products, specifically petrol and diesel, may also be relevant to energy security. Although the EU has ample refining capacity to cover its overall demand for petroleum products, there is a mismatch between supply and demand for particular products. As noted in Section 3.3, Europe’s demand for diesel is partially met by imports from Russia, but also from the US, Norway and others. However, demand for petroleum products in non-EU regions is projected to grow significantly — especially for middle distillates such as diesel. Thus, global competition is expected to grow for supplies of diesel and thus prices are expected to increase. At the same time, the capacity of the US market to absorb excess European petrol production is declining, and finding new outlets is becoming increasingly difficult. This may lead European refiners to lower overall production, thus further increasing import dependence for diesel and other middle distillates.

Even taking into account falling EU demand, it appears highly likely that the EU’s import dependence on diesel will increase in future (European Commission, 2014c). While structural imbalances in the transport fuel market may not necessarily pose security of supply issues as long as a sufficiently diverse number of suppliers is maintained, an increasing (worldwide) imbalance in demand may lead to higher fuel prices.

Although disaggregated statistics are not typically available to show what proportion of total diesel consumption is accounted for by cars, national sources from Germany, France and UK indicate that close to two thirds of road fuels are used by cars (GOV.UK, 2014; MEDDE, 2013; DIW, 2013). This indicates that the increasing market share of diesel-fuelled cars is likely to be an important reason for the shift in transport fuel demand in Europe.

Nevertheless, while the structural imbalances in European refining and demand for petrol and diesel are clearly negative in terms of energy security implications, it appears that the CO₂ Regulations have not had a clear role in contributing to this imbalance. The results from the empirical analysis, discussed in Section 5.2 and Annex E, suggest that the Regulations have not had a significant impact on increasing the share of diesel-fuelled cars to date. This is further supported by a large body of economic literature using econometric models, which suggests that in Europe, it is likely that factors other than the Regulations (especially national vehicle registration taxes and consumer preferences) have had a large impact on the trend towards dieselisation (see Annex C – Section 7.6).
5.4.2.3 Impacts on the diversity of transport fuel consumption

Energy security could also be enhanced by diversifying the fuel sources – a wider range of fuels used in road transport will generally mean a wider supplier base and reduced import dependency.

The car and LCV CO₂ Regulations encourage the uptake of alternative fuels through two mechanisms:

- **Indirect incentives:** for example, LPG- and CNG-fuelled vehicles tend to have lower CO₂ emissions compared to petrol variants due to the lower carbon content per unit of energy in these fuels. While diesel and petrol have similar CO₂ emissions per kWh on combustion, CO₂ emissions from burning gaseous fuels are substantially lower, in the case of LPG around 10-15% and in the case of CNG around 25% (Defra 2014).

- **Direct incentives:**
  - For vehicles fuelled by E85\(^{27}\)
  - Super-credits for vehicles with emissions <50 gCO₂/km, which mostly affects battery electric and plug-in hybrid vehicles, as every electrically driven km is rated at zero gCO₂ (i.e. only tailpipe emissions are included).

The impact of the Regulations on uptake of alternative fuels in cars and LCVs has to date been relatively small in terms of overall shares in fuel consumption. Consequently, there has been a very minor level of diversification away from petrol and diesel in road transportation, which is mostly due to the increasing share of biofuels in road transport, which is regulated separately in Europe under the Renewable Energy Directive (2009/28/EC) and the Fuel Quality Directive (2009/30/EC) (see also Section 5.8).

Although the share of new alternatively-fuelled cars in new registrations has grown in recent years, the share of alternatively fuelled passenger cars in the total fleet remains low, although it has increased from approximately 1.7% in 2004 to 4% in 2012 across the 13 Member States for which data are available\(^{28}\) (Eurostat, 2014b). Most of these are LPG cars. However, there are vast differences across Member States: for example, while most Member States have virtually no uptake, the share of passenger cars running on LPG in Poland is 15%. Similarly, for LCVs the penetration level is low across the EU-28, with the share of alternatively fuelled LCVs in new registrations at 1.5% in 2013 (EEA, 2014).

Furthermore, it is likely that Member States’ incentives play a far more decisive role for uptake of gaseous fuels and bioethanol compared to the Regulation. As a result, Member States with long term reductions in excise duty for gaseous fuels, tax rebates for the purchase of such vehicles and infrastructure in place tend to be more successful in encouraging uptake as this reduces the breakeven point (see Figure 5-11). In general, the quicker the additional costs for an LPG vehicle over a petrol vehicle are recovered in a country (expressed as breakeven distance), the higher the uptake of LPG as a vehicle fuel.

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\(^{27}\) A petrol blend containing 85% bioethanol. Article 6 of the Cars Regulation grants a further 5% reduction over measured test cycle emissions in the case of E85-capable vehicles if E85 is available in at least 30% of the Member State’s filling stations

\(^{28}\) Austria, Belgium, Croatia, Cyprus, Estonia, Finland, Germany, Italy, Latvia, Netherlands, Poland, Sweden, United Kingdom
评价443/2009和510/2011号法规对轻型车辆CO₂排放的影响

图5-11: 液化石油气(LPG)在汽车燃料消耗中的份额与汽油的致损距离对比图

来源: World LP Gas Association (2012)

总体差异在经济上不能完全解释LPG在欧盟成员国之间的巨大差异;公共意识和感知以及基础设施的可用性可能是起重要作用的因素(Hu和Green, 2011)。

在实践中,许多目前在欧洲运行的CNG和LPG车辆是汽油车辆的转换。也就是说,该法规不会成为这些车辆采用的驱动力,因为这些车辆的实际排放节省不会计入制造商的官方CO₂车队平均数。有迹象表明制造商在近年来引入了CNG和LPG变体(单燃料和双燃料)(NGVA, 2014)。例如,斯柯达Citigo Greentech在汽油变体中排放95 gCO₂/km,而等效的CNG变体排放79 gCO₂/km(NGVA, 2014)。

同样,生物乙醇(E85)车辆,除了瑞典之外,在欧洲没有显著使用(ICCT, 2014b)。E85车辆在瑞典的采用主要是由于国家激励(瑞典绿色汽车退税)而不是法规(Huse, 2012);(Sprei, 2013)。

鉴于石油在欧洲电网发电中已基本被淘汰(European Commission, 2014b),插电式混合动力和电池电动车辆也对多样化运输能源使用有贡献。2012年,电动车辆在欧洲的新车注册中占0.2% (ICCT, 2014b)。其在整个车队中的份额远低于其对运输燃料组合的影响是可以忽略不计的。决定电动车辆采用的主要因素是国家/区域财政激励和充电基础设施的建设(Sierzchula et al, 2014)。

总体而言,法规对多样化运输燃料的影响到目前为止非常有限,任何对能源安全的显著改善都归因于电动车辆的电气化是尚未看到的。然而,这些车辆的发展可能受到了法规尾气排放目标的影响,国家/区域的市场需求被认为对支持商业化是重要的(Sierzchula et al, 2014)。由于所有电网的电力均被视为0 gCO₂/km下NEDC测试程序,并根据达成2020目标的妥协(Regulation (EU) 333/2014)
grants super-credits to passenger cars with emissions below 50 gCO₂/km, the sale of BEVs, RE-EVs and PHEVs may become an attractive way for manufacturers to fulfil their 2020 targets. It is thus conceivable that the CO₂ Regulations may contribute to reduced oil dependence through electrification over the coming years (although part of this will be replaced by the share of fossil fuels – particularly coal and gas – in the electricity generation mix).

5.4.3 Fostering the competitiveness of the European automotive industry and encouraging innovation in fuel efficiency technologies

5.4.3.1 Impacts on competitiveness

Leadership in fuel efficiency was expected to encourage exports of technologies and vehicles to emerging markets in the short term, and provide a long-term competitive advantage in low-carbon technologies for cars and LCVs. It has been recognised by industry that (CARS 21 High Level Group, 2012):

"...competitiveness in the medium term can only be ensured if the industry delivers the sustainable and advanced products required by the markets”,

And further that:

"Manufacturing activity in the EU, particularly for volume segments, is facing serious and structural challenges which impact its competitiveness and may put pressure towards further restructuring. Technological innovation is definitely an asset of the EU industry, in part linked to ambitious regulation, in part to a demanding and diverse customer base”.

At this stage it would be premature to try to quantify the impacts of the Regulation on indicators of competitiveness due to the short timescales involved (and considering that the most significant impacts are expected in the long term) and the turbulence of the recent economic climate.

Nevertheless, it appears that stakeholders are generally supportive of the view that the Regulations have positive impacts on innovation and competitiveness. As part of a public consultation carried out by the Commission, 72% of stakeholders (over 130 groups) and 83% of individuals (over 3,000 responses) agreed or partly agreed that EU regulation of road-vehicle emissions stimulates innovation in the automotive sector and helps keep Europe's automotive industry competitive (European Commission, 2012b).

Additional views were sought from stakeholders in the survey carried out for this study in order to better understand any differences in short- and long-term impacts. Despite the smaller sample size compared to the public consultation, the results are in general agreement with a majority (59%) responding that the Regulations were at least somewhat effective in terms of improving long-term competitiveness of the automotive industry, while the short-term impacts on competitiveness were expected to be less positive (see Section 15.2 of Annex I). In general it appears that the stakeholders responding to the survey judged there to be a relatively strong relationship between the impacts on short- and long-term competitiveness. There was also a moderate relationship between impacts on innovation and competitiveness, but only a weak relationship between impacts on R&D spending and innovation and/or competitiveness. In the longer term, it was generally considered that manufacturers would be able to adapt more easily, hence impacts on competitiveness would be more positive.

Explanations provided by stakeholders for the possibility of detrimental impacts on competitiveness in the short term mainly stemmed around mismatches in supply and
demand for fuel efficient technologies, since the Regulation “has not necessarily followed natural market cycles”. One stakeholder noted that it was not always possible to market certain fuel efficient technologies outside of Europe due to issues around fuel quality (e.g. stratified injection engines that could not be sold in other markets) or regulatory design (e.g. flex fuel vehicles are recognised under the US legislation, but not in Europe).

A comparison with developments in international legislation (see Annex G for further detail) shows that globally, targets for CO$_2$ emission reductions are converging. The EU regulatory targets for passenger cars in 2021 are currently more stringent than those in other major markets. However, targets in all countries are clearly tightening. A number of countries have either introduced or plan to introduce targets for LCVs. While targets set in Europe are the most stringent of those currently enacted or planned for 2020, without further tightening the European targets will be overtaken by the USA and Canada by 2025. The annual rate of reductions required for the European passenger car fleet are among the highest in the world (albeit lower than for the USA and China), whereas the targets for LCVs require the least rapid rate of annual reductions of all global standards currently enacted (including USA, Mexico and China).

Thus far the fuel efficiency regulations implemented globally show a great deal of diversity in terms of their structure, test cycles and utility parameters. While it is generally recognised that international harmonisation of standards would be beneficial for manufacturers, the EPA and NHTSA (2012) note that “it is entirely possible that footprint-based and weight-based systems can coexist internationally and not present an undue burden for manufacturers if they are carefully crafted”. They further note that the key interaction is thought to be how stringent the standards are, as well as how they are tested and enforced (EPA and NHTSA, 2012).

Comparisons between the USA, Germany, Australia and France have found that vehicle fuel efficiency technology is very similar in spite of significant differences in fuel prices and incomes (GFEI, 2014). One explanation for the similar rates of CO$_2$ emission reductions seen across developed country markets is that they are being supplied by the same set of major global auto-manufacturers, who are responding to regulatory pressure by adopting similar technology for all developed country market (GFEI, 2014). Nations that rely on imported vehicles for most or all of their vehicle fleet also enjoy positive spillover effects in terms of having the latest fuel economy technology, since most vehicles are imported from the EU, Japan and Korea – for example, the Australian situation shows that improvements in its light vehicle fleet have kept pace with the EU and US fleets even though there are no fuel economy standards in Australia. This suggests that fuel economy regulations in these countries play an important role in determining manufacturer technology introduction plans (GFEI, 2014). This effect has also been reported for developing countries that import most of their vehicles from Europe and Japan, such as South Africa; however the CO$_2$ emission savings from exported EU models has not been quantified (GFEI, 2014).

5.4.3.2 Impact on innovation in fuel efficient technologies

The policy objective of setting tighter requirements on CO$_2$ emissions and fuel efficiency was expected to promote innovation, development and market penetration of new environmental technologies. It was thought that the target provided the main stimulus for impacts in the area of research (European Commission, 2007b). This was further confirmed by industry in the CARS 21 report (CARS 21 High Level Group, 2012):

“The regulatory targets for light duty vehicle CO$_2$ emissions are essential for ensuring the reductions needed to meet the EU medium and long term climate objectives. These are also expected to drive innovation.”
Further analysis in this section is based on key indicators of innovation and technology development, as follows:

- Analysis of impacts on R&D;
- Analysis of impacts on patenting activity;
- Analysis of impacts on technology development;
- Analysis of impacts on technology adoption.

Evaluating the impact of the Regulation on R&D spending is challenging since the specific areas of research that are funded are not reported and many other factors are likely to have had an impact, such as changes in business strategy and adjustments in R&D capacity in response to the decrease in production and sales volumes in Western Europe (JRC, 2013). Nevertheless, in 2012 the European automobiles and parts sector had a higher R&D intensity compared to Japan and the USA, at 5.1% compared to 4.3% in Japan and 3.7% in the USA (JRC, 2013). Drivers of increased R&D spending are reported to include fuel economy standards, as well as emission standards, product differentiation and cost reduction (JRC, 2012).

Although the relative importance of these factors is difficult to quantify, Bonilla et al. (2014) found that the propensity of firms to innovate in diesel engine efficiency is partly correlated with market size (i.e. increasing popularity of diesel cars) and more weakly affected by the ACEA voluntary agreement (the car and LCV CO₂ Regulations were not explicitly investigated). Other literature suggests that international fuel efficiency regulations may induce increases in R&D spending on fuel-efficient technologies: for example, recent increases in R&D spending by Toyota are thought to have been largely to meet fuel economy standards and improve electronics (The Economist, 2012), while historical evidence from the USA suggests that the introduction and adoption of the CAFE standards increased US firms’ R&D activities respectively by 30% and 40% (Cho, 2012). The trends suggest that the industry has responded to the Regulations by increasing its R&D intensity.

Stakeholder opinions also suggest that the Regulation may have had a positive impact on R&D spending. Several noted that many of the factors driving R&D for fuel-efficient technologies were growing more intense (including national incentives and road charges). However, even stakeholders within the industry were not able to concretely determine the impact of the Regulation on R&D spending, with most noting that decisions were affected by many factors. Even so, the overall opinion was that the impact is naturally positive in terms of encouraging greater R&D.

On the other hand, qualitative responses to the survey indicated that several stakeholders felt that spending on R&D did not necessarily contribute to innovations or competitiveness because the outcomes of R&D investment are uncertain.

Despite this, stakeholder responses were largely supportive of the impact on innovation. Of those surveyed, 90% stated that they felt the Regulations had been somewhat effective or highly effective in fostering innovation in the automotive sector. Similarly, a wider public consultation carried out by the European Commission in 2012 found that 72% of stakeholders and 83% of individuals agreed or partly agreed that EU regulation of road-vehicle emissions stimulates innovation in the automotive sector and helps keep Europe’s automotive industry competitive (European Commission, 2012b).

Another avenue for analysis is to examine patent applications, which can provide an indication of the level of interest and investment in a technical field and can be considered as output indicators of research efforts. Patents give the owner power to restrict or license the use of the invention, and thus secure some market advantage. A patent application is created when a firm files a written request for patent protection at a patent office. Patent applications provide the most recent data, as it takes several years to reach grant stage.
Statistics for "triad" patent applications are used for the analysis in this report – i.e. those filed in Europe, the US and Japan. There are several reasons for this:

- In general, inventions with promising economic possibilities are patented in multiple countries whereas trivial contributions are not. This is because of the additional costs of filing abroad, so only the most valuable inventions are filed in several countries.
- It mitigates the effect of 'home advantage', where typically applicants prefer to file applications in their own countries, and consequently a disproportionate weight would usually be given to local applicants if analysing European patent data;
- Statistics are more comparable, as national filings are influenced by many factors, including differences in culture, local industry, government incentives, economic climate and intellectual property laws.

Figure 5-12 shows the evolution of international patent applications between 2005 and 2011 for technologies specific to Internal Combustion Engine (ICE) and technologies specific to electric motors (including electric and hybrid vehicles) according to the country of origin. Europe has historically been the leader in patenting ICE technology; however, Japan has been catching up with a 47% increase between 2005 and 2011, compared to a 13% increase for Europe. Japanese companies are clearly the most active in technology clusters related to propulsion using electric motors – and although overall activity has historically been much lower compared to ICE technologies there have been rapid gains in recent years, especially since 2008. In Japan the number of new patent applications in 2011 was about equal for ICE and electric motor technologies, while Europe and the USA continue to file a higher proportion of their patents for ICE technologies.

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29 Including technology clusters related to engines in general, control of combustion engines, fuel injection/supply, engine values, gearing, control of lubrication, exhaust apparatus, couplings/crankshafts and steering.
Figure 5-12 Evolution of international patent applications in technologies specific to propulsion using ICE and electric motors

Notes: A three-year rolling average is used, as patent applications tend to fluctuate year-on-year due to factors unrelated to inventive activity. A rolling average provides more reliable data and helps to reduce the influence of random fluctuations in patenting dynamics. The technology areas are selected according to the International Patent Code (IPC), indicated in the title of each graph. The IPC classification is a standardised system to identify the technology groups to which an innovation belongs, which has been published since 1968. Currently the IPC is used in more than 100 countries as the major (or, in some cases, the only) form of classifying patents.

Source: data from OECD Patstat database, analysis by Ricardo-AEA

These data show that Europe maintains its lead in patenting activity for ICES, while Japan maintains its lead in patenting of technologies for electric vehicles.

The results should also be taken in context with trends in general patenting activity as well. Figure 5-13 shows the trend in growth rate for overall patenting activity in the EU-28 compared to the previous year. While trends in ICE patenting activity tend to follow the overall patenting activity quite closely, there have been significant deviations for propulsion using electric motors, with growth rates far exceeding overall patenting rates. This indicates increasing focus of European firms on electric and hybrid vehicles, with activity spiking just before and following the introduction of the car CO₂ Regulations in 2007 and falling after the economic crisis in 2008/2009.
The market share of hybrid electric vehicles is still relatively low at 1.4% of all new car sales in 2013, lagging behind Japan (at around 20% of all new car sales in 2013) and the USA (around 6% of passenger cars sales) (ICCT, 2014c). Plug-in hybrid (PHEV) and battery-electric vehicles (BEV) make up about 0.4% of vehicle registrations in the EU, with registrations reaching around 25,000 for BEVs in 2013 compared to 700 in 2010, and 31,000 PHEVs in 2013 (EEA, 2014). For LCVs, there were around 6,000 newly registered electric vehicles in 2013 compared to 5,600 in 2012 (EEA, 2014).

Finally, examining trends in uptake of fuel efficient vehicle technologies shows that they are gaining increasing traction in the European market. Figure 5-14 compared the uptake of fuel efficient technologies applicable to gasoline and diesel vehicles, all of which have seen strong growth in uptake between 2010 and 2013 (especially for weight reduction of at least 5% across the whole vehicle).
Examining trends specific to technologies in diesel cars shows that start stop technology has seen the highest growth rate, reaching around 55% in 2013 (see Figure 5-15). Other technologies have increased their market penetration by around 17%, including advanced high pressure fuel injection and auxiliary system improvement, while micro-hybrids, downsizing, 6-speed dual clutch transmission and advanced EGR technology have all increased their penetration rates by 7-9 percentage points.

*Source: (Ricardo-AEA et al, forthcoming)*
Similarly, several technologies specific to gasoline passenger cars (see Figure 5-16) have seen strong growth of around 15-20 percentage points between 2010 and 2013, including downsizing and turbocharging, low friction design and materials, gas wall heat transfer reduction, auxiliary system improvement and variable valve actuation. Start stop technology has seen the most impressive uptake, rising from around 11% in 2010 to more than 40% in 2013.

Figure 5-16: Trends in uptake of fuel-efficient technologies in European passenger cars (gasoline)

Overall it appears that the penetration of a number of fuel-efficient technologies has increased significantly in European cars between 2010 and 2013. Data from the USA show that the rate of technology adoption can be very rapid after new technologies are deployed for the first time due to platform sharing, improved manufacturer flexibility and the competitive nature of the market, especially in response to performance standards (ICCT, 2013c). A somewhat similar pattern has also been observed in the Chinese new car fleet (although technology adoption still lags Europe and the US), which is likely driven by the Phase 3 fuel consumption standards proposed in 2009 and formally adopted in 2011, as well as multiple incentive policies (ICCT, 2013c). Hence, the increasing pace of technology diffusion in the past decade in the USA and China appears to be, at least in part, a function of the light-duty vehicle GHG emissions regulations,
suggesting that overall regulations play a role in supporting technology uptake (see also Annex G).

As shown in Table 5-8, the rate of technology uptake in LCVs has also increased between 2010 and 2013, although the penetration rates are usually slightly lower for each technology compared to the level of uptake in cars. This is to be expected since the standards have not been in place for as long and the target year is in 2017. It can also be seen in Table 5-8 that in many cases, similar technologies are being applied to both cars and LCVs.

**Table 5-8: Technology adoption rate for LCVs (2010 and 2013) and cars (2013)**

<table>
<thead>
<tr>
<th>Technology</th>
<th>LCVs</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2013</td>
<td>2010</td>
<td>2013</td>
</tr>
<tr>
<td>Gasoline - Gas wall heat transfer reduction</td>
<td>50%</td>
<td>67%</td>
<td>50%</td>
<td>67%</td>
</tr>
<tr>
<td>Gasoline - direct injection (homogeneous and</td>
<td>5%</td>
<td>19%</td>
<td>21%</td>
<td>41%</td>
</tr>
<tr>
<td>stratified charge)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline - Downsizing and turbocharging</td>
<td>36%</td>
<td>63%</td>
<td>59%</td>
<td>75%</td>
</tr>
<tr>
<td>Gasoline - Variable Valve Actuation and Lift</td>
<td>3%</td>
<td>8%</td>
<td>12%</td>
<td>15%</td>
</tr>
<tr>
<td>Gasoline - Cam phasing</td>
<td>74%</td>
<td>73%</td>
<td>66%</td>
<td>73%</td>
</tr>
<tr>
<td>Gasoline - low friction design and materials</td>
<td>36%</td>
<td>63%</td>
<td>59%</td>
<td>75%</td>
</tr>
<tr>
<td>Gasoline - cylinder deactivation</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>Gasoline - 6-speed dual clutch transmission</td>
<td>0%</td>
<td>3%</td>
<td>0%</td>
<td>12%</td>
</tr>
<tr>
<td>Gasoline - automated manual transmission</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>Gasoline - CVT</td>
<td>0%</td>
<td>0%</td>
<td>6%</td>
<td>2%</td>
</tr>
<tr>
<td>Gasoline - Belt alternator starter HEV (micro-</td>
<td>0%</td>
<td>0%</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>hybrid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline - Belt-driven starter generator start-stop system</td>
<td>10%</td>
<td>18%</td>
<td>3%</td>
<td>43%</td>
</tr>
<tr>
<td>Gasoline - Power split hybrid</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (replacing</td>
<td>0%</td>
<td>0%</td>
<td>11%</td>
<td>8%</td>
</tr>
<tr>
<td>uncooled)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (no EGR in</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>8%</td>
</tr>
<tr>
<td>baseline)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline - Electrical air conditioning (auxiliary system improvement)</td>
<td>50%</td>
<td>67%</td>
<td>1%</td>
<td>67%</td>
</tr>
<tr>
<td>Gasoline - Electric / electro-hydraulic power steering</td>
<td>30%</td>
<td>42%</td>
<td>6%</td>
<td>89%</td>
</tr>
<tr>
<td>Diesel - downsizing</td>
<td>17%</td>
<td>23%</td>
<td>6%</td>
<td>59%</td>
</tr>
<tr>
<td>Diesel - advanced high pressure fuel injection (combustion improvement)</td>
<td>0%</td>
<td>0%</td>
<td>50%</td>
<td>67%</td>
</tr>
<tr>
<td>Diesel - VVT</td>
<td>8%</td>
<td>12%</td>
<td>89%</td>
<td>10%</td>
</tr>
<tr>
<td>Diesel - high pressure, low pressure cooled EGR (Thermal management)</td>
<td>0%</td>
<td>0%</td>
<td>51%</td>
<td>10%</td>
</tr>
<tr>
<td>Diesel - automated manual transmission</td>
<td>2%</td>
<td>3%</td>
<td>50%</td>
<td>4%</td>
</tr>
<tr>
<td>Diesel - CVT</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
<td>1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>LCVs</th>
<th>Cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel - dry 6-speed dual clutch transmission</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td>Diesel - Belt alternator starter HEV (micro-hybrid)</td>
<td>1%</td>
<td>9%</td>
</tr>
<tr>
<td>Diesel - Belt-driven starter generator start-stop system</td>
<td>16%</td>
<td>29%</td>
</tr>
<tr>
<td>Diesel - Electrical air conditioning (auxiliary system improvement)</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Diesel - Electric / electro-hydraulic power steering</td>
<td>16%</td>
<td>41%</td>
</tr>
<tr>
<td>Weight reduction - whole vehicle: At least 2.5% reduction</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 5% reduction</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 10% reduction</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Aerodynamic improvements - mild</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Aerodynamic improvements - strong</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Low rolling resistance tyres</td>
<td>6%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Source: (Ricardo-AEA et al, forthcoming)

Additional supporting evidence comes from the analysis of Berggreen and Magnusson (2012) suggests that the EU CO₂ emission Regulation has stimulated the initial development of fuel-saving model variants by some manufacturers, which has kicked-started broader competition for reducing fuel consumption among all mainstream manufacturers - setting a new trend in this direction. For example, their interviews with staff at Volvo suggest that the company initially had very few fuel-savings concepts in the pipeline when other manufacturers started introducing their fuel-saving model variants to the market.

Several respondents specifically mentioned the provisions for eco-innovations in encouraging this innovation for off-cycle technologies. One stakeholder mentioned that this provision is "starting to have a real impact and with a number of technologies in the pipeline". Several eco-innovation applications had already been approved at the time of writing, including:

- Audi Light-emitting diodes in exterior applications;
- Valeo efficient Generation Alternator;
- Daimler engine compartment encapsulation system;
- Bosch system for navigation-based preconditioning of the battery state of charge for hybrid vehicles;
- Automotive Lighting Reutlingen GmbH light emitting diodes (LEDs) low beam module, 'E-Light';
- Denso efficient alternator; and
- Webasto solar roof.

Source: (Ricardo-AEA et al, forthcoming)

Additionally, when asked to provide specific examples of technologies that the Regulations had helped bring to market (excluding eco-innovations), stakeholders provided the following examples, which are broadly in line with the findings above:

- Start-stop technology and other forms of hybridisation, including hybrid versions of high-performance cars (e.g. McLaren P1 hybrid);
- Lightweight construction, such as new welding procedures to produce lighter and thinner exhaust systems and carbon fibre components.
- New technology companies and start-ups, such as Flybrid.

Concluding, there is sufficient evidence supporting the view that the introduction of the Regulations has had a positive impact on innovation through encouraging higher R&D, development of technologies and deployment of fuel efficient technologies in the market.

5.4.4 Ensuring competitively neutral targets

The car and LCV CO₂ Regulations aimed to implement the CO₂ reduction targets in a way that was as neutral as possible from the point of view of competition.

“Competitive neutrality” refers to differences in impacts between manufacturers of vehicles and components operating in the same market. The Regulations aimed to avoid any (unjustified) distortion of competition between manufacturers. Note that the focus in this section is on the neutrality of the impacts on competition, and not on promoting the competitiveness of the industry overall (see previous Section for analysis of this issue).

This section is based on the analysis of:

- Observed compliance with CO₂ emission reduction targets;
- Predicted and observed vehicle retail price changes in relation to CO₂ emission reductions;
- Vehicle retail price changes in relation to vehicle mass;
- Changes in average vehicle mass and by vehicle segment;
- The use of super-credits for target achievement; and
- The change in market shares of different manufacturers.

Each section treats passenger cars and LCVs separately. However, since the data available for LCVs is very limited (especially regarding average retail prices) not all aspects could be explored equally. Furthermore, developments such as changes in average vehicle mass or market shares that might be due to the Regulation can only be observed over a shorter period of time for LCVs, resulting in less reliable findings.

5.4.4.1 Compliance with CO₂ emission reduction targets

Regulation (EC) No 443/2009 for passenger cars allows for several flexibilities regarding manufacturers’ specific CO₂ emission targets as calculated according to the formulas given in Annex I of the Regulation. These flexibilities contribute significantly in enabling certain manufacturers to achieve their targets (as is shown in the following analysis). The following four flexibilities have been introduced:

1. **Pooling of manufacturers**: Manufacturers can decide to form a pool of two or more distinct manufacturers. These manufacturers then have to meet their pool-specific CO₂ emission target, which is based on the average mass of all new registered passenger cars of the manufacturers in the respective pool. Hence, individual manufacturers that fail their manufacturer-specific target but belong
to a pool that meets its pool-specific target do not face any penalty payments. (Art. 7)

2. **Derogations for small-volume manufacturers**: A small-volume manufacturer derogation is available for a manufacturer which is responsible, together with all of its connected undertakings, for **fewer than 10,000** new passenger cars registered in the Community per calendar year. Such a manufacturer has to apply for a derogation by suggesting an **alternative CO₂ emission target** (which has to be in line with its reduction potential, and take into account the characteristics of the market for the type of car manufactured). (Art 11(3))

3. **Derogations for niche manufacturers**: A niche manufacturer derogation is available for a manufacturer that is responsible, together with all of its connected undertakings, for **between 10,000 and 300,000** new passenger cars registered in the Community per calendar year (Art 11(4)). Such a manufacturer has to apply for a derogation by setting a **target which is a 25 % reduction on the average specific emissions of CO₂ in 2007** (or of the undertakings’ average specific emissions of CO₂ in 2007 where a single application is made in respect of a number of connected undertakings). (Art 11(4))

4. **De minimis derogations**: Manufacturers responsible for **less than 1,000** new passenger cars in the Community per calendar year, **as well as for special purpose vehicles**, such as vehicles built to accommodate wheelchair access, do not have to comply with any CO₂ emission targets as set out in the Regulation. They are not within the scope of this Regulation.

These flexibilities are available for manufacturers to use in order to reduce the stringency of their manufacturer-specific CO₂ emission target as it would have otherwise been calculated according to the formulas given in Annex I of the Regulation.

Table 5-9 sets out the number of manufacturers that used/benefited from one or more of the above flexibilities, as well as the number of manufacturers that fall into the real scope of the Regulation. The table shows that most car manufacturers (namely 69 out of 84) used one of the above flexibilities. 17 of these benefit from the de minimis derogation and thus do not fall into the scope of the Regulation.

**Table 5-9: Passenger car manufacturers that used/benefitted from flexibilities in 2013**

<table>
<thead>
<tr>
<th>Manufacturers...</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of car manufacturers</td>
<td>84</td>
</tr>
<tr>
<td>... benefiting from a de minimis derogation (hence out of scope of the Regulation)</td>
<td>17</td>
</tr>
<tr>
<td>Total number of car manufacturers within the scope of the Regulation</td>
<td>67 (=84-17)</td>
</tr>
<tr>
<td>... of which are not using any flexibility</td>
<td>15</td>
</tr>
<tr>
<td>... of which are using one (or more) of the above-described flexibilities</td>
<td>52</td>
</tr>
<tr>
<td>... taking part in a pool</td>
<td>42*</td>
</tr>
<tr>
<td>... benefiting from a small-manufacturer derogation</td>
<td>8</td>
</tr>
<tr>
<td>... benefiting from a niche-manufacturer derogation</td>
<td>7*</td>
</tr>
</tbody>
</table>

*of which 5 benefit from pooling and a niche-manufacturer derogation
As might be expected, those manufacturers with relatively high average CO₂ emissions and higher average mass appear more likely to join pools and/or make use of small volume/niche derogations where available. The manufacturers that did not join pools are typically characterised by having average CO₂ emissions that are lower than average, including a number of electric vehicle manufacturers.

Since it is not possible to directly measure the costs to manufacturers of meeting their targets, various proxy indicators must be used. One such indicator is the level of non-compliance, since the extent to which manufacturers are able (or not) to meet their targets may give an indication of how challenging the targets are to meet. High levels of non-compliance in certain segments of the fleet may indicate that there are disproportionate impacts in these segments.

Each manufacturer is given a manufacturer-specific target for 2013, either as set out in Annex I of the Regulation, or by means of a small volume- or niche-manufacturer derogation. The manufacturer-specific targets can be met either on an individual basis, or as part of a pool (in which case a pool-specific target applies, as described above). Table 5-10 shows the manufacturers’ achievements against their targets in 2013. Most manufacturers complied with their manufacturer-specific target (48 manufacturers), whereas 17 manufacturers relied on their inclusion in a pool to meet their 2013 targets (and the fact that all 12 pools achieved their pool-specific targets). Only 2 manufacturers (namely Ferrari and Avtovaz) were obliged to penalty payments. The targets of the two penalty-paying manufacturers were set under the small-volume manufacturer derogation scheme and were missed respectively by 2 and 14 gCO₂/km. In total therefore, 65 out of the 67 manufacturers that are within the scope of the Regulation met their manufacturer- and/or pool-specific CO₂ emission reduction target and were not obliged to make any penalty payments.

Table 5-10: Passenger car manufacturers’ target achievement (2013)

<table>
<thead>
<tr>
<th>Manufacturers that...</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>... complied with their manufacturer-specific target*</td>
<td>48</td>
</tr>
<tr>
<td>... Did not comply with manufacturer-specific target, but avoided penalties due to pooling and meeting the pool-specific target</td>
<td>17</td>
</tr>
<tr>
<td>... were obliged to pay penalties due to missing their manufacture-specific targets (and were not included in a pool)</td>
<td>2</td>
</tr>
<tr>
<td>Total (car manufacturers within the scope of the Regulation)</td>
<td>67</td>
</tr>
</tbody>
</table>

*irrespective of whether the target was set by the Regulation itself (Annex I) or by a granted niche- or small volume- derogation

Figure 5-17 shows the extent to which manufacturers over-complied with the 2013 targets: over 80% (39) of these manufacturers over-complied by more than 5 gCO₂/km; 19% (or 9) did so by more than 50 gCO₂/km (of which 4 produce solely electric vehicles; they therefore attain tailpipe emission of 0 gCO₂/km and hence significantly over-comply with the emission target set according to Annex I of the Regulation)

31 Ferrari, responsible for 2,049 car registrations, was set a target of 303 gCO₂/km; Avtovaz, responsible for 1,295 registrations, was set a target of 201 gCO₂/km

32 These manufacturers are Tesla Motors Ltd. (1,671 registrations), Cecomp S.P.A. (566 registrations), Pininfarina-Bolloro SAS (72 registrations) and MIA Electric SAS (257 registrations).
Manufacturers that were non-compliant with their manufacturer-specific targets could benefit from pooling with these over-compliant manufacturers. In total, 12 pools were created, all of which complied with their pool-specific emission targets. Also within the pools, the over-compliance was still significant: on average, the pools over-complied with their respective targets by 17 gCO₂/km (with the lowest level of over-compliance at 6 gCO₂/km and the highest at 45 gCO₂/km).

The very high (over-)compliance rate for all but two manufacturers suggests that in general manufacturers of all vehicle segments were able to comply with the 2013 targets relatively easily. Given the over-compliance seen in all segments, this suggests that to date there have not been very significant disproportionate cost impacts on any specific segments, as if this were the case it could be expected that some segments would not have met the required targets. However, due to the confidentiality of cost information, there is no direct evidence as to what the cost impacts on different manufacturers have been. On the basis of the available information, there do not appear to be any signs of significant competitive distortion, but it is not possible to verify whether or not the Regulations have met their objectives of competitive neutrality. Furthermore, any impacts on the competitive neutrality may not yet have emerged, since it remains to be seen how manufacturers perform against the more stringent targets in future years.

For LCVs the manufacturer-specific emission target is defined by vehicle mass-based formulae given in Annex I of the Regulation (Regulation (EC) No 510/2011 for light commercial vehicles). The Regulation allows for flexibilities that contribute significantly to the target achievement of certain manufacturers.

For LCVs the following flexibilities are available:

1. **Pooling of manufacturers**: The same rules as for passenger cars apply (Art 7)
2. **Derogations for niche/small-volume manufacturers**: Derogations are available for a manufacturer which is responsible, together with all of its connected undertakings, for fewer than 22,000 new LCVs registered in the Community per calendar year. Such a manufacturer has to apply for a derogation by suggesting an alternative CO₂ emission target (which has to be in line with its reduction potential, and take into account the characteristics of the market for the type of LCV manufactured). (Art 11(2(d)))
3. **De minimis derogations**: As is the case for passenger cars, manufacturers responsible for **less than 1,000** new LCVs in the Community per calendar year, **as well as for special purpose vehicles** do not have to comply with any CO₂ emission targets as set out in the Regulation. They are not within the scope of the LCV CO₂ Regulation.

Table 5-11 shows the number of LCV manufacturers that used/benefited from one or more of the flexibilities, as well as the number of manufacturers that fall into the scope of the Regulation. Nine of these benefit from the *de minimis* derogation and hence do not fall into the scope of the LCV Regulation. Overall, in 2013, there were two pools comprising three manufacturers each. The first pool consisted of Ford and its subsidiaries, whereas the second pool consisted of Mitsubishi and its subsidiaries, showing that cross-company pools have not yet developed in the same way as they have done so for cars.

**Table 5-11**: LCV manufacturers that used/benefitted from flexibilities

<table>
<thead>
<tr>
<th>Manufacturers...</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total number of LCV manufacturers</strong></td>
<td>58</td>
</tr>
<tr>
<td>... benefiting from a <em>de minimis</em> derogation (hence out of scope of the Regulation)</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total number of LCV manufacturers within the scope of the Regulation</strong></td>
<td>49 (=58-9)</td>
</tr>
<tr>
<td>... of which are not using any flexibility</td>
<td>38</td>
</tr>
<tr>
<td>... of which are using one (or more) of the above-described flexibilities</td>
<td>11</td>
</tr>
<tr>
<td>... taking part in a pool</td>
<td>6*</td>
</tr>
<tr>
<td>... benefiting from a small-manufacturer derogation</td>
<td>8*</td>
</tr>
</tbody>
</table>

*of which 3 benefit from pooling and a small-manufacturer derogation

Table 5-12 shows that 37 LCV manufacturers met their manufacturer-specific target and three manufacturers met their pool-specific target in 2013. Nine manufacturers did not achieve their emission target (whether set on the manufacturer or pool level) although the targets for 2013 were only indicative. In total, 40 out of the 49 manufacturers that are within the scope of the Regulation met their manufacturer- or pool-specific CO₂ emission reduction target (indicative) in 2013.

**Table 5-12**: LCV manufacturers’ target achievement (2013)

<table>
<thead>
<tr>
<th>Manufacturers that...</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>... complied with their manufacturer-specific target*</td>
<td>37</td>
</tr>
<tr>
<td>... <em>Did not comply with manufacturer-specific target, but were included in a pool that met its pool-specific target</em></td>
<td>3</td>
</tr>
<tr>
<td>... <em>Did not comply with manufacturer-specific targets and were not part of a pool</em></td>
<td>9</td>
</tr>
<tr>
<td><strong>Total (LCV manufacturers within the scope of the Regulation)</strong></td>
<td>49</td>
</tr>
</tbody>
</table>

*Irrespective of whether the target was set by the Regulation itself (Annex I) or by a granted niche- or small volume- derogation
Figure 5-18 shows that all of the manufacturers that complied with their manufacturer-specific targets exceeded the target by over 5 gCO₂/km. More than 80% did so by over 10 gCO₂/km. Three manufacturers over-complied by over 50 gCO₂/km (of which two (MIA Electric SAS and Alke) produce electric LCVs only. Renault over-complied by 52 gCO₂/km, largely due to the introduction of their electric Kangoo Z.E. van).

**Figure 5-18: Over-compliance with manufacturer-specific CO₂ reduction targets (2013)**

<table>
<thead>
<tr>
<th>Overcompliance with target (g CO₂/km)</th>
<th>Number of manufacturers* (% of total that overcomplied)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 50</td>
<td>8%</td>
</tr>
<tr>
<td>10 – 50</td>
<td>76%</td>
</tr>
<tr>
<td>5 – 10</td>
<td>16%</td>
</tr>
<tr>
<td>&lt; 5</td>
<td>0%</td>
</tr>
</tbody>
</table>

*excluding manufacturers that got a de minimis derogation and hence did not have to comply with any CO₂ emission reduction target*

There is significant potential for pooling of LCV manufacturers, in the same way that there is for passenger cars. However, so far pooling is not as widely used.

Judging by the extent of over-compliance, it appears that most LCV manufacturers have not experienced difficulties in meeting their indicative 2013 targets. However, there are nine manufacturers that did not comply with their targets in 2013 (of which 3 had small volume manufacturer derogations, and of which all but one were responsible for less than 700 registrations). The extent to which this may reflect difficulties in meeting the targets is not clear at this stage, since there are no penalties incurred and hence no obligation to do so – it may be the case that these manufacturers will comply with later targets either directly or by joining pools. It is furthermore unclear why those manufacturers that did not comply and were eligible for a small volume manufacturer derogation did not apply for, or were not granted such a derogation. Overall, it is too early to be able to conclude as to whether the LCV Regulation is having a different impact on different manufacturers.

5.4.4.2 Predicted and observed vehicle retail price changes in relation to CO₂ emission reductions

The European Commission’s Impact Assessment of the Regulation (European Commission, 2007d) analysed the effect of the different options for defining CO₂ emission reduction targets on manufacturers’ vehicle retail prices.

The ex-ante values can be compared to the price increases that have actually been observed in order to verify whether the Regulation’s expected degree of competitive neutrality (as measured by vehicle retail price increases per manufacturer) was met in practice. Table 5-13 compares the ex-ante estimates of retail price increases with the ex-post outturns of retail price increases. The latter are derived from ICCT (2014c). Nominal prices (as stated in the Pocket book) were adjusted to real values by applying the annual EUR inflation rate for the same period.
Table 5-13: Average retail price increase of passenger cars 2006 - 2013

<table>
<thead>
<tr>
<th></th>
<th>Ex-ante estimates (based on EC’s impact assessment, 2007)</th>
<th>Ex-post outturns (based on vehicle sales data; ICCT pocketbook, 2014)</th>
<th>Difference between ex-ante and ex-post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>+ 1,099 + 5%</td>
<td>+ 912 + 4%</td>
<td>-187 -1%</td>
</tr>
<tr>
<td>Min</td>
<td>+ 513 + 3%</td>
<td>- 934 - 5%</td>
<td>-1,447 -8%</td>
</tr>
<tr>
<td>Max</td>
<td>+ 11,883 + 19%</td>
<td>+ 2,149 + 11%</td>
<td>-9,734 -8%</td>
</tr>
<tr>
<td>Med</td>
<td>+ 1,222 + 6%</td>
<td>+ 1,215 + 3%</td>
<td>-7 -3%</td>
</tr>
<tr>
<td>St. Dev.</td>
<td>753 2%</td>
<td>866 4%</td>
<td>113 2%</td>
</tr>
</tbody>
</table>

The most striking observation is that observed average vehicle retail prices did not increase as a general rule. In fact, out of the 18 car manufacturers for which data are available, five appear to have decreased their average retail prices over the period (with a maximum reduction of 5%). There are several possible reasons for this, which may or may not relate to the CO₂ Regulations, and the difficult economic conditions will undoubtedly have had an effect on pricing strategies. Due to confidentiality reasons, it is not possible to obtain any further information on the underlying costs and strategies of the manufacturers, hence the impact of the Regulations is not entirely clear. The available data suggests that the Regulations have not had such a dramatic impact on underlying manufacturing costs that this could not be counteracted by other means (such as absorbing costs, making cost savings elsewhere etc).

The standard deviation, or spread, of retail price increases, together with the range of the observed values, may provide some insight into the variance of the cost burdens across the different vehicle manufacturers, and hence for the competitive neutrality of the Regulation. The bigger the standard deviation and/or the range is, the more unbalanced the retail price changes across the different vehicle manufacturers are – and assuming that retail price is linked to underlying cost, this suggests in turn that there may be an imbalance of costs. The range between minimum and maximum values is 16% for both the ex-ante cost estimates and ex-post cost outturns. The standard deviation of ex-post cost outturns is 2% bigger than the initially predicted ex-ante standard deviation. This can be explained by the fact that ex-ante cost estimates did not account for the possibility of retail price decreases. Hence, the slightly increased spread cannot be taken as a reliable indicator for a worse degree of competitive neutrality across vehicle manufacturers of the Regulation. It rather simply indicates that applying CO₂ reduction technologies does not necessarily coincide with increased costs and retail prices.

For LCVs the above analysis of retail prices cannot be conducted due to the lack of average retail price data per manufacturer.

Overall, the above analysis has not found any strong indications that the Regulation is in contradiction to its competitive neutrality objective. However, there are several important limitations that mean it is not possible to categorically assert that there is no competitive distortion. The most important is that due to lack of available cost data, the analysis is based on retail price changes, which are not necessarily correlated with changes in vehicle manufacturing costs resulting from the imposed emission standards. Secondly, the analysis is based on data from 2013 as the most recent year, and hence
the full impacts may not yet have been realised. Finally, the derived values as presented are not fully comparable for the following reasons:

- Whereas the ex-ante analysis assumed that technology costs would be fully transferred to the consumer (including a mark-up factor), it is unknown if and to what extent the ex-post values comprise CO₂ reduction technology costs and/or mark-ups.
- Whereas the ex-ante analysis was based on the analysis of the estimated technology cost structure of 17 vehicle manufactures, the ex-post analysis is based on cost outturns of 19 vehicle manufacturers that do not fully overlap with the 17 used in the ex-ante analysis.

5.4.4.3 Retail price changes in relation to CO₂ emission reductions and vehicle weight

In the following section, the extent to which retail price changes coincide with CO₂ reductions is analysed (e.g. whether higher retail prices appears to be due to higher CO₂ emission reductions).

Figure 5-19 shows that vehicle manufacturers with higher average vehicle mass achieved higher CO₂ emission reductions, which is in line with the requirements of the Regulations under the utility parameter.

**Figure 5-19: Achieved CO₂ emission reductions by average vehicle mass of passenger cars**

Source: values from (ICCT, 2014c)

Figure 5-20 shows the relative real retail price change per manufacturer against the CO₂ emission reduction achieved. Retail price changes do not appear to strongly correlate with the magnitude of achieved CO₂ emission reductions.
Figure 5-20: Relative real retail price change by achieved CO\textsubscript{2} emission reductions of passenger cars

![Graph showing relative real retail price change by achieved CO\textsubscript{2} emission reductions of passenger cars.](image)

*Source: values from (ICCT, 2014c)*

Figure 5-21 shows the same retail price change as before, plotted against the manufacturers’ average vehicle mass. Again, the changes in relative retail price do not appear to correlate with the mass of the vehicles. For all mass classes and all levels of CO\textsubscript{2} emission reductions, price changes range from negative to positive values.

**Figure 5-21**: Relative real retail price change by average vehicle mass of passenger cars

![Graph showing relative real retail price change by average vehicle mass of passenger cars.](image)

*Source: values from (ICCT, 2014c)*

The above graphs suggest that on average manufacturers of heavier premium cars are somewhat better off (despite the higher CO\textsubscript{2} emission reductions achieved, they were able to reduce retail prices; manufacturers of smaller vehicle segments increased retail...
prices despite realising only smaller CO\textsubscript{2} emission savings). However, the analysis does also show that at least some manufacturers of lighter vehicle segments can offer similar retail price changes per gCO\textsubscript{2} reduced.

While the average costs of CO\textsubscript{2} reductions appear to be lower for heavier vehicle classes, it is not possible to ascertain from the available data what the underlying reasons for this are. As a result, it is not possible to determine whether or not it was generally easier (cheaper) for manufacturers of vehicles in heavier segments to meet their targets. For example, manufacturers of the premium segments might have chosen to pass on costs of CO\textsubscript{2} reduction technologies to a lesser extent than manufacturers of smaller segments and/or have other pricing strategies that do not reflect the actual cost of these technologies. Manufacturers of vehicles in premium segments may have higher profit margins and hence more scope for absorbing additional manufacturing costs. Conclusions on whether these businesses have as a result been less profitable than their competitors cannot be drawn though, since their profitability will depend on many more factors other than “just” EU vehicle sales (such as sales in other non-EU markets, other non-vehicle manufacturing related activities bringing revenue streams, etc.).

For LCVs the above analysis cannot be conducted due to the lack of average retail price data per manufacturer. Conclusion on the basis of vehicle retail price data hence cannot be drawn.

5.4.4.4 Changes in average vehicle mass

Changes in average vehicle mass may be indicative of manufacturer strategies to comply with the Regulations. One effect of the Regulation might have been that vehicle manufacturers, especially those operating in premium segments, choose to supplement their vehicle fleet with smaller, lighter cars that typically show better CO\textsubscript{2} performance compared to the larger segments.

Figure 5-22 shows however that there has not been any clear tendency of average mass increases or decreases for different manufacturers. On average, newly registered cars in the EU have increased in mass by 1.3\% between 2006 and 2013. Both, manufacturers of premium and smaller segments have contributed to this slight increase. Out of four manufacturers of the upper segment (>2,000 kg), three have increased their average vehicle weight by more than 3\%, while one has decreased the average weight by just above 2\%. 
Table 5-14 now shows average vehicle mass changes by vehicle segment (the weighted averages of their respective sub-segments). The table shows that average vehicle masses increased in each sub-segment and segment. At the same time, the market shares of different segments stayed fairly stable in the period from 2006 to 2013. Only multi-purpose vehicles (categorised among ‘other’) significantly decreased their average weight in the period from 2006-2013 (by 12%), while increasing their market share from 7 to 17%. Except for this increase in multi-purpose vehicles, the average fleet composition has remained similar across all manufacturers.

Table 5-14: Weighted average masses by passenger car segment and their market shares

<table>
<thead>
<tr>
<th>Segment</th>
<th>Weighted average change in vehicle mass</th>
<th>Market Shares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006-2013</td>
<td>2006</td>
</tr>
<tr>
<td>Upper</td>
<td>5.1%</td>
<td>3.9%</td>
</tr>
<tr>
<td>Luxury</td>
<td>3.9%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Upper Medium</td>
<td>5.7%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Medium</td>
<td>5.0%</td>
<td>13.6%</td>
</tr>
<tr>
<td>Medium</td>
<td>5.0%</td>
<td>13.6%</td>
</tr>
</tbody>
</table>

Also refer to Figure 5-26 that graphically shows the evolution of vehicle characteristics (incl. mass) by segment.
From this analysis, it does not appear that manufacturers of vehicles in premium segments (or any other segments) have significantly benefited from producing lighter vehicles in order to reduce the average CO₂ emissions of their vehicle fleet. Conversely, many vehicle manufacturers have slightly increased the average masses of their vehicles. While this could be an indication that there might have been some ‘gaming’ by manufacturers – increasing the mass of vehicles to have less stringent targets (which is the case if the impact of increased mass on CO₂ is smaller than the increase in target, making the higher target easier to meet) -, it is also possible that this slight weight increase simply reflects many cars’ increased infotainment and safety features.

The EC’s Impact Assessment underlying the Regulation stated that the likelihood of mass increase being used by manufacturers as a means to reduce required CO₂ reduction effort (i.e. “gaming”) was lower for LCVs than for passenger cars. The main reasons are that (i) LCVs are used to transport goods, hence any mass increase would come at the expense of payload or performance which then needs to be compensated by increased engine power leading to higher vehicle cost and (ii) market shifts in the LCV market are usually not driven by incentives such as luxury or increased comfort, which could also increase the mass of LCVs. Given this assumption that mass increases were less likely, only the upper range of utility curve slopes was analysed in more detail in the impact assessment and a 100% slope for the limit value curve was chosen.

To establish whether the Regulation has affected the specific average LCV mass, the changes in mass in running order between 2009 and 2013 have been analysed. Figure 5-23 shows the changes in average vehicle mass in the period 2009-2013. Across the whole EU, the average mass increased by around 10% (compared to just 1.3% that can be observed for passenger cars). While two manufacturers (Mercedes-Benz and Nissan) had small decreases in vehicle mass, all other manufacturers showed increases. The values for Ford, Opel and Renault are even above 10%. Manufacturers of smaller LCV segments show substantial increases in mass, while the two manufacturers that showed a decrease in mass are in the heavier range. In general it can be said that changes in mass are less significant for manufacturers of predominantly heavier LCV segments than for manufacturers of predominantly lighter LCV segments.
Figure 5-23: Average vehicle mass changes for LCVs 2009-2013

Source: values from (ICCT, 2014c)

The above analysis could give an indication that there may have been a certain degree of “gaming”, especially among those LCV manufacturers that produce lighter LCVs, and for which mass increases are hence less of a trade-off with payload than for manufacturers of heavier LCV segments. On the other hand, the same changes in mass could be due to other reasons such as changes in consumer preferences or due to the impacts of the economic crisis affecting the composition of demand – at this stage it is very difficult to ascertain the underlying reasons, hence no definite conclusions can be drawn as to the extent (if any) of gaming.

5.4.4.5 The use and impact of super-credits
Another option for car manufacturers to comply with their CO₂ emissions reduction targets was to opt for super-credits. These are awarded for sales of ultra-low emission vehicles (vehicles that emit less than 50 gCO₂/km). A possible shift to ultra-low emission vehicles is not easily identifiable in the fleets’ average vehicle mass, since these vehicles (predominantly battery electric or plug-in hybrid electric vehicles) are often heavier than their conventional counterparts.

Table 5-15 shows the CO₂ reduction that was achieved due to super-credits in the year 2013. Manufacturers that did not file any super-credits are disregarded. It can be seen that the effect of super-credits was above 2 gCO₂/km for only three manufacturers. However, for these same manufacturers, the super-credit scheme was not crucial for achieving their manufacturer-specific emission target. There is no clear tendency for manufacturers of heavier vehicle segments to benefit from super-credits. Volvo has benefitted the most from this scheme; however super-credits are responsible for less than 25% of their over-compliance. This suggests that the initial concern that manufacturers could significantly increase their offer of vehicles with ultra-low tailpipe
CO₂ emissions, which would come at the expense of the average CO₂ emission of conventional vehicles has so far not materialised.

Given that super-credits were not crucial for any manufacturer for achieving its manufacturer-specific target, this analysis does not suggest that this provision of the Regulation contradicts its competitive neutrality target.

Table 5-15: Car manufacturers that benefited from super-credits and the super-credits’ contribution to target achievement

<table>
<thead>
<tr>
<th>Car manufacturer</th>
<th>Over-compliance with 2013 target [in gCO₂/km]</th>
<th>Contribution to CO₂ reductions due to super-credits [in gCO₂/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volvo</td>
<td>31</td>
<td>7.42</td>
</tr>
<tr>
<td>Nissan</td>
<td>10</td>
<td>5.77</td>
</tr>
<tr>
<td>Renault</td>
<td>25</td>
<td>3.59</td>
</tr>
<tr>
<td>Mercedes</td>
<td>18</td>
<td>1.83</td>
</tr>
<tr>
<td>Toyota</td>
<td>24</td>
<td>1.60</td>
</tr>
<tr>
<td>Opel</td>
<td>10</td>
<td>1.17</td>
</tr>
<tr>
<td>BMW</td>
<td>14</td>
<td>0.71</td>
</tr>
<tr>
<td>Citroen</td>
<td>22</td>
<td>0.32</td>
</tr>
<tr>
<td>VW</td>
<td>14</td>
<td>0.25</td>
</tr>
<tr>
<td>PSA</td>
<td>23</td>
<td>0.17</td>
</tr>
<tr>
<td>Hyundai</td>
<td>2</td>
<td>0.05</td>
</tr>
<tr>
<td>Ford</td>
<td>17</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Source: EEA (2014)

For LCVs the provisions for super-credits apply only from the year 2014 onwards.

5.4.4.6 Changes in market shares by manufacturer

Figure 5-24 shows the change in market shares against the average retail price change over the period from 2006 to 2013; no obvious correlation between the two variables can be identified. Market shares have changed in the range of +/- 2% over the whole range of retail price changes. Manufacturers in premium segments appear to have slightly increased their market shares in general, irrespective of their average retail price change. Manufacturers of vehicles in smaller segments have both increased and decreased their market shares (depending on specific brand) over the whole range of retail price changes.
Figure 5-24: Change in passenger vehicle market shares by retail price change (2006-2013)

Source: values from (ICCT, 2014c)

Analysing the data provided in the EC’s implementing decisions on the amendment of the Regulation (as, for example, provided in the year 201134 and 201435), the market shares for manufacturers that benefitted from derogations did not change significantly over the period 2010-2013. Hence, no significant impact of these provisions on the competitiveness of any type of manufacturer can be inferred.

Given the observed heterogeneity in market share changes and/or their insignificant magnitude, the data on market shares and changes in retail prices does not provide any strong evidence that the Regulations are in contradiction with their competitive neutrality objective. As for the previous indicators, it is possible that any impact may not yet have materialised.

Table 5-16 and Figure 5-25 show how the market shares of different LCV manufacturers changed between 2009 and 2013. While five of the manufacturers had suffered losses in their market shares and another three had only small changes in market share, two manufacturers achieved increases in market share of over 1%. From Figure 5-25 it appears that the manufacturers of smaller LCVs suffered market share decreases. However, this pattern is not clear cut and cannot be further analysed without average retail price data for these manufacturers.

Table 5-16: Market shares of LCV manufacturers

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>2009</th>
<th>2013</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citroën</td>
<td>12%</td>
<td>11%</td>
<td>-1.6%</td>
</tr>
<tr>
<td>Fiat</td>
<td>12%</td>
<td>10%</td>
<td>-2.1%</td>
</tr>
<tr>
<td>Ford</td>
<td>11%</td>
<td>12%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Iveco</td>
<td>3%</td>
<td>3%</td>
<td>-0.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2013</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercedes-Benz</td>
<td>8%</td>
<td>10%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Nissan</td>
<td>3%</td>
<td>3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Opel</td>
<td>5%</td>
<td>3%</td>
<td>-2.3%</td>
</tr>
<tr>
<td>Peugeot</td>
<td>11%</td>
<td>11%</td>
<td>-0.4%</td>
</tr>
<tr>
<td>Renault</td>
<td>15%</td>
<td>15%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Toyota</td>
<td>3%</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>VW</td>
<td>10%</td>
<td>13%</td>
<td>3.2%</td>
</tr>
</tbody>
</table>

Note: Based on EU-28 total registrations
Source: values from (ICCT, 2014c)

### Figure 5-25: Change in market share by average running mass

Source: values from (ICCT, 2014c)

#### 5.4.4.7 Overall assessment

On the basis of the available information, there do not appear to be any signs of significant competitive distortion. However, data availability does not allow for a thorough analysis that could rule it out entirely: The above analysis is mainly based on retail price changes, which were used as a proxy for technology costs faced by vehicle manufacturers. Whether retail price changes are indeed a reliable proxy for manufacturing costs, remains questionable and might depend on the specific manufacturer. Furthermore, any impacts on the competitive neutrality may not yet have emerged, since it remains to be seen how manufacturers perform against the more stringent targets in future years.

The above analysis does show that:

- Targets in 2013 were over-achieved by the manufacturers of all vehicle segments (partly thanks to the provisions of flexibilities, i.e. pooling and derogations): manufacturers mostly significantly over-complied with their pool-specific, but
also their manufacturer-specific targets. The difficulty with which these targets were achieved by the single manufacturers remains uncertain.

Manufacturers of premium segment vehicles did not circumvent tight targets by shifting their production to lighter segments: average vehicle mass of these manufacturers has, on average, slightly increased over the period 2006-2013.

Whether 'gaming' (deliberate increases of vehicle weights in order to face less stringent targets) played a factor in these vehicle increases cannot be ruled out. However, these weight increases might also be due to increased safety measures, infotainment tools or other weight increasing technologies that have been increasingly deployed in the regarded timeframe in vehicles.

The above analysis for LCVs is very limited due to a lack of data. Any conclusions are therefore tentative. A decreasing market share of smaller LCVs might suggest that these are under higher pressure to comply with their emission targets. However, this decrease in market share could also be a result of changing consumer preferences and the higher competition of these LCVs with passenger cars. A lack of data on the LCV market does not allow to explore this further.

5.4.5 Ensuring socially equitable targets

The Impact Assessment supporting the car CO₂ Regulations (European Commission, 2007b) considered that a possible proxy for social equity is that buyers of smaller vehicles tend to be households with proportionally lower purchasing power. This is a useful approximation, but the situation is more complicated in reality. Some evidence suggests that cars owned by poorer households tend to be smaller than those owned by wealthier households, but the difference from the average is not very large (Bayliss, 2009). Other evidence suggests that poorer households living in rural areas tend to own the largest and heaviest cars (Thornton et al, 2011). Overall, there is not a direct or consistent link between a person’s income and the type of car they drive, since many other variables affect vehicle choice - including geographical location, travel attitudes, personality, lifestyle, mobility needs, and demographics (Choo and Mokhtarian, 2004); (Thornton et al, 2011); (Bayliss, 2009).

Hence, a broader investigation of the impact on social equity is carried out here, in terms of:

- Impacts on fuel expenditure.
- Changes in retail prices of new vehicles and how this could affect different social groups;
- Impacts on the used vehicle market;

5.4.5.1 Impacts on fuel expenditure

Wealthier households tend to spend more on transportation on average, mainly because poorer householders have lower car ownership rates and tend to own cheaper cars. Restricting the analysis to consider only car-owning households changes the picture somewhat – since poorer households tend to own cheaper, older cars, the running costs are much higher, and hence they tend to spend a higher proportion of their income on running their cars compared to other income groups (Bayliss, 2009).

Table 5-17 shows the reduction in fuel expenditure compared to the baseline counterfactual. This shows that the Regulation has led to overall savings in lifetime fuel expenditure. The savings compared to the baseline grow with each year as the performance of the vehicles improves further. However, the levels of reductions are lower than anticipated in the ex-ante Impact Assessment because of the observed increasing divergence between test cycle and real-world fuel economy / emissions performance. The Impact Assessment quantified the lifetime fuel expenditure savings
associated with the car CO$_2$ Regulation as falling in the range €2,649 to €3,709 (2014 prices), significantly higher than the ex-post estimates of €981 to €1,336 for new cars registered in 2013. If the ex-post estimates of savings in fuel expenditure are calculated using the outturn NEDC test-cycle fuel consumption / emissions performance figures, lifetime savings range from €2,506 to €2,811; these figures are much more in line with the ex-ante estimates, and demonstrate the significant negative effect that the increasing divergence between test cycle and real-world emissions performance is having in eroding the benefits of the car CO$_2$ Regulation.

**Table 5-17: Change in fuel expenditure compared to the baseline scenario for cars registered between 2006 and 2013**

<table>
<thead>
<tr>
<th></th>
<th>Petrol</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars registered in 2006</td>
<td>€0</td>
<td>€0</td>
</tr>
<tr>
<td>Cars registered in 2007</td>
<td>-€10</td>
<td>-€10</td>
</tr>
<tr>
<td>Cars registered in 2008</td>
<td>-€479</td>
<td>-€491</td>
</tr>
<tr>
<td>Cars registered in 2009</td>
<td>-€642</td>
<td>-€350</td>
</tr>
<tr>
<td>Cars registered in 2010</td>
<td>-€875</td>
<td>-€686</td>
</tr>
<tr>
<td>Cars registered in 2011</td>
<td>-€1,057</td>
<td>-€868</td>
</tr>
<tr>
<td>Cars registered in 2012</td>
<td>-€1,432</td>
<td>-€1,143</td>
</tr>
<tr>
<td>Cars registered in 2013</td>
<td>-€1,336</td>
<td>-€981</td>
</tr>
</tbody>
</table>

Notes: Test cycle uplift factor derived from ICCT (2014e), fuel expenditure values include taxes to reflect consumer perspective.
Source: baseline calculations, see Section 5.5 and Annex B

Table 5-18 shows the same calculations for LCVs. The same issue of divergence between real-world and test cycle emissions performance affects these results too, albeit with more extreme effects than for cars. The calculations include taxes; however in some cases businesses do not have to pay fuel taxes and hence the savings seen by the consumer may be somewhat lower.

**Table 5-18: Reduction in fuel expenditure compared to the baseline scenario for cars registered between 2006 and 2013**

<table>
<thead>
<tr>
<th></th>
<th>Petrol</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCVs registered in 2010</td>
<td>-€315</td>
<td>-€256</td>
</tr>
<tr>
<td>LCVs registered in 2011</td>
<td>-€340</td>
<td>-€203</td>
</tr>
<tr>
<td>LCVs registered in 2012</td>
<td>-€363</td>
<td>-€146</td>
</tr>
<tr>
<td>LCVs registered in 2013</td>
<td>-€1,466</td>
<td>-€982</td>
</tr>
</tbody>
</table>

Notes: Test cycle uplift factor derived from ICCT (2014e), fuel expenditure values include taxes to reflect consumer perspective.
Source: baseline calculations, see Section 5.5 and Annex B

A key basis for assessing the social equity of targets is to compare the overall retail price increase of the vehicles against the expected fuel cost savings (net present value) over the lifetime of the vehicle. Hence, the impacts on retail prices are assessed in the following section.
5.4.5.2 Impacts on retail price (affordability) of new vehicles

It is necessary to consider the impacts on retail prices (affordability) since consumers can only benefit from fuel savings if they can afford to buy the more efficient vehicle in the first place. Social equity may be affected by changes in vehicle prices that impact more or less heavily on different social groups. For consumers purchasing new vehicles in the lowest price segments with limited access to credit, the purchase price is likely to outweigh a fully rational assessment of the lifetime costs. Social equity may also be affected by interactions between the new vehicle market and the used vehicle market (analysed in the next section).

Comparing car retail prices is challenging because consumers are offered options to choose additional technical features and/or service packages, and they may also be offered discounts from the retail price, so the actual transaction price paid may vary significantly. For example, the 2014 price specifications for the VW Golf offer a range of models and options, with the most expensive variant being around double the price of the basic model (VW, 2014). This type of pricing is a common strategy for many different product types (i.e. not just vehicles) – an extensive review of pricing strategies would require the purchase of datasets that were not foreseen within the scope of this study.

In practice, it is difficult to find evidence that legislation has actually led to real-world increases in end-user vehicle prices, and indeed data from ICCT (2014c) suggests that retail prices adjusted for inflation have remained the same or slightly decreased for most segments, with the exception of sports cars (which are unlikely to be relevant to low-income consumers). In addition, when assessed in terms of maximum engine power output (a measure of vehicle performance), there does not appear to have been any compromise in consumer utility (see Figure 5-26).
Figure 5-26: Evolution of vehicle characteristics

Notes: Retail prices including tax. Sales taxes in the EU are between 18% and 27% in addition to the general tax. Prices are adjusted for inflation.
Source: (ICCT, 2014c)
These findings are broadly in line with aggregate trends in consumer price indices, which indicate that vehicle purchase prices have steadily fallen in relation to average consumer prices, while the price of operation has increased (see Figure 5-27).

**Figure 5-27: Real inflation-adjusted price indices of passenger transport in EU-25 (2005=0)**

![Graph showing real inflation-adjusted price indices of passenger transport in EU-25 (2005=0)](image)

*Source: EEA TERM indicator 020*

According to industry stakeholders consulted for this study, regulatory compliance does in fact increase production costs, but these have been partially offset by new production strategies (this is analysed in more detail in Section 5.5). Manufacturers typically offer a variety of models to the same consumer base. Thus, a manufacturer that lowers the price of one of its models will reduce demand for its other models, as well as attracting demand away from other firms. Nevertheless, even modest increases in the prices of the low cost vehicles may price low-income consumers out of the new-vehicle market. Since buyers of lower-end cars tend to be particularly sensitive to price, manufacturers operating in the lower market segments tend to compete on prices (ITF, 2010). Although it is not known how manufacturers decide to pass on any costs across their fleets, the competitive nature of the market suggests that they will aim to optimise the affordability of their products in the lower-price segments.

As such, the precise mechanisms of price adjustment are not clearly attributable to the Regulations compared to other factors. In addition, the overall observed trends indicate that the impacts on car retail prices to date have been minor, particularly in the lower segments, while engine power and fuel efficiency has increased. This suggests that overall, consumers are unlikely to have been negatively affected by any changes in vehicle retail prices/affordability.

Furthermore, higher-income groups are more likely to own (multiple) cars and to have purchased a new car recently, suggesting that they will be most affected by any changes in new vehicle prices. For example, in the UK around 65% of non-working households do not own a car compared to only 10% when upper middle class and middle class social segments of the population are considered (Figure 5-28).
Figure 5-28: Number of cars per UK household by social grade

Notes: Social grade correlates strongly with income\(^{36}\) (NRS, 2014). Upper-middle class = Higher/intermediate managerial, administrative or professional; Lower middle class = Supervisory or clerical and junior managerial, administrative or professional; Skilled working class = Skilled manual workers; Working class = Semi and unskilled manual workers; Non working = Casual or lowest grade workers, pensioners, and others who depend on the welfare state for their income.

Source: (BCA, 2013)

Similar trends are seen when considering the level of recent car purchases. Around 70% of upper-middle class households have recently bought a new car, while only 50% of lower middle class households and 45% of skilled working class households have recently purchased a new vehicle. These values drop to around 20% when the non-working group is considered (BCA, 2013). This suggests that higher income households are more likely to be affected by changes in new vehicle retail prices, whereas impacts on lower income householders are more likely be realised in the used car market.

For new LCVs, no information on average retail prices could be located. New LCV units are typically acquired by major users such as public utilities, leasing companies, rental operators, logistics organisations etc., commonly in large numbers and often at heavily discounted prices. Hence the relevance of the issue of social equity is likely to be more limited for new LCVs compared to used LCVs (analysed below). However, to assess the knock-on consequences of vehicles that eventually enter the used LCV market, it is worth noting that general trends in the average fleet characteristics indicate that proxies of consumer utility, as measured by average engine power and footprint, have increased while CO\(_2\) emissions have decreased (see Figure 5-29).

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\(^{36}\) Although it is not a perfect indicator - for instance, it is not sufficient to identify low-income houses in the pensioner group.
5.4.5.3 Impacts on the affordability of used vehicles

Poorer households typically gain access to the car market by purchasing relatively cheap vehicles, most probably on the used car market (Bayliss, 2009). The rapid rate of depreciation of cars with age means that this factor alone implies that poorer households will pay significantly less for their cars.

The effects of the Regulations on the used car market depend on the relative changes in retail prices and fuel efficiency of new vehicles, as well as the total sales of new vehicles. The new and used car markets are linked on the demand side by the substitutability of new and used vehicle purchases. They are also linked on the supply side, since many new car purchases are dependent on the owner being able to sell their existing car.

As can be seen in the analysis below in Section 5.4.5.1, on average the fuel savings have led to reductions in total cost of ownership for new vehicle owners. Since the value of fuel savings due to improvements in fuel efficiency are greater than the retail price increase for a potential new vehicle buyer, the volume of the used car market may increase (as buyers of new vehicles sell their old vehicles). In this scenario, low-income consumers are likely to benefit from the increased availability (hence lower prices) of used vehicles (EPA, 2012b).

In addition, it is likely that owners in the second-hand market will benefit significantly more from fuel efficiency improvements compared to the first owners due to the rapid depreciation rates in the first few years of a car’s life. Data from the UK (Europe’s second-largest used car market) suggests that on average after one year a car will have lost around 40% of its value, and after three years it has lost around 60% of its original value, although this varies substantially depending on the mileage, condition and specific vehicle model (the AA, 2014).

Although fuel efficiency benefits are recognised to some extent (more fuel efficient vehicles tend to better retain their value due to increased interest in cars that are cheaper to run), the fuel cost savings do not appear to be fully reflected in used car prices (the AA, 2012). Empirical evidence from used car auctions in the USA also suggests that prices for relatively new used vehicles move closely in line with expected future fuel costs/savings, but that the fuel costs savings are not fully incorporated into the pricing of used vehicles.
prices. A change of $1 in future discounted fuel costs is associated with a change of only 76 cents in used vehicle prices with a lag of four to six months – i.e. that the future costs savings are not fully reflected in the purchase price, which suggests that consumers have high implied discount rates37 (Allcott & Wozny, 2012). The findings did not significantly vary for hybrid-electric vehicles or other vehicles marketed as “green”. In addition, prices for older vehicles aged 11-15 years were found to be highly insensitive to fluctuations in fuel prices – that is, buyers of older vehicles appear to undervalue future fuel costs more than any other segment (Allcott & Wozny, 2012). Although vehicles affected by the Regulations have not yet reached the 11-15 year old age bracket, this suggests that there will be significant benefits to buyers of these vehicles (typically the lowest income groups), since welfare gains are largest when vehicle buyers undervalue future fuel cost savings (i.e. the consumers still enjoy the fuel efficiency benefits even though they are not reflected in the market prices).

For the LCV market, the most relevant social impacts are in the context of SMEs. For most SMEs, buying a new LCV is purely aspirational and a used LCV is often the only sensible option within financial reach (BCA, 2012). The trends in new LCV characteristics as noted in Figure 5-29 indicate that buyers of used LCVs will experience some knock-on positive effects in terms of improvements in fuel efficiency without trade-offs in other vehicle characteristics. Figure 5-30 shows average used fleet and lease LCVs prices at auction from 2008 to 2011, where a severe drop in prices following the recession in 2008 is evident, along with a slow recovery. The peaks and troughs are likely caused by the impact of fleet updating and supply or demand moving out of projected equilibrium for a short period.

Figure 5-30: Used fleet and lease LCVs average prices at auction (UK)

Source: (BCA, 2012)

The prices that buyers will face are extremely uncertain due to the impacts of the recession filtering through to the used market – these market dynamics are likely to be

37 The implied discount rate is a way of capturing how people appear to trade off upfront costs against future cash flows. Many underlying factors other than consumers’ actual discount rates might affect the implied discount rate, including time horizons, beliefs, and inattention.
more important determinants of prices paid for used LCVs than any impacts on new LCV prices due to the Regulations. Thus, the impacts on the affordability of used LCVs is difficult to determine – nevertheless, improvements in fuel efficiency are likely to benefit used LCVs buyers due to reductions in fuel expenditure.

5.4.6 Conclusions
In order to ensure a high level of environmental protection, possible trade-offs between different emissions and lifecycle stages were examined. The environmental impacts of ICE technologies are expected to decline in line with reduced fuel consumption, indicating that lower GHG emissions from conventional ICE vehicles are likely to result in reductions of other pollutants over the lifecycle. Furthermore, in most cases the technologies and alternative fuels with the greatest potential reductions in lifecycle GHG emissions, generally also have the greatest potential to reduce NOx and PM emissions (and lifecycle external costs).

In terms of energy security, the Regulations have contributed to lifetime reductions in oil-based road transport fuel consumption for new cars registered between 2006 and 2013 were around 35.9 Mtoe compared to what would have been expected in the absence of the Regulations (see Annex B for discussion of the baseline calculations and assumptions). For future years these difference are likely to grow further as the number of vehicles affected by the Regulation increases. The impacts of the LCV CO2 Regulation to date are likely to be much smaller, estimated at 1.4 Mtoe between 2010 and 2013 under the Regulations compared to the baseline situation for new LCVs registered between 2010 and 2013. This is because the net reductions in oil consumption are accumulated according to the distance driven and the LCV legislation was adopted later.

The impact of the Regulations on diversification of fuels to date has been low, although recently the market penetration of these vehicles has been increasing. Hence, the Regulations are expected to contribute even more to improved energy security in future years.

Impacts on competitiveness and innovation generally appear to be positive. There is some evidence that fuel economy standards may induce R&D spending, but the magnitude of this impact in Europe is not certain. Quantitative and qualitative evidence suggests that European firms have become more innovative in fuel-saving technologies. Patent application trends suggest that European firms been increasingly focused on researching hybrid and electric vehicles (although they remain behind Japan in this respect), while maintaining their levels of research into conventional ICE technologies. Stakeholder views collected during this study as well as for other studies also generally support the hypothesis that the Regulations have enhanced innovation.

It can be concluded that the Regulation was not in contradiction to its competitive neutrality objective. The above analysis shows that targets were over-achieved by most manufacturers, including manufacturers in all vehicle segments. Furthermore it cannot be shown that manufacturers of premium segments have circumvented targets by shifting their production to lighter segments. For passenger cars, the average vehicle mass has slightly increased over the period 2006-2013; the market share of smaller vehicle segments has decreased (mainly to the advantage of the Sport-Utility Vehicle (SUV) segment) and the average mass per vehicle segment has slightly but steadily increased over the same period. The latter suggests a possible “gaming” approach by car manufacturers, meaning that vehicle masses are slightly increased as long as the impact of the resulting less stringent CO2 emission target is less than the impact of the increased mass on CO2 emissions. The analysis for LCVs is more limited due to a lack of data, but tentative conclusions suggest that manufacturers of smaller LCVs are under higher pressure to comply with their emission targets since (i) their market shares
decreased over the period 2009-2013 and (ii) their average vehicle masses increased over the same period. 

From the perspective of social equity, overall the impacts of the Regulations can be considered positive. In terms of the impacts on fuel expenditure, it is clear that the car and LCV CO₂ Regulations have led to significant reductions in annual fuel expenditure. For new cars registered in 2013, the expected lifetime (discounted) fuel savings are €1,336 for petrol cars and €981 for diesel cars compared to the baseline counterfactual scenario. It is notable that these fuel expenditure savings are significantly lower than anticipated in the ex-ante Impact Assessment and reflect the fact that the increasing divergence between real-world and test cycle emissions performance is eroding the benefits of the Regulation. In terms of balancing these savings against increases in retail price, for passenger cars, it is likely that changes in the affordability of new vehicles will affect higher income consumers and in any case market data do not show increases in average retail prices for relevant vehicle segments. On the other hand, as more fuel efficient vehicles move into the second-hand car market, where lower income consumers are more likely to purchase them, it is clear that the savings due to improved fuel efficiency will benefit these users. Similarly for LCVs, SMEs typically only purchase used vehicles, and they will similarly benefit from fuel efficiency improvements. The lifetime real-world fuel savings for new LCVs registered in 2013 are expected to be €1,466 for petrol LCVs and €982 for diesel LCVs compared to the baseline counterfactual scenario.
5.5 Efficiency: Are the costs resulting from the implementation of the Regulations proportional to the results that have been achieved?

This section focuses on the direct economic costs associated with the Regulations and compares these costs to what has been achieved in terms of emissions reductions, and fuel efficiency improvements. The issue of costs is important as the estimated costs of reducing CO₂ emissions from passenger cars and vans played a pivotal role in agreeing the emissions targets. Full details of the methods used for quantifying costs and cost effectiveness can be found in Annex B.

5.5.1 Cost effectiveness - ensuring that costs are proportional to the results achieved

Cost-effectiveness is an important indicator for any policy instrument. This is measured in terms of the costs incurred in order to achieve the results. The costs of the Regulations can be measured in direct economic terms, such as increased production costs for manufacturers or changes in fuel expenditure to consumers.

5.5.1.1 Passenger cars

The original Impact Assessment for the passenger car CO₂ Regulation included detailed analysis of cost effectiveness, with an assessment of the net present value (NPV) of costs to society over the time period 2006 to 2020, estimates of the emissions reductions that would be achieved over this time period, and quantification of cost effectiveness in €/tonne of CO₂ abated. These cost effectiveness figures were originally calculated in 2006 prices; these have been included in the table below along with adjusted figures converted to 2014 prices.

Table 5-19: Ex-ante analysis of cost effectiveness of the proposal for the car CO₂ Regulation (from the Impact Assessment of proposals for the Regulation)

<table>
<thead>
<tr>
<th>Price index year for cost analysis</th>
<th>TREMOVE analysis results</th>
<th>Support study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NPV costs to society 2006-2020</td>
<td>Well-to-wheels CO₂ abatement (2006-2020) (Mt)</td>
</tr>
<tr>
<td>2006 prices</td>
<td>€20.5 billion to €21.6 billion</td>
<td>-634 to -638</td>
</tr>
<tr>
<td>2014 prices</td>
<td>€24.2 billion to €25.5 billion</td>
<td></td>
</tr>
</tbody>
</table>

Source: (European Commission, 2007d)

The central analysis from the Impact Assessment indicated that there would be net economic costs to society associated with implementing the Regulation (i.e. that the costs of applying new technologies would outweigh the savings in fuel expenditure achieved), but that there would be very significant reductions in CO₂ emissions over the period 2006-2020. However, these estimates were based on pre-tax fuel price estimate of €0.40 per litre for diesel and €0.50 per litre for petrol. Sensitivity analysis was also carried out as part of the Impact Assessment to assess the impacts on cost effectiveness of fuel prices that are 30% higher and lower than these figures. As would be expected, higher fuel prices improved the estimated cost effectiveness; in fact, with 30% higher fuel prices, the ex-ante analysis concluded that there would be net reductions in costs.
to society as savings in fuel expenditure would outweigh the costs of the new vehicle technologies required.

**Table 5-20: Sensitivity analysis on cost effectiveness (ex-ante analysis from the impact assessment of proposals for the car CO\(_2\) Regulation, 2006 prices)**

<table>
<thead>
<tr>
<th>Fuel price scenario</th>
<th>Cost effectiveness (2006 prices)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central (€0.50/litre for petrol; €0.40/litre for diesel)</td>
<td>€32.4/tCO(_2) to €38.7/tCO(_2)</td>
</tr>
<tr>
<td>High fuel price scenario (+30%; €0.65/litre for petrol; €0.52/litre for diesel)</td>
<td>-€2.6/tCO(_2) to +€1.4/tCO(_2)</td>
</tr>
<tr>
<td>Low fuel price scenario (-30%; €0.35/litre for petrol; €0.28/litre for diesel)</td>
<td>€72.1/tCO(_2) to €76.0/tCO(_2)</td>
</tr>
</tbody>
</table>

Converting these figures to 2014 prices gives the following adjusted ex-ante estimates for cost effectiveness for each fuel price scenario.

**Table 5-21: Sensitivity analysis on cost effectiveness (ex-ante analysis from the impact assessment of proposals for the car CO\(_2\) Regulation, 2014 prices)**

<table>
<thead>
<tr>
<th>Fuel price scenario</th>
<th>Cost effectiveness (2014 prices)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central (€0.59/litre for petrol; €0.47/litre for diesel)</td>
<td>€38.3/tCO(_2) to €45.7/tCO(_2)</td>
</tr>
<tr>
<td>High fuel price scenario (+30%; €0.77/litre for petrol; €0.61/litre for diesel)</td>
<td>-€3.1/tCO(_2) to +€1.7/tCO(_2)</td>
</tr>
<tr>
<td>Low fuel price scenario (-30%; €0.41/litre for petrol; €0.33/litre for diesel)</td>
<td>€85.1/tCO(_2) to €89.7/tCO(_2)</td>
</tr>
</tbody>
</table>

Actual fuel prices over the period 2006 to 2013 have been higher than the central values assumed in the Impact Assessment, and in some years they have been more than 30% above these central values. This has consequences for the actual outturn levels of cost effectiveness.

**Table 5-22: Historic trends in pre-tax road transport fuel prices**

<table>
<thead>
<tr>
<th>Year</th>
<th>EU-average pre-tax fuel prices (€), 2006-2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Petrol</td>
</tr>
<tr>
<td>2006</td>
<td>0.47</td>
</tr>
<tr>
<td>2007</td>
<td>0.48</td>
</tr>
<tr>
<td>2008</td>
<td>0.55</td>
</tr>
<tr>
<td>2009</td>
<td>0.41</td>
</tr>
<tr>
<td>2010</td>
<td>0.53</td>
</tr>
<tr>
<td>2011</td>
<td>0.64</td>
</tr>
<tr>
<td>2012</td>
<td>0.72</td>
</tr>
<tr>
<td>2013</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Source: EU Oil Bulletin
It is not possible at this point in time (i.e. in 2015) to carry out an equivalent ex-post assessment of cost effectiveness for the full 2006-2020 period because it is unknown what the actual emissions performance of new vehicles entering the fleet between 2014 and 2020 will be (the impact assessment analysed the costs and emissions benefits of new vehicles entering the fleet in each year over that full time period). However, it is possible to analyse the lifetime costs and benefits associated with new vehicles that entered the EU’s vehicle fleet between 2006 and 2013. Using the baseline scenario, information on the actual emissions performance of new vehicles that entered the fleet between 2006 and 2013, and knowledge of average vehicle lifetimes and survival rates, the total lifetime costs to society and cumulative lifetime emissions savings due to the Regulation can be quantified.

Table 5-23: Ex-post analysis of costs, emissions benefits and cost effectiveness of the car CO₂ Regulation (2014 prices)

<table>
<thead>
<tr>
<th>Costs and benefits to society</th>
<th>Net Present Value Costs to Society (€)</th>
<th>Well-to-wheels CO₂ Abatement (Mt)</th>
<th>Cost per Tonne CO₂ (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-€6.4 billion</td>
<td>138</td>
<td>-€46/tCO₂</td>
<td></td>
</tr>
</tbody>
</table>

The analysis carried out for this ex-post evaluation shows that the Regulation will be responsible for achieving total real-world lifetime well-to-wheel emissions savings for new cars that entered the fleet between 2006 and 2013 of 138 MtCO₂. The Regulation will also lead to a net reduction in costs to society based on the improved fuel efficiency of the vehicles that have already entered the fleet. Costs to society will be €6.4 billion lower than if the Regulation had not been introduced. Furthermore, these figures indicate that the Regulation is very cost effective with average abatement costs of -€46 per tonne of CO₂ abated. Note that these figures are not directly comparable to the ex-ante analysis results because the original Impact Assessment included the effects of new cars entering the fleet up to 2020.

5.5.1.2 Light commercial vehicles

For LCVs, the relevant ex-ante Impact Assessment analysed costs to society based on the emissions reduction target being achieved by 2015. Net costs to society for the period were estimated at -€4 billion for 2010-2020 and -€11 billion for 2010-2030 (i.e. cost savings in both cases). Emissions reductions of at least 60 MtCO₂ were estimated in the Impact Assessment for the period from 2010 to 2020. Note that the cost impacts were estimated in year 2000 prices; these figures and adjusted values in 2014 prices are presented in Table 5-24.

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38 Real-world emissions savings have been estimated using uplift factors identified in ICCT (2014) for each year from 2006 through to 2013.
Table 5-24: Ex-ante analysis of cost effectiveness of the proposal for the LCV CO₂ Regulation (from the Impact Assessment of proposals for the Regulation, 2000 prices)

<table>
<thead>
<tr>
<th>Price index year for cost analysis</th>
<th>Time period</th>
<th>NPV costs to society 2010-2020</th>
<th>Well-to-wheels CO₂ abatement (2010-2020) (Mt)</th>
<th>Cost effectiveness €/tonne CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 prices (as per estimates from the original Impact Assessment)</td>
<td>2010-2020</td>
<td>-€3.9 billion</td>
<td>-60 MtCO₂</td>
<td>-€38.9/tCO₂ to -€32.6/tCO₂</td>
</tr>
<tr>
<td></td>
<td>2010-2030</td>
<td>-€11.0 billion</td>
<td>-201 MtCO₂</td>
<td>-€34.9/tCO₂ to -€20.6/tCO₂</td>
</tr>
<tr>
<td>2014 prices</td>
<td>2010-2020</td>
<td>-€5.3 billion</td>
<td>-60 MtCO₂</td>
<td>-€53.1/tCO₂ to -€47.6/tCO₂</td>
</tr>
<tr>
<td></td>
<td>2010-2030</td>
<td>-€15.0 billion</td>
<td>-201 MtCO₂</td>
<td>-€44.5/tCO₂ to -€28.1/tCO₂</td>
</tr>
</tbody>
</table>

As for the car CO₂ Regulation, the ex-post costs and benefits to society that have been realised as a result of the LCV CO₂ Regulation have been quantified on the basis of the vehicles that have entered the fleet in the period since the Regulation was announced, up to and including 2013. The lifetime costs and emissions benefits for these vehicles have been quantified, and are presented in the table below. It must be stressed that the changes in costs and emissions realised to date cannot be directly compared with those developed in the Impact Assessment. The Impact Assessment analysed the predicted changes that would occur out to 2020 and 2030 as a result of new, more fuel-efficient vehicles entering the fleet each year between 2010 and 2020, and between 2010 and 2030 respectively. This ex-post evaluation can only analyse the actual and anticipated impacts of vehicles that have already entered the fleet (i.e. up to 2013).

Table 5-25: Ex-post costs and benefits to society associated with the LCV CO₂ Regulation (2014 prices)

<table>
<thead>
<tr>
<th>Costs and benefits to society</th>
<th>NPV costs to society</th>
<th>Well-to-wheels CO₂ abatement (Mt)</th>
<th>€/tonne CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-€0.9 billion</td>
<td>-5.2</td>
<td>-€172/tCO₂</td>
</tr>
</tbody>
</table>

Even though the Regulation has only been in force since 2011, there are already significant benefits in terms of reductions in costs to society and reductions in CO₂ emissions. Based on the improved fuel efficiency of only the new LCVs that entered the fleet between 2009 and 2013, it is already clear that emissions reductions of around 2.0 MtCO₂ will be achieved over the full lives of these vehicles, and costs to society will reduce by €0.9 billion compared to the baseline scenario. The figures in the table also clearly indicate that the Regulation has already proved to be very cost effective, with savings to society of €172 per tonne of CO₂ abated.
However, the emissions savings achieved to date look low compared to the ex-ante estimates developed in the original Impact Assessment of proposals for the LCV CO₂ Regulation. This is because the original Impact Assessment overestimated the emissions savings that would result from the Regulation because of uncertainty in the baseline emissions performance of LCVs prior to the Regulation’s introduction. As discussed in Section 5.2, the Impact Assessment was based on quantifying the total emissions benefits associated with reducing average LCV emissions from 203 gCO₂/km to 175 gCO₂/km. However, in practice, prior to the introduction of the Regulation, fleet-average LCV emissions were already lower than 203 gCO₂/km, which is why the total emissions savings achieved in practice are low compared to the ex-ante estimates. Analysis of the data now available shows that the Regulation has been responsible for reducing NEDC emissions from 185 gCO₂/km to 173.3 gCO₂/km to date. Once the divergence between real-world and test cycle emissions are taken into account, the level of achievement is even smaller than expected (although the level of divergence between real-world and test cycle emissions is lower for LCVs than it is for cars). This has implications for the costs and benefits to society, with reductions in economic benefits as well as reductions in emissions savings.

5.5.2 Manufacturer costs

5.5.2.1 Passenger cars

The original Impact Assessment drew on research from a number of supporting studies carried out for the Commission to assess the cost impact on manufacturers associated with the Regulation. In particular, (IEEP, 2007) estimated that the impacts of the Regulation on the retail prices of passenger cars would range from €1,050 to €2,400 per car (2006 prices), depending on the baseline scenario and the level of autonomous mass increase assumed. The study assumed that costs to manufacturers and retail prices are related by a factor of 1.44, and hence the cost impacts were estimated to range from €730 to €1,670 per car in 2006 prices (€860 to €1,970 per car in 2014 prices). The costs calculated in this study were the incremental costs to manufacturers of achieving the 130 gCO₂/km target in 2012 from a starting point of 159.2 gCO₂/km, the average emissions performance for the 2006 new car fleet estimated as part of the same study. (TNO, 2006), also included estimates for the average manufacturer costs per vehicle for meeting the targets using the various policy options that were under discussion at the time. That study provided estimates for the unit costs to manufacturers of (a) achieving the 140 gCO₂/km ACEA voluntary agreement target in 2008 and (b) the incremental cost of reducing emissions from 140 gCO₂/km in 2008 to a Regulatory target of 130 gCO₂/km by 2012. To reach the voluntary agreement target of 140 gCO₂/km (from a starting point of 166 gCO₂/km), costs were estimated at €832 per vehicle in 2006 prices (€982 in 2014 prices); the incremental costs of reducing emissions from 140 gCO₂/km to 130 gCO₂/km were estimated at €620 per vehicle in 2006 prices (€732 per vehicle in 2014 prices). Hence, to reduce emissions from 166 gCO₂/km to 130 gCO₂/km was estimated to cost €1,452 in 2006 prices (€1,714 in 2014 prices).

Using the unit cost estimates from the IEEP and TNO studies, the total predicted ex-ante costs to the industry can also be estimated when this cost information is combined with data on the new car market. Between 2007 (the first year when advance notice of the Regulation would have had any impact on the industry) and 2012 (the year assumed in the Impact Assessment for achieving the 130 gCO₂/km target), a total of 82.6 million new cars were registered in the EU. Assuming a linear reduction in emissions between 2007 and 2012, the average cost per vehicle sold to achieve the target would be 50% of the unit cost of reducing emissions from the baseline starting point (i.e. 159.2g/km as assumed in IEEP (2007) or 166 gCO₂/km as assumed in TNO (2006)) to the 130

gCO₂/km target value. Using the data on actual new car registrations for the time period of interest, and 50% of the ex-ante estimated unit incremental manufacturer costs, the total costs to the industry for meeting the target were predicted to fall in the range €35.6 billion to €81.3 billion (in 2014 prices).

The actual costs incurred by the industry to comply with the Regulation have been investigated by carrying out detailed analysis of how the market penetration of these CO₂ abatement technologies has changed over the time period of interest (Ricardo-AEA, 2015 (forthcoming)) and cross-referencing the data on market penetration with vehicle teardown-based estimates of the unit costs of these technologies from the literature (FEV, 2013, National Academies, 2011). This analysis has allowed estimates of the actual costs incurred by the automotive industry to be quantified, based on the technologies that have been adopted in practice. Using this approach, the total costs to manufacturers associated with the car CO₂ Regulation to date (i.e. up to 2013) have been estimated at €17.3 billion compared to the baseline scenario. Based on the numbers of new cars registered between 2007 and 2013, the average incremental cost incurred by manufacturers per car sold is €182.

**Table 5-26: Comparison of ex-ante and ex-post estimates of manufacturer costs for meeting the 130 gCO₂/km target for passenger cars**

<table>
<thead>
<tr>
<th></th>
<th>Reduction in fleet-average new car emissions</th>
<th>Average manufacturer cost per car (2014 prices)</th>
<th>Total costs to manufacturers (based on cars sold between 2007 and 2012/2013)</th>
<th>Cost per gCO₂/km reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex-ante cost estimate (TNO, 2006)</td>
<td>From 166 to 130 gCO₂/km</td>
<td>€857</td>
<td>€70.8 billion</td>
<td>€48 per gCO₂/km</td>
</tr>
<tr>
<td>Ex-ante cost estimate (IEEP, 2007)</td>
<td>From 159 to 130 gCO₂/km</td>
<td>€430 to €984</td>
<td>€35.6 billion to €81.3 billion</td>
<td>€30 to €68 per gCO₂/km</td>
</tr>
<tr>
<td>Ex-post cost assessment (this study)</td>
<td>From 161 to 126.7 gCO₂/km</td>
<td>€183</td>
<td>€17.3 billion</td>
<td>€10 per gCO₂/km</td>
</tr>
</tbody>
</table>

Note: Ex-ante total costs to manufacturers are based on cars sold between 2007 and 2012, as the original Impact Assessment was based on a regulatory target of 130 gCO₂/km being achieved by 2012. Ex-post total costs are based on cars sold between 2007 and 2013 (2013 was the year that the 130 gCO₂/km was first achieved).

The costs that have been incurred by manufacturers are significantly lower than those predicted prior to the Regulation being introduced and reflect the fact that the costs of CO₂ abatement technologies for vehicles have proved to be less expensive than was expected before the Regulation was introduced. Overall, these results indicate that the Regulation has been very significantly more cost-efficient in practice compared to expectations in advance of its introduction.

The analysis indicates that whilst there has been a significant increase in the market penetration of CO₂ abatement technologies in new cars since 2002, in most cases (as expected), the technologies with high levels of market penetration have been relatively low cost technologies. Furthermore, in many cases the actual costs associated with individual technologies are significantly lower than was anticipated when the car CO₂
Regulation was under development (TNO, 2011). In particular, teardown studies commissioned by the US EPA and others have provided more detail on the costs associated with individual technologies. (FEV, 2013) presents detailed teardown data on technology costs for the European market and many of the technologies included in this analysis were found to be significantly cheaper than previously thought. Furthermore, the analysis in (FEV, 2013) indicates that for most of the technologies, costs will decline in the future due to learning and other effects.

A comparison of unit cost estimates for specific vehicle technologies as used for the Impact Assessment (TNO, 2006) compared with the most recent cost estimates for the same technologies is presented in the table below. All cost values have been converted to 2014 prices and are based on a typical upper medium sized passenger car (D-segment).

**Table 5-27: Unit costs of selected technologies fitted to new passenger cars to reduce tailpipe CO\(_2\) emissions (all figures quoted in 2014 prices)**

<table>
<thead>
<tr>
<th>CO(_2) abatement technology</th>
<th>Ex-ante cost estimates (TNO, 2006)</th>
<th>Updated cost estimates (FEV, 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Valve Actuation and Lift</td>
<td>€236</td>
<td>€150</td>
</tr>
<tr>
<td>Downsized/turbocharged petrol engines (medium-strong)</td>
<td>€460</td>
<td>€336</td>
</tr>
<tr>
<td>Dual clutch transmission</td>
<td>€1,062</td>
<td>€458</td>
</tr>
<tr>
<td>Power-split hybrid electric drive system</td>
<td>€4,131</td>
<td>€5,871</td>
</tr>
<tr>
<td>Diesel engine downsizing</td>
<td>€177</td>
<td>€133</td>
</tr>
<tr>
<td>Gasoline Direct Injection (GDI) technology</td>
<td>€472</td>
<td>€203</td>
</tr>
<tr>
<td>Micro-hybrid (stop-start plus regenerative braking)</td>
<td>€1,052</td>
<td>€643</td>
</tr>
</tbody>
</table>

As can be seen from the table, the majority of these technologies are now estimated to have lower costs than at the time the Impact Assessment was carried out. In particular, the reductions in cost estimates for dual clutch transmissions, GDI technology and micro-hybrid technology are more than 40% lower than was anticipated at the time the Impact Assessment was carried out. The data also indicate that downsized diesel engines reduce costs for manufacturers, whereas this technology was originally predicted to incur costs of €177. Only full hybrid-electric vehicle technology is now estimated to be more costly than the estimates made in 2006, but it is notable that this technology has not been widely adopted in the passenger car market (only 1.4% of new cars sold in the EU in 2013 were equipped with this technology). Costs are likely to be higher than expected because this technology has not been widely used to meet the CO\(_2\) targets, meaning that cost reductions linked to economies of scale have not been achieved to the extent expected at the time the Impact Assessment was carried out.

**5.5.2.2 Light commercial vehicles**

Ex-ante cost estimates for the LCV CO\(_2\) Regulation were developed as part of the supporting study to the Regulation’s Impact Assessment (AEA, 2009). This study estimated retail price impacts associated with reducing average LCV emissions from 203 gCO\(_2\)/km in 2007 to various different target levels, including 175 gCO\(_2\)/km by 2015.
Costs to manufacturers were then derived from these figures using a factor to of 1.11 convert between retail prices (excluding taxes) and manufacturer costs. The study estimated retail price impacts (in 2007 prices) of €1,996 per vehicle for reducing the emissions of an LCV from 203 gCO₂/km to 175 gCO₂/km (€2,302 in 2014 prices), which translates to manufacturer costs of €1,798 per vehicle (€2,074 in 2014 prices). As for passenger cars, the average cost to manufacturers of achieving the fleet CO₂ targets would be 50% of this value assuming that fleet average emissions decline in a linear manner between 2007 and 2015 (i.e. €1,037 in 2014 prices).

However, in retrospect there is a potential weakness with this ex-ante assessment that stems from the fact that there was a lack of robust data on LCV CO₂ emissions at the time this assessment was carried out. The best information at the time indicated that 203 gCO₂/km was representative of average LCV emissions performance in 2007, but as discussed previously, this is likely to have been an overestimate. The analysis carried out for this ex-post evaluation study assumes a baseline LCV emissions performance of 185 gCO₂/km, and hence the ex-post manufacturer cost assessment is based on reducing emissions from this level in 2009 to the achieved level of 173.3 gCO₂/km in 2013. A comparison of these estimated ex-post costs, and the ex-ante manufacturer costs used in the Impact Assessment are presented below. As can be seen from the table below, the estimated ex-post costs to manufacturers to comply with the Regulation are very significantly lower than estimated for the Impact Assessment.

Table 5-28: Comparison of ex-ante and ex-post estimates of manufacturer costs for meeting the 175 gCO₂/km target for LCVs (2014 prices)

<table>
<thead>
<tr>
<th>Reduction in fleet-average new car emissions</th>
<th>Average manufacturer cost per LCV (2014 prices)</th>
<th>Total costs to manufacturers (based on LCVs sold between 2009 and 2013)</th>
<th>Cost per gCO₂/km reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex-ante cost estimate (AEA, 2009)</td>
<td>203 to 175 gCO₂/km</td>
<td>€1,037</td>
<td>€74 per gCO₂/km</td>
</tr>
<tr>
<td>Ex-post cost assessment (this study)</td>
<td>185 to 173.3 gCO₂/km</td>
<td>€115</td>
<td>€20 per gCO₂/km</td>
</tr>
</tbody>
</table>

5.5.3 Changes in consumer fuel expenditure

5.5.3.1 Passenger cars

Reductions in tailpipe CO₂ emissions are directly correlated with reductions in vehicle fuel consumption, and hence the Regulations were predicted to lead to decreases in consumer expenditure on road transport fuels. The supporting studies that underpinned the Impact Assessment of the passenger car CO₂ Regulation investigated the impacts of the 130 gCO₂/km target on lifetime fuel cost savings at the consumer level (IEEP, 2007). This work estimated average lifetime fuel cost savings based on two fuel price scenarios: 2006 post-tax prices of (a) €1.00 per litre and (b) €1.20 per litre (€1.18 per litre and €1.42 per litre respectively in 2014 prices). As previously noted, actual fuel prices over the time period of have been significantly higher than this, and hence it is also useful to examine how the ex-ante costs would have changed if an even higher average fuel price of €1.40 per litre (€1.65 per litre in 2014 prices) had been used.
Table 5-29: Ex-ante assessment of lifetime fuel cost savings due to the car CO$_2$ regulation

<table>
<thead>
<tr>
<th>Fuel price scenario</th>
<th>2014 equivalent fuel prices</th>
<th>Average lifetime fuel savings in fuel costs per vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-tax fuel price of €1.00 per litre</td>
<td>€1.18 per litre</td>
<td>€2,649 per car</td>
</tr>
<tr>
<td>Post-tax fuel price of €1.20 per litre</td>
<td>€1.42 per litre</td>
<td>€3,179 per car</td>
</tr>
<tr>
<td>Post-tax fuel price of €1.40 per litre</td>
<td>€1.65 per litre</td>
<td>€3,709 per car</td>
</tr>
</tbody>
</table>

Ex-post analysis of fuel cost savings has been carried out by comparing the actual average fuel efficiency of new cars registered between 2007 and 2013 with the counterfactual scenario for changes in new car fuel efficiency under the assumption that the Regulation did not exist. Between 2007 and 2013, actual fleet-average NEDC emissions for new cars have declined from 158.7 gCO$_2$/km to 126.7 gCO$_2$/km. In the counterfactual scenario, improvements in emissions still occur in the absence of the Regulation, albeit at a much slower rate of 0.5 gCO$_2$/km per year. Hence, in the counterfactual scenario, NEDC emissions are assumed to reduce from 158.7 gCO$_2$/km in 2007 to 155.7 gCO$_2$/km in 2013. However, NEDC performance is not representative of real-world emissions performance, and this has also been taken into account in the analysis of fuel cost savings.

Table 5-30: NEDC and real-world new car CO$_2$ performance: (a) actual outturn and (b) counterfactual scenario assuming there was no CO$_2$ Regulation in place

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Emissions performance due to the car CO$_2$ Regulation (gCO$_2$/km)</th>
<th>Baseline counterfactual emissions performance (assumes no Regulation (gCO$_2$/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEDC</td>
<td>Real-world</td>
<td>NEDC</td>
</tr>
<tr>
<td>2007</td>
<td>158.7</td>
<td>176.9</td>
</tr>
<tr>
<td>2008</td>
<td>153.6</td>
<td>172.0</td>
</tr>
<tr>
<td>2009</td>
<td>145.7</td>
<td>172.0</td>
</tr>
<tr>
<td>2010</td>
<td>140.3</td>
<td>169.8</td>
</tr>
<tr>
<td>2011</td>
<td>135.7</td>
<td>168.3</td>
</tr>
<tr>
<td>2012</td>
<td>132.2</td>
<td>165.2</td>
</tr>
<tr>
<td>2013</td>
<td>126.7</td>
<td>166.3</td>
</tr>
</tbody>
</table>

The ex-post analysis of fuel cost savings is based on comparing actual outturn real-world performance with real-world emissions performance for the baseline counterfactual scenario. This shows that, as would be expected, the savings accrued depend on the year in which the new car was registered. This takes into account (a) fuel price variation between 2007 and 2013 and (b) the improved fuel efficiency of newer vehicles. The findings from this analysis are presented in the table below.
Table 5-31: Ex-post assessment of lifetime fuel cost savings due to the car CO\(_2\) Regulation

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Average NEDC tailpipe emissions (gCO(_2)/km)</th>
<th>Average real-world lifetime fuel savings in fuel costs per vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Petrol cars</td>
</tr>
<tr>
<td>2007</td>
<td>158.7</td>
<td>€10</td>
</tr>
<tr>
<td>2008</td>
<td>153.6</td>
<td>€464</td>
</tr>
<tr>
<td>2009</td>
<td>145.7</td>
<td>€628</td>
</tr>
<tr>
<td>2010</td>
<td>140.3</td>
<td>€861</td>
</tr>
<tr>
<td>2011</td>
<td>135.7</td>
<td>€1,047</td>
</tr>
<tr>
<td>2012</td>
<td>132.2</td>
<td>€1,423</td>
</tr>
<tr>
<td>2013</td>
<td>126.7</td>
<td>€1,330</td>
</tr>
</tbody>
</table>

By 2013 it can be seen that the levels of lifetime fuel cost savings for new cars are lower than predicted in the Impact Assessment. This is almost wholly due to the increasing divergence between test-cycle and real-world emissions and fuel economy performance. As can be seen from Table 5-30, the level of divergence between test cycle and real-world CO\(_2\) emissions performance increased between 2007 and 2013, to the extent that by 2013, real-world average emissions from new cars were higher than they were in 2012, even though NEDC average emissions decreased between 2012 and 2013. This explains why the real-world savings in fuel costs due to the Regulation for new vehicles registered in 2013 are lower than for those registered in 2012.

Carrying out the analysis on the basis of NEDC test-cycle fuel consumption performance, the lifetime average fuel expenditure savings due to the Regulation for new petrol and diesel cars registered would be €2,811 and €2,506 respectively (based on 2013 average petrol and diesel fuel prices of €1.46 per litre for petrol and €1.60 per litre for diesel (quoted in 2014 prices); these fuel expenditure savings are in line with the ex-ante estimates from the Impact Assessment. Again, this issue highlights how the unrepresentative nature of the test cycle has eroded the real-world benefits of the Regulation.

5.5.3.2 Light commercial vehicles

For LCVs, the ex-ante Impact Assessment analysed total savings in fuel expenditure as a result of the Regulation for all new vehicles entering the EU vehicle parc between 2010 and 2020. This is in a different form to the ex-ante analysis carried out for passenger cars which assessed lifetime fuel expenditure savings per vehicle. As with the analysis of emissions benefits, it is not possible at this point in time (2014) to carry out a consistent ex-post analysis of total 2010-2020 fuel expenditure savings. However, analysis of total and per vehicle lifetime fuel savings for all new LCVs that entered the EU vehicle parc between 2010 and 2013 can be carried out instead to assess the levels of savings achieved as a result of the Regulation to date. The ex-ante and ex-post fuel expenditure savings are presented in Table 5-32.
Table 5-32: Ex-ante and ex-post assessment of fuel expenditure savings resulting from the LCV CO\textsubscript{2} Regulation

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex-ante estimate of fuel expenditure savings</td>
<td>-€16.4 billion</td>
<td>-€21.5 billion</td>
<td>N/A</td>
</tr>
<tr>
<td>Ex-post estimate of fuel expenditure savings</td>
<td>N/A</td>
<td>N/A</td>
<td>-€0.4 billion</td>
</tr>
</tbody>
</table>

It is notable that the ex-ante 2010 to 2020 fuel expenditure savings are very significantly higher than the ex-post assessment of lifetime fuel expenditure savings for vehicles that entered the EU vehicle parc between 2010 and 2013. Even taking into account the much shorter time period for the ex-post analysis, it is clear that the ex-ante estimate of this benefit are significantly greater than the ex-post outcomes. However, this can be explained by examining the baseline scenario used for the ex-ante analysis. As discussed earlier, the Impact Assessment of proposals for the LCV CO\textsubscript{2} Regulation assumed that baseline average emissions performance for LCVs was 203 gCO\textsubscript{2}/km, and this figure was used as the basis for assessing the costs, emissions benefits and fuel expenditure savings associated with the various options for the Regulation. More recent information on baseline average emissions performance in 2009 indicates that the average new LCV emitted 185 gCO\textsubscript{2}/km in that year. The typical pre-Regulation baseline LCV was already significantly more fuel efficient than the baseline vehicle assumed for the Impact Assessment meaning that the ex-ante fuel expenditure savings calculated for the Impact Assessment were significantly overestimated.

The ex-post analysis carried out for this evaluation indicates that lifetime fuel savings of €0.4 billion will be achieved due to the new, more efficient vehicles already on the road as a result of the Regulation. However, as is the case for passenger cars, the fuel expenditure savings for consumers have been eroded by the fact that the test cycle is unrepresentative of real-world conditions. If test cycle fuel economy and emissions performance were representative of real-world conditions, then the total value of lifetime fuel savings based on the improvements in emissions performance achieved to date would have been €1.2 billion – very significantly higher than the actual real-world estimate.

Ex-post lifetime fuel cost savings for LCVs that entered the EU vehicle parc between 2010 and 2013 have also been calculated on a per vehicle basis in the same was as for passenger cars. Actual NEDC and real-world emissions performance have been compared to a counterfactual baseline scenario in order to calculate the savings in fuel costs (see Table 5-33). For LCVs, the counterfactual scenario assumes that there is no improvement in emissions performance (and hence in fuel economy) without the LCV CO\textsubscript{2} Regulation. With the Regulation in place, the divergence between test cycle and real-world emissions is assumed to increase from 11% in 2009 to 15% in 2013. For the counterfactual scenario, the level of divergence is assumed to increase more slowly – i.e. from 11% in 2009 to 13% in 2013.
Table 5-33: NEDC and real-world new LCV CO₂ performance: (a) actual outturn and (b) counterfactual scenario assuming there was no CO₂ Regulation in place

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>NEDC</th>
<th>Real-world</th>
<th>NEDC</th>
<th>Real-world</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>181.5</td>
<td>203.3</td>
<td>185.0</td>
<td>206.3</td>
</tr>
<tr>
<td>2011</td>
<td>180.9</td>
<td>205.5</td>
<td>185.0</td>
<td>207.2</td>
</tr>
<tr>
<td>2012</td>
<td>180.2</td>
<td>206.4</td>
<td>185.0</td>
<td>208.1</td>
</tr>
<tr>
<td>2013</td>
<td>173.3</td>
<td>199.7</td>
<td>185.0</td>
<td>209.1</td>
</tr>
</tbody>
</table>

Using these data, lifetime fuel costs for vehicles registered as new in each year of interest were calculated and compared to the counterfactual scenario for the same year in order to calculate the net fuel cost savings due to the Regulation (see Table 5-34). These figures show a high level of variability from year to year and are highly sensitive to the assumptions in the divergence between test-cycle and real-world performance for each year of interest.

Table 5-34: Ex-post assessment of lifetime fuel cost savings due to the LCV CO₂ Regulation

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Average NEDC tailpipe emissions (gCO₂/km)</th>
<th>Average lifetime fuel savings in fuel costs per vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Petrol LCVs</td>
</tr>
<tr>
<td>2010</td>
<td>181.5</td>
<td>€315</td>
</tr>
<tr>
<td>2011</td>
<td>180.9</td>
<td>€340</td>
</tr>
<tr>
<td>2012</td>
<td>180.2</td>
<td>€363</td>
</tr>
<tr>
<td>2013</td>
<td>173.3</td>
<td>€1,466</td>
</tr>
</tbody>
</table>

5.5.4 Changes in taxation revenue

As a direct result of the reduction in fuel expenditures described in the previous section, there have also been reductions in tax revenues associated with fuel use. Estimates for changes in tax revenues were not provided in the original Impact Assessments, but an ex-post analysis of this issue has been carried out as part of this evaluation.

Table 5-35: Change in fuel tax revenues as a result of the Regulations

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Baseline taxation revenue (no Regulation)</th>
<th>Post-Regulation taxation revenue</th>
<th>Change in tax revenues</th>
</tr>
</thead>
<tbody>
<tr>
<td>New cars (2006 to 2013)</td>
<td>€649.3 billion</td>
<td>€626.9 billion</td>
<td>-€22.4 billion</td>
</tr>
<tr>
<td>New LCVs (2010 to 2013)</td>
<td>€58.1 billion</td>
<td>€57.0 billion</td>
<td>-€1.1 billion</td>
</tr>
</tbody>
</table>
As can be seen from the table above, for passenger cars, the loss in fuel tax revenues is estimated at €22.4 billion over the period 2006 to 2013. For LCVs, the loss in fuel tax revenues is estimated at €1.1 billion over the period 2010 to 2013.

5.5.5 Administrative burdens

In the respective Impact Assessments, there was no explicit quantification of the administrative burden that would result from the implementation of the Regulations; instead, the focus was on additional administrative costs. Since the monitoring elements would be based on the framework that had already been set up by the monitoring mechanism under Decision 1753/2000, the implication in the Impact Assessment accompanying the original proposal for the passenger car CO\textsubscript{2} Regulation was that there was little in the way of additional administrative costs as a result of the Regulation (European Commission, 2007d). The Impact Assessment accompanying the original LCV CO\textsubscript{2} Regulation was more explicit in this respect. It concluded that there would be little additional administrative burden on manufacturers, as: i) they were already obliged to report the data needed to assess compliance with the Regulation as part of the type approval process; and ii) while they would need to monitor and forecast sales in order to ensure compliance, most would have already put such procedures in place as a result of the passenger car CO\textsubscript{2} Regulation. Similarly for Member States, it was concluded that the adaptation of existing processes under the passenger car CO\textsubscript{2} Regulation to also cover LCVs would incur only negligible additional costs (European Commission, 2009b). The only detailed consideration of administrative costs in the Impact Assessment accompanying the proposal to confirm the 2020 modalities was in relation to the smallest manufacturers, which resulted in the introduction of a de minimis in the Regulations to exclude these manufacturers from having to have a CO\textsubscript{2} reduction target (European Commission, 2012b).

The survey responses provided limited information on the nature and extent of administrative burdens encountered, and very few stakeholders raised any issues in this area.

The monitoring process\textsuperscript{39} (see Section 2.5), has evolved over time, as the process improves and any issues that have been identified are recognised and addressed. While the Regulations introduce some new monitoring requirements, they also build on existing processes. For example, even though the requirements on Member States to collate and report the relevant data to enable the Commission to monitor the implementation of the two Regulations and the requirements on the Commission in this respect are new, they build on systems that are already in place. The latter include the Certificates of Conformity (CoCs) and the type approval documents (TADs), which are part of well-established systems for approving and monitoring vehicles in the EU. However, the fact that the Regulations’ monitoring and reporting systems relay on other legislation in this way means that some issues can only be properly addressed by amending this related legislation, e.g. that relating to CoCs or TADs. Also, as a result of these linkages, amendments to these other pieces of legislation that are undertaken through other legislative processes have the potential to adversely affect the monitoring of the LDV CO\textsubscript{2} Regulations, so it is important for those responsible for the Regulations in the Commission to be aware of any changes that are being considered by other parts of the Commission to other important pieces of legislation.

The use of these pre-existing systems has clearly reduced the additional administrative burden that the Regulations have imposed on industry compared to if new systems had

\textsuperscript{39} This section is based on interviews with officials at the European Commission and at the European Environment Agency.
been introduced. In response to the questionnaires and in the course of the interviews, no issues were raised in relation to the administrative burden associated with the monitoring and reporting elements of the Regulations. The only issue raised from an administrative perspective was in relation to the costs associated with applying for a small volume manufacturer derogation for very small manufacturers (see below), which has been addressed by the introduction of the de minimis provision (see Section 2.4).

As manufacturers would potentially be subject to an excess emissions premium in the event of non-compliance (see Section 2.4), the quality of the data and the ability to track records is crucial. The important information in this respect relates to the mass and CO₂ emissions of cars and LCVs. As noted in Section 2.5, it is the responsibility of the registration authorities in the Member States to collate the data and to transmit these to the European Environment Agency (EEA). The Regulations require the use of the ‘mass of a vehicle in running order’, as stated on the CoC, to be used. In turn, the CoC should use the information on mass that has been included in the TAD and the type approval certificate issued by the type approval authority. However, in the TAD the mass in running order has been expressed as a range (minimum-maximum) for a vehicle version. It is also evident that there has been some inconsistency in how the mass has been recorded in the CoCs. For example, it appears that in a number of cases, the actual mass (i.e. which is higher than the mass in running order) has been provided in the CoCs by manufacturers, sometimes it seems on the recommendation of the Member State in which the vehicle is to be registered. A survey by the Commission of Member State practises showed however that these inconsistencies in the ‘mass’ data are difficult to detect and it can be concluded that this has introduced some uncertainty in the dataset. A new Regulation – Commission Regulation 1230/2012, which amends Directive 2007/46/EC (European Commission, 2012) – that amends Directive 2007/46/EC (European Commission, 2012) – that amends should address this issue, as it requires manufacturers to include both information on the ‘mass in running order’ and the ‘actual mass’ in the CoC.

With respect to the tracking of records, the numbering of records has been made mandatory, in order to enable manufacturers to better identify the variants reported by the Member States, but there are still a number of cases each year where it has not been possible to unambiguously identify a vehicle. In order to take account of these, a margin of error is applied, which leads to very small changes in the figures reported. This underlines the importance of manufacturers checking the data. For LCVs it is expected that with the new monitoring system based on vehicle identification numbers it will be possible to clearly identify the vehicles and then to quickly cross-check. For LCVs, there has been an issue around the identification of multi-stage vehicles, so the system being applied to LCVs will be changed to monitor these using their unique Vehicle Identification Numbers (VINs). Indeed, lack of VINs as a monitoring parameter has previously been cited by several manufacturers as a reason for not being able to completely verify or correct the monitoring data and introducing this into the Regulations has been the subject of a recent study for the European Commission (Okopol et al, 2013). An initial reluctance from Member States about using VINs, due to concerns over privacy, has been overcome.

Another issue is that, even though the monitoring is coordinated at the EU level, each Member State is involved in the collation and transmission of the data to the EU and some of the systems are better than others. Some Member States still report manually and so have no automatic checks on the data, which increases the risks of errors, but this is only an issue with probably less than 3% of records. While some errors are easy to identify at the EU level, e.g. if figures for mass are unexpectedly high in one year, it is more difficult to spot smaller, less significant errors. Hence, since the Member States have access to the TADs, it would be easier for them to double check the information before sending it to the EEA. A European-wide reference database is available (the ETAES database) but this is in a format that is difficult to use. If there was a common,
usable reference database for the whole of the EU, it would be beneficial as Member States could use this to quality check their data.

Although the overall differences in 2013 between the provisional and final data were insignificant (<0.3g/km after corrections were made), one manufacturer estimated that around 5% of data returned to them could not be recognised, and a further 5% required revisions.

A final issue relates to the timings. The Regulation requires that the provisional analysis of manufacturers’ average emissions and targets is complete by the end of June each year, after which manufacturers have three months (which would be until the end of September) to check the data before it is finalised. However, the report has to be considered and approved by the Commission in October. For this, it has to be submitted to the Commission six weeks in advance, which would be mid-September at the latest, which according to the timescales of the Regulation is when manufacturers are still checking the data. Hence, in practice, the provisional analysis is completed two months earlier than required to by the Regulation, i.e. by the end of April, but this can be problematic if the information received from Member States is not of sufficient quality.

If, at some point in the future, the utility parameter for either Regulation were to change, it would be important to ensure that any potential issues, along the lines of those that have arisen in relation to ‘mass’ or other issues of particular relevance to the chosen parameter, are identified and addressed. As ‘mass’ is currently the utility parameter used for calculating the targets, there has not yet been as much focus on the information that has been provided on the potential alternative parameter ‘footprint’ (see Section 3.4.2). Information that enables the calculation of ‘footprint’ is now received for the majority of Member States, but the data are probably not yet sufficiently sound to be used for the purposes of estimating the targets. In spite of the fact that the Regulation required Member States to collate this information of relevance to ‘footprint’, many individual Member State systems did not collate this information initially. Hence, they have needed time to change their systems, and most have now done this. Additionally, manufacturers also do not generally check the information on ‘footprint’ yet, as this is not of relevance to the Regulation. Hence, there has been less feedback on the collation of this information, so there has not yet been the opportunity to identify and address any issues. If the utility parameter were to change, it would take time for the Member States and the EEA to ensure that the full dataset was of good enough quality to be used for the calculation of the targets.

In the course of the interviews, representatives of small volume manufacturers were strongly in favour of the derogations and considered that they provide the right balance between providing the necessary flexibility for small volume manufacturers and the need for environmental integrity. Positive aspects of the procedure were noted to be the ability to apply year-round. On the other hand, stakeholders suggested that the process could be streamlined and currently there is a lot of information required in the application that could be reduced, such as the level of detail on competitors. When asked specifically about the administrative burden, small volume stakeholders referenced the estimate in the Impact Assessment supporting the review of the Regulations, which showed that the burden of applications is around €25,000.

5.5.6 Conclusions

The analysis carried out in this section has highlighted the high levels of efficiency associated with both the car and LCV CO2 Regulations. In both cases, the ex-post assessment demonstrates that there have been net economic benefits to society as savings in fuel expenditure have outweighed the compliance costs. For both passenger cars and vans, the costs to manufacturers associated with the Regulations have been much lower than anticipated prior to implementation. However, for LCVs, costs are also
likely to have been lower because the level of effort (emissions reductions) required was lower than estimated in the Impact Assessment. Both of the Regulations have generated reductions in fuel expenditure for vehicle users; the savings for passenger car users are greater than anticipated, whilst for LCVs, the benefits are lower than anticipated due to the lower than expected levels of fuel efficiency improvements required to meet the 175 gCO₂/km.

However, a major source of inefficiency in the Regulations is the dependence on the NEDC test cycle as the basis for quantifying improvements in vehicle emissions performance. It is clear from the ex-post analysis carried out in this areas that the net economic benefits to society, the overall emissions reductions and the savings in fuel expenditure for consumers have all been eroded because of the increasing levels of divergence between real-world and test-cycle emissions performance. For any future regulatory actions on car and LCV CO₂ emissions, it will be important that this major source of inefficiency is addressed. The forthcoming World-Harmonised Light Duty Test Procedure (WLTP) which will replace the NEDC in 2017 should help to solve this problem, but it will be important to ensure that no new sources of inefficiency arise alongside this new test protocol.

While the majority of the additional administrative burden as a result of the Regulations has been placed on Member States (e.g. to collate and report the necessary data to the Commission) and on the Commission (i.e. to verify and analyse these data), it is worth noting that other pre-existing processes have needed to be changed in order to improve the monitoring and reporting of the Regulations. However, first, it is worth noting that the fact that the monitoring and reporting provisions built on pre-existing systems, such as the CoC and TAD, was clearly beneficial from the perspective of minimising administrative burdens. However, these did not specify with sufficient accuracy, as such accuracy was previously not necessary, how and what 'mass' was to be recorded on the various documents, which demonstrates one of the challenges of using pre-existing systems. Hence, amendments have had to be made in order to clarify the information to be recorded for the purpose of the Regulations. If a decision is made to change the utility parameter used in either (or both) of the two LDV CO₂ Regulations, it will be important to apply the lessons that have been learnt with respect to the use of 'mass' – particularly the need to be clear about which value of 'mass' should be specified where and by whom. This is important in order to ensure that the data needed for the new utility parameter are as accurate as possible as soon as possible in order to ensure a seamless transition between the use of the two utility parameters, which would be important in order to maintain confidence in the functioning of the Regulation(s).
5.6 Efficiency: What are the major sources of inefficiencies? What steps could be taken to improve the efficiency of the Regulations? Are there missing tools and/or actions to implement the Regulations more efficiently?

The difference between the inefficiencies that are covered in this section and the weaknesses that were discussed in Section 5.2.3 is that inefficiencies relate to whether the CO₂ emissions reduction that have been delivered could have been achieved at lower costs, rather than considering the actual level of CO₂ emissions achieved. It is worth noting at this point that stakeholders often do not make this distinction (as discussed in Section 15.3 of Annex I). The main sources of inefficiency are both linked to emerging issues that were discussed in Section 3.4.2 (and the associated Annex), i.e.:

- The choice of utility parameter for the passenger car CO₂ Regulation; and
- The assumptions about the average annual distances that cars travel.

The choice of utility parameter relates to the decision to use ‘mass’ as the utility parameter in the Regulations as opposed to ‘footprint’ (see Section 3.4.2). Ricardo-AEA et al (2015) demonstrated that if the average mass of an average manufacturer’s new fleet declined by 10%, it could be 8.7 gCO₂/km closer to its target if ‘footprint’ was the utility parameter compared to being only 4 gCO₂/km closer if ‘mass’ was the utility parameter (see Section 9.1 of Annex C). As this CO₂ reduction would be achieved at the same cost, in this example more than twice as much CO₂ emissions reductions would be delivered for the same cost (from the perspective of the manufacturer) if footprint was the utility parameter. This suggests that for weight reduction options, having ‘mass’ as the utility parameter could be less than half as efficient as having ‘footprint’ would have been. Note that this only applies to the introduction of mass reduction options, which have not been used that widely to date, so the impact on efficiency overall will not be anywhere near this much.

However, as manufacturers are starting to use mass reduction options, a continued use of ‘mass’ as the utility parameter risks increasing the inefficiency of the car Regulation. However, it is worth noting that the stakeholder engagement that was undertaken as part of the Ricardo-AEA et al (2015) study showed that many manufacturers supported the retention of ‘mass’ as the utility parameter, whereas fewer supported a switch to ‘footprint’. Of the issues that were identified by stakeholders as being most detrimental to the effectiveness of Regulations, the use of ‘mass’ as the utility parameter was amongst the most frequent issues raised (see Section 15.3 in Annex I).

With respect to the assumptions about the average annual distances that cars travel, Ricardo-AEA and TEPR (2014) identified that larger and heavier petrol cars are driven farther than smaller petrol cars over their lifetime, although there were no such differences identified for diesel cars (see Section 7.3 in Annex A). If these different mileages are taken into account in the passenger car CO₂ Regulation, e.g. by weighting manufacturer’s targets according to the distance a car travels, it will have implications for the way in which CO₂ reduction technologies are applied to vehicles; a greater average CO₂ reduction would be achieved by applying more technologies to the cars that are used more, i.e. those that are heavier and larger. It was estimated that taking such an approach would reduce the costs associated with delivering the same level of CO₂ emissions reduction overall by between 1.62% and 1.75%, depending on, respectively, whether ‘footprint’ or ‘mass’ was the utility parameter. In this way, the efficiency of the Regulation would be improved (see Section 9.2 in Annex C).

The above discussion focuses on cars and not on LCVs. In relation to the choice of utility parameter, this is due to the conclusions of the study undertaken for the Commission in support of the confirmation of the 2020 target for LCVs (TNO et al, 2012). This concluded that ‘mass’ was a better utility parameter for LCVs than either ‘footprint’ or
'payload', which is another possible utility parameter for LCVs, as it correlated better with CO₂ and had less potential for gaming (see Section 9.3 in Annex C). If ‘footprint’ had been considered to be a better utility parameter than ‘mass’ for LCVs, the discussion above with respect to use of ‘footprint’ as the utility parameter for cars would also apply to LCVs. With respect to mileage, Ricardo-AEA and TEPR (2014) concluded that there was no apparent relationship between the lifetime mileage and the different masses and footprints of LCVs. Hence, there would be no improvements in efficiency by using mileage-weighted targets (see also Section 7.3 in Annex A).
5.7 Coherence: How coherent are the Regulations' modalities with their objectives?

The evaluation of ‘coherence’ identifies the extent to which the intervention logic of the Regulations is internally consistent. Since this evaluation focuses on two Regulations, the evaluation of ‘internal’ coherence has three elements, i.e. the extent to which:

- The individual modalities/elements of the passenger car CO\textsubscript{2} Regulation work together to provide a consistent incentive to manufacturers and an appropriate level of trade-offs between the economic, social and environmental pillars.
- The individual modalities/elements of the LCV CO\textsubscript{2} Regulation work together to provide a consistent incentive to manufacturers and an appropriate level of trade-offs between the economic, social and environmental pillars.
- The two Regulations work together to provide a consistent incentive to manufacturers and to provide an appropriate level of trade-offs between the economic, social and environmental pillars.

5.7.1 Coherence of the individual modalities of the LDV CO\textsubscript{2} Regulations

As the modalities of the two Regulations are very similar (see Section 2), this section focuses on the passenger car CO\textsubscript{2} Regulation and makes references to the LCV CO\textsubscript{2} Regulation as appropriate, before discussing the coherence between the two Regulations. The references to the LCV CO\textsubscript{2} Regulation identify where and how the discussion relating to LCVs is different to that for cars.

Before beginning the discussion, it is important to recall that: i) not all of the modalities were included in the Commission’s original proposals and were therefore assessed in the same detail as other modalities; and ii) each modality was introduced for a particular reason in order to perform a particular function. The aim of this section is to evaluate whether they work together to provide a coherent incentive and appropriate trade-offs. As noted in Section 2.4, the Commission’s original proposal for the passenger car CO\textsubscript{2} Regulation did not include: the phase-in period; super-credits; the derogation for niche manufacturers; or eco-innovations. Further analysis in support of the discussion in this section can be found in Annex H, while the stakeholders’ views on relevant issues can be found in Annex I.

The evaluation of the internal coherence of the Regulations needs to consider the extent to which the various modalities were designed to work together as a whole in order to deliver the objectives of the Regulations and the extent to which they do in practice. The first step in this process is to map the modalities against the various objectives in order to summarise what each was intended to achieve and to recognise where it was acknowledged that there were trade-offs. This draws on the overview of the modalities provided in Section 2.4, as well as the discussion of their theoretical performance, as set out in Section 3.4.2 for the choice of utility parameter and Section 4.2.3 for the phase-in period, super-credits and derogations. An overview of the principal contribution of the main modalities against the main objectives of the Regulations is provided in Table 5-36, which draws on these earlier sections. This table has two parts: the first focuses on those modalities that were part of the original proposal from the Commission for a Regulation on passenger car CO\textsubscript{2}, as these were analysed in detail at this stage and included so as to provide a coherent approach; the second focuses on those modalities that were subsequently introduced into the Regulation in the course of the co-decision process.
### Table 5-36: Overview of the contribution of the main modalities to the main objectives of the passenger car CO\textsubscript{2} Regulation

<table>
<thead>
<tr>
<th>Modality</th>
<th>Reducing CO\textsubscript{2} emissions from LDVs</th>
<th>Improve cost-effectiveness</th>
<th>Ensure competitive neutrality</th>
<th>Ensure social equity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use of utility parameter</strong></td>
<td>Impact on emissions reductions depends on other details</td>
<td>Impact on cost-effectiveness depends on other elements, e.g. the slope</td>
<td>Approach selected as it takes account of the diversity of the fleet by enabling manufacturers that make larger or smaller vehicles to have different targets</td>
<td>As the diversity of the fleet is maintained, the choice for consumers – who have different willingness to pay for new cars – is maintained</td>
</tr>
<tr>
<td><strong>Shape/slope of limit value curve</strong></td>
<td>Impact on emissions reductions depends on other details</td>
<td>Shape and slope selected in order to deliver a balance between cost-effectiveness, competitive neutrality and social equity</td>
<td>Shape and slope can be selected dependent on the choice of utility parameter to deliver a balance across these objectives</td>
<td>Some potential utility parameters – e.g. ‘mass’ - discriminate against some CO\textsubscript{2} reduction options</td>
</tr>
<tr>
<td><strong>Choice of utility parameter</strong></td>
<td>Impact on emissions reductions depends on other details</td>
<td>Shape and slope selected in order to deliver a balance between cost-effectiveness, competitive neutrality and social equity</td>
<td>Shape and slope can be selected dependent on the choice of utility parameter to deliver a balance across these objectives</td>
<td>Some potential utility parameters – e.g. ‘mass’ - discriminate against some CO\textsubscript{2} reduction options</td>
</tr>
<tr>
<td><strong>Pooling</strong></td>
<td>Small, negative impact as without pooling all manufacturers would have to meet the targets themselves and more CO\textsubscript{2} reductions (in excess of the intended reductions) would be delivered</td>
<td>Aim was to improve the cost-effectiveness of the Regulation</td>
<td>Facilitates compliance for those manufacturers that do not have a range of vehicles – particularly those that focus on larger vehicles – thus helping to preserve the diversity of the fleet</td>
<td>Beneficial, as it contributes to maintaining the diversity of the fleet</td>
</tr>
</tbody>
</table>
## Evaluation of Regulations 443/2009 and 510/2011 on CO₂ emissions from light-duty vehicles

<table>
<thead>
<tr>
<th>Modality</th>
<th>Reducing CO₂ emissions from LDVs</th>
<th>Improve cost-effectiveness</th>
<th>Ensure competitive neutrality</th>
<th>Ensure social equity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Excess emissions premium</strong></td>
<td>Set so as to increase the chances of the emissions reductions being delivered</td>
<td>Set at a level to provide a sufficient incentive for action – reflects technological costs</td>
<td>No obvious impact on competitive neutrality</td>
<td>No direct impact on social equity</td>
</tr>
<tr>
<td><strong>Derogations – small volume, including the ‘de minimis’</strong></td>
<td>Allows derogated manufacturers to request less stringent targets than would otherwise be the case</td>
<td>Aims to reduce costs for derogated manufacturers</td>
<td>Any impact would be small, as covers few vehicles and many small volume manufacturers are specialists who compete with each other</td>
<td>No direct impact on social equity, as similar manufacturers affected</td>
</tr>
<tr>
<td><strong>M₀ adjustment</strong>*</td>
<td>Designed to ensure that intended emissions reductions are delivered</td>
<td>No obvious impact on cost-effectiveness</td>
<td>No obvious impact on competitive neutrality</td>
<td>If stimulates mass reduction, would deliver fuel savings that would be proportionately more beneficial for drivers on lower incomes in the longer-term</td>
</tr>
</tbody>
</table>

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**Modalities not included in the original proposal for the passenger car CO₂ Regulation**

<table>
<thead>
<tr>
<th>Phase-in of target</th>
<th>Date by which the targets fully apply is delayed, therefore total emissions will be higher for a given timeframe</th>
<th>As the targets were identified as being cost-effective, delaying their implementation incurs unnecessary costs to society</th>
<th>Put in place to facilitate the transition for manufacturers</th>
<th>Delays the introduction of fuel saving technologies, which would proportionately benefit consumers on lower incomes more in the longer-term</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Super-credits</strong></td>
<td>A lower level of overall emissions reductions could be delivered</td>
<td>Net impact depends on the balance between reductions in costs to manufacturers, and the lower emissions reductions required</td>
<td>Theoretically open to all manufacturers, but potentially more attractive to those with more vehicles at the high end of the market</td>
<td>Net impact depends on the balance of the negative effect of delaying the introduction of fuel saving technologies more generally, and the positive effect of encouraging more very low emitting vehicles</td>
</tr>
<tr>
<td><strong>Derogations – niche</strong></td>
<td>Allows derogated manufacturers to request less stringent targets than would otherwise be the case</td>
<td>Aims to reduce costs for derogated manufacturers</td>
<td>Some niche manufacturers compete with larger volume manufacturers</td>
<td>No obvious impact on social equity</td>
</tr>
</tbody>
</table>
There are a number of points worth making on the basis of the analysis in Table 5-36. First, all of most of the modalities support the achievement of at least one of the main objectives of the Regulation. While this might be expected, it is indicative of a coherent approach, at least at a high level. Second, the impacts on social equity are largely indirect, i.e. they result from an impact that directly affects one of the other objectives first such as a weakening of the level of CO₂ reductions delivered. This does not necessarily suggest a lack of coherence as the Regulation aims to deliver CO₂ emissions reduction in a cost-effective way by setting requirements on the vehicles produced by manufacturers. That this should be achieved in a socially equitable manner is in effect an additional, indirect objective, which is arguably appropriate. Third, where tensions occur, these are often between reducing CO₂ emissions and ensuring competitive neutrality and improving cost-effectiveness. Where tensions exist, the evaluation of coherence needs to assess the extent to which the detrimental impact is justified compared to the benefits that are delivered in relation to other objectives.

The analysis in Table 5-36 suggests that the three modalities that are arguably at the core of the passenger car CO₂ Regulation – the use and choice of the utility parameter and the slope and shape of the limit curve – are largely beneficial to meeting the Regulation’s main objectives. The decision to use a utility parameter, and the linked issues such as the details of the slope, are simply the means to deliver the required emissions reductions, and so are independent of this objective. The decision to use a utility parameter was largely taken as it can reflect the diversity of the fleet, while the shape (and slope) of the limit value curve (for the selected utility parameter) was selected to deliver a balance between the three other objectives. The choice of the utility parameter, however, can have an adverse impact on the selection of some CO₂ reduction options, e.g. the use of ‘mass’ discriminates against mass reduction technologies. There is no reason why similar conclusions cannot be reached for LCVs, with perhaps the exception being the choice of ‘mass’ as utility parameter, as this is currently considered to be more appropriate for LCVs (see Section 9.1 of Annex C). Hence, these modalities, as they currently exist, arguably make a greater contribution to coherence for the LCV CO₂ Regulation than for the passenger car CO₂ Regulation.
There are no significant issues with the other four modalities that were included in the original proposal for the passenger car CO\textsubscript{2} Regulation. The provisions relating to pooling contribute beneficially to all but the main objective of reducing CO\textsubscript{2} emissions, to which it has no impact as it does not affect the achievement of the intended target, while those relating to the ‘excess emissions premium’ beneficially contribute to two objectives and have no direct impact on the other two. The derogation for small volume manufacturers aims to reduce costs for these manufacturers and although it weakens the target marginally, the potential weakening is small (see Section 12.3 in Annex F). Hence, on balance, the benefits of this derogation outweigh the negative impacts. Finally, the M\textsubscript{0} adjustment is an important element in ensuring the intended CO\textsubscript{2} emission reductions are delivered, and has no adverse impacts on the other objectives.

The assessment of the four modalities that were incorporated into the passenger car Regulation in the course of the co-decision procedure generally requires more detailed consideration. The exception to this is the provisions on eco-innovations, which provide benefits for two of the objectives, and no detrimental impacts. For the other three modalities, the evaluation of coherence depends on the extent to which the detrimental effects of a modality is an acceptable trade-off compared to the benefits that they bring.

With respect to the derogation for niche car manufacturers, the first point worth noting is the range of manufacturers that are eligible to apply for the derogation, e.g. a manufacturer that is responsible for between 10,000 and 300,000 new car registrations annually. No manufacturer that is responsible for more than 150,000 new cars, but less than 300,000, benefited from the derogation in 2013 (see Annex H), which suggests that the range of eligibility for the niche derogations might be larger than necessary. However, most of these manufacturers had emissions levels in 2007 (i.e. the base year for identifying alternative targets for niche manufacturers) that were similar to the overall fleet-wide average that year, suggesting that they would have received little benefit from seeking a niche derogation. However, four manufacturers that had emission levels more than 10% higher than the 2007 fleet-wide average and which would be eligible for a niche derogation in 2013, did not have one. Overall, less than one third of manufacturers that are responsible for between 10,000 and 300,000 new car registrations annually make use of the derogation, which covers less than 20% of the eligible cars. This suggests that the derogation itself is not needed by at least some of the manufacturers that are eligible to request it and which might be considered likely to benefit from it. These findings suggest that the derogation might not be coherent with the other elements of the Regulation as the subsequent potential weakening of CO\textsubscript{2} emissions reductions is not insignificant even only considering those manufacturers that currently benefit from it (see Section 5.2.3). Additionally, as some of the eligible, similar-sized manufacturers do not use the derogation, there is a potential issue with respect to the impact of the derogation on competitive neutrality, as many eligible manufacturers do not benefit from a weaker target. While it is clearly the choice of manufacturers not to apply for the derogation, there would be a risk of further weakening if they choose to do so, e.g. to be treated consistently with similar manufacturers, when the need for such derogations is not completely in evidence.

For super-credits, the potential weakening of the objective of delivering CO\textsubscript{2} emissions is the major issue, accompanied by the extent to which the super-credits bring added value to the Regulation. TNO et al (2011) argued that the 95 gCO\textsubscript{2}/km target for 2020 was already sufficiently strong for super-credits not to be needed to incentivise the uptake of low emission vehicles. The contribution of super-credits to the other objectives is also not clear cut. If it is considered that an additional incentive is needed to encourage manufacturers to develop and market low emission vehicles, an alternative mechanism might be considered (see, for example, Section 5.2.3).

Finally, with respect to the phase-in periods the potential weakening in relation to reducing CO\textsubscript{2} emissions again needs to be balanced with the benefits to manufacturers
of easing the transition in relation to the application of the Regulation. As was noted in Section 5.2.3, the full extent of the potential weakening of the objective of delivering CO₂ emissions reductions resulting from the phase-in period was not delivered in practice as the target for the passenger car CO₂ Regulation was fully met in 2013, instead of in 2015 as permitted by the phase-in period. This could be taken to suggest that such a lengthy phase-in period was not necessary. Indeed, as car manufacturers had been subject to the voluntary agreements prior to the Regulation, it might be argued that manufacturers were already improving the CO₂ emissions performance of their cars and so were not in need of any phase-in period to facilitate the transition to the Regulation. However, as noted in Section 5.3, the progress under the voluntary agreements was less than needed and was less than the progress that has been delivered under the Regulation, suggesting that manufacturers had not previously been as focused on delivering CO₂ emission reductions. Consequently, as the phase-in period increased the period in which the first targets for both cars and LCVs had to be met from five to eight years, which is closer to manufacturers’ typical planning cycles, the first phase-in was potentially justifiable. However, this was only justifiable as a result of the lack of sufficient action to reduce CO₂ emissions under the voluntary agreement (see Annex H). For the second car CO₂ target, manufacturers have had 11 years notice, so the existence of the phase-in for 2020 undermines the coherence of the Regulation for 2020 as a result of its potential impact on CO₂ emissions reductions.

5.7.2 Coherence of the Regulations with each other

In relation to the coherence of the two LDV CO₂ Regulations with each other, on paper they should be coherent as they cover distinct types of vehicle. However, in practice, the distinction between some cars and some LCVs is becoming blurred, as many of the smaller LCVs are derived from similar car models and so could be used instead of a car, and vice versa, if the Regulations were not sufficiently coherent. As the two Regulations share many modalities, they are clearly broadly coherent in design and there is no evidence to suggest that this commonality has caused an issue. However, there has been concern about the relative stringency of the two Regulations, which was the main issue raised by stakeholders in relation to the coherence of the Regulations (see Annex H. In order to meet the agreed targets for 2020, compared to the first targets emissions from cars needed to decline by 60% more than LCV emissions (European Commission, 2012). It has also been calculated, if the marginal costs of meeting the respective 2020 targets under both Regulations were the same, that the LCV target for 2020 that would have been equivalent to the 95 gCO₂/km target for cars is around 118 gCO₂/km (as opposed to 147g; see Section 2.4). The other, related issue that is often discussed with respect to the ‘car-derived’ LCVs is to potentially include these in the car CO₂ Regulation. However, this is likely to prove difficult from the perspective of identifying a suitably tight legal definition of the vehicles that would move from the LCV to the car CO₂ Regulation. The fact that LCV models can shift between LCV classes as their mass changes, further complicates the issue (see Annex H).

5.7.3 Conclusions

It can be concluded that the two Regulations are largely coherent internally and with each other, with some important caveats. The derogation for niche manufacturers potentially weakens the delivery of CO₂ emissions reductions, and also potentially has issues for competitive neutrality. Less than one third of the manufacturers eligible – i.e. that are responsible for between 10,000 and 300,000 cars registered in 2013 – actually benefit from a derogation, as it is not needed by these manufacturers to meet their targets, even though for some of these their 2007 emissions (i.e. the base year for identifying alternative targets for niche manufacturers) were significantly higher than the fleet-wide average. If all of the other manufacturers that were eligible for a niche derogation applied for it, the numbers of cars covered could increase by five times,
which could have a not insignificant impact on the overall level of CO₂ emissions reductions achieved. Super-credits provide an additional incentive for manufacturers to develop and market low CO₂ emitting cars, but they potentially weaken the respective targets, although their application is capped for the first LCV target and the second car target. If an additional incentive to develop low CO₂ emission vehicles is required – although the respective targets should be set to be cost-effective and therefore provide a sufficient incentive – one that does not potentially weaken the target might be explored. In relation to the phase-in period, that for the second car target is not coherent as it potentially weakens the Regulation and delivers little with respect to any other objective, as manufacturers will have had sufficient time to develop their cars in order to deliver the targets. This does however highlight the importance of setting a post 2020 target as soon as possible in order to give manufacturers sufficient time to plan to meet this target.

In relation to the coherence between the two Regulations, the main issue is the different level of stringency between the targets in the two Regulations and the potential to move car-derived LCVs to the car CO₂ Regulation. If the targets in the respective Regulations were set so as to be equivalent, which included a recognition of the fact that some LCVs are car-derived and therefore would benefit from technology applied in order to deliver the targets in the passenger car CO₂ Regulation, the Regulations would be a lot more coherent with each other. In this case, it would probably make little difference that car-derived LCVs were covered in a separate piece of legislation.
5.8 Coherence: How well do the Regulations fit with other EU policy objectives?

The aim of this question is to identify the extent to which the Regulations are aligned with other EU interventions. It therefore assesses the extent to which the Regulations:

- Support and complement other objectives;
- Overlap with other objectives, i.e. those that aim to control the same target (tailpipe CO\textsubscript{2} emissions) through the exact same mode of action; and
- Have contradictory objectives to other policies.

With respect to identifying overlaps, it should be noted that different policy tools can aim for the same target but use different modes of action to operate in a complementary manner. Each of the key strategies and policies explored below were assessed in terms of their coherence with the general objectives of the Regulations, which are:

1. Providing for a high level of environmental protection in the EU and contributing to reaching the EU’s Kyoto targets;
2. Improving the EU energy security of supply;
3. Fostering the competitiveness of the European automotive industry and encouraging research into fuel efficient technologies.

5.8.1 Overarching strategies

Various overarching EU strategies set out the general framework under which the car CO\textsubscript{2} and LCV CO\textsubscript{2} Regulations were designed. In addition, further strategies have been introduced since the Regulations were developed, and so the coherence of the Regulations with the current policy agenda in Europe is also assessed.

The Europe 2020 Strategy (European Commission, 2010a) sets a series of targets including those aimed at reducing CO\textsubscript{2} and improving energy efficiency. These targets include a 20% reduction in EU GHG emissions from 1990 levels by 2020; 40% by 2030 (domestic); and 80% by 2050. It is within this framework that emissions from transport must also be addressed to meet these targets. Hence, all targets aimed at reducing CO\textsubscript{2} and energy efficiency implicitly include vehicles. In addition, part of the justification for the policy was to ensure energy security of supply, a target of 20% of energy from renewables and a 20% increase in energy efficiency. The targets also encompass smart and inclusive growth, with relevant actions to promote innovation, competitiveness and growth in Europe: 3% of the EU’s GDP to be invested in R&D; also targets for employment (75% of 20-64 year olds to be employed).

The 2011 Transport White Paper (European Commission, 2011c): contains a high-level goal to reduce GHG emissions from the transport sector by 60% by 2050 (against 1990 levels). These goals directly reinforce the Regulation’s objective to reduce CO\textsubscript{2} from vehicles. In addition, specific goals on improving energy security of supply were included, as well as the aim to achieve a competitive and resource efficient transport system in the EU and the development of a transport research, R&D strategy, which are coherent with the car and LCV CO\textsubscript{2} Regulation objectives of fostering competitiveness and encouraging R&D in the automotive industry.

The Sustainable Development Strategy (Council of the EU, 2006): sets out high level objectives that are coherent with the car and LCV CO\textsubscript{2} Regulations, specifically aiming to ensure high level of protection / improvement of the quality of the environment; and prevent/reduce environmental pollution whilst promoting sustainable consumption. The objective was also to increase global market share in the field of environmental technologies and eco-innovations (thus promoting competitiveness), while respecting the limits of the planet’s natural resources.
**The Commission’s ‘Cars 2020 Action Plan’** (European Commission, 2012): sets out the key characteristics of a strong and competitive automotive industry and progress towards sustainable mobility for EU society. It reinforces the objectives of the Regulations through aiming to promote the use of clean, more energy efficient vehicles, including alternative powertrains (such as electric/fuel cells), thus contributing to reducing CO₂ emissions from vehicles, improving energy security through diversification of transport fuels and encouraging R&D in these areas.

**European Energy Security Strategy:** The European Commission released an EU energy security strategy on 28 May 2014. It includes short term measures to help Member States cope with supply risks, including increasing stocks, developing emergency infrastructure, reducing short-term energy demand and switching to alternative fuels. It also covers medium to long-term challenges, including increasing energy efficiency and reaching the proposed 2030 energy and climate goals, as well as other measures to improve infrastructure and the internal market.

With respect to transport (including cars and LCVs), the paper specifically identifies that in the long-term, the EU’s oil dependency, in particular in transport, needs to be reduced. The plan for the reduction of EU energy dependence requires substantial changes to the energy system in the medium to long term, including calls for shifting to alternative fuels and improving energy efficiency in transport. Hence the strategy is coherent with the objectives of the car and LCV CO₂ Regulations.

### 5.8.2 Demand-side measures

The car and LCV CO₂ Regulations are supply-side measures in that they aim to reduce CO₂ at the source – these are generally complemented by demand-side measures that aim to reduce CO₂ emissions through influencing the demand for certain vehicle types.

The two most relevant demand-side measures are:

- **The Directive relating to the availability of consumer information on fuel economy and CO₂ emissions in respect of the marketing of new passenger cars ("Car CO₂ Labelling Directive" - 1999/94/EC):** Requires fuel economy and CO₂ performance information to be publicly provided for all new cars on sale (European Commission, 1999).

- **The Directive on the promotion of clean and energy efficient vehicles (‘Clean Vehicle Directive’ - 2009/33/EC):** requires public contracting authorities, contracting entities as well as certain operators to take into account lifetime energy and environmental impacts, including energy consumption and emissions of CO₂ and of certain pollutants, when purchasing road transport vehicles (European Commission, 2009d).

Whilst they do not directly aim to reduce tailpipe CO₂ emissions of vehicles, the above-mentioned demand-side policies are coherent with the objectives of the LDV CO₂ Regulations through complementary measures to encourage the demand for, and uptake of low carbon vehicles. The Car CO₂ Labelling Directive does this through improving consumers’ knowledge, enabling them to differentiate between vehicles and demand better fuel efficiency, whereas the Clean Vehicle Directive uses public procurement as a mechanism to stimulate the uptake of low carbon vehicles, helping to develop an early market for such vehicles and to bring down costs. Energy security objectives are also supported through stimulating the uptake of low carbon vehicles, whereas objectives of ‘fostering competitiveness’ and ‘encouraging R&D into fuel efficient technologies’ are supported only to the extent that demand stimulates investment and innovation.

In addition, Member States often use vehicle taxation as a fiscal instrument to reduce CO₂ from passenger cars and LCVs, which can have an effect on vehicle demand.
Currently 20 EU Member States apply some form of CO₂ tax to the registration and/or ownership of passenger cars (ACEA, 2014b).

Whilst the trend towards CO₂-based taxation in Member States is generally thought to support demand for low CO₂ vehicles, the lack of uniformity does not provide consistent incentives for manufacturers. Industry stakeholders and the Commission have identified that a harmonised taxation approach would be beneficial in supporting EU-wide achievement of CO₂ emission reduction targets. The existence of differing tax regimes/incentives is thought to add to the economic burden experienced by vehicle manufacturers. However, Member States do not fully support this desire for harmonised taxation.

The impact of these national policies varies significantly – in some cases there is evidence of cars being specifically designed to meet nationally-specific taxation thresholds (for example, the green car rebate in Sweden (Sprei, 2013). The extent to which these impacts are sustainable (due to fiscal policies being phased out) varies greatly depending on the design of the scheme (see Section 11.2.6), but in general their impact can be considered coherent with the car and LCV CO₂ Regulations in terms of reducing CO₂ emissions from vehicles and concurrently improve energy security of supply and fostering R&D.

5.8.3 Fuel, energy carrier and infrastructure policies

Through setting targets to increase the percentage of renewable fuels in transport and setting fuel quality specifications, the objectives of fuel and energy carrier related legislation directly reinforce those of the LDV CO₂ Regulations in supporting the reduction of tailpipe CO₂ emissions. Relevant policies include:

- **The Biofuels Directive (2003/30/EC):** Promotion of the use of biofuels or other renewable fuels for transport and established a goal of reaching a 5.75% share of renewable energy in the transport sector by 2010 (European Commission, 2003).

- **Renewable Energy Directive (RED) (2009/28/EC):** Established a common framework for the production and promotion of energy from renewable sources (European Commission, 2009e). The RED goal related to a share of energy from renewable sources in the transport sector was increased to at least 10% of final energy consumption by 2020 under the RED.

- **Fuel Quality Directive (FQD) (2009/30/EC):** Established minimum specifications for petrol and diesel fuels for use in road and non-road mobile applications for health and environmental reasons (European Commission, 2009f). In particular, this includes targets for reducing the GHG intensity of transport fuels by 2020, as well as facilitating lower air pollutant emissions. In its Article 7a, it requires fuel suppliers to reduce the greenhouse gas intensity of energy supplied for road transport (Low Carbon Fuel Standard).

- **Proposal for a Directive on the deployment of alternative fuels infrastructure for Europe (European Commission, 2013c):** This proposal was put forward to help overcome barriers to uptake of alternatively-fuelled vehicles due to low level of consumer acceptance and lack of recharging and refuelling stations. The proposed directive therefore aims to provide minimum infrastructure for alternative fuels, such as electricity, hydrogen and natural gas, as well as common EU wide standards for equipment needed and user information.

Each of the above-mentioned policies aims to promote the reduction of CO₂ emissions from vehicles and diversification of transport fuels (thus supporting energy security), which is coherent with the car and LCV CO₂ Regulations. They also support
technological development and innovation by providing incentives to develop relevant technologies.

A potential conflict may be found when considering the overall lifecycle impacts of biofuels. The extent of carbon reduction and other environmental effects varies widely according to the feedstock employed, the way the feedstock and the biofuels are produced, how they are transported and how far. The Renewable Energy Directive (RED) aims to ensure net GHG reductions by setting out minimum sustainability criteria, as well as monitoring and reporting of compliance with these conditions. These criteria aim to prevent the conversion of areas of high carbon stock and high biodiversity for the production of raw materials for biofuels.

However in the last few years there have been many studies that have shown the effect of Indirect Land Use (ILUC) changes on the GHG emissions of biofuels studies (Fritsche & Wiegman, 2011). Global studies suggest that the shift from conventional energy production, with a negligible land demand, to low-carbon energy sources, including bioenergy, could become a major driver of land-use change. On the other hand, there are several biofuels for which ILUC are not thought to be a major issue, but these tend to be more expensive (Fritsche & Wiegman, 2011). To reduce the risk of ILUC, in 2012 the European Commission proposed amending the current legislation on biofuels, specifically the Renewable Energy Directive and the Fuel Quality Directive. The proposed new rules seek to promote biofuels that help achieving substantial emission cuts, do not directly compete with food and are more sustainable at the same time (European Commission, 2012d). The measures include revisions to increase the minimum GHG saving threshold for new installations to 60%; to include ILUC factors in the reporting requirements set out in Article 7a of the Fuel Quality Directive; to limit the amount of food crop-based biofuels and bioliquids that can be counted towards the EU’s 10% target for renewable energy in the transport sector by 2020; to provide market incentives for biofuels with no or low indirect land use change emissions, and in particular the 2nd and 3rd generation biofuels.

5.8.4 End-of-Life vehicles

The main end-of-life policy is:

- **End-of-Life Vehicle (ELV) Directive (2000/53/EC):** this Directive primarily aims at the prevention of waste from vehicles. It required that in each Member State an average of at least 80% of the mass of an ELV is reused or recycled and another 5% or more of its mass is energetically recovered. In 2015 the rates will increase to 85% and 10%, respectively

- **Directive 2006/66/CE** on batteries requires a recycling rate of 50% for electric vehicle Lithium-Ion batteries. It also requires the recycling of 65% by average weight of lead-acid batteries and accumulators, including the recycling of the lead content to the highest degree that is technically feasible while avoiding excessive costs. The Directive does not specifically address nickel-metal hydride batteries that are sometimes used in hybrid cars.

The LDV CO\textsubscript{2} Regulations and the ELV Directive are focussed on two different points within a vehicle’s life cycle (‘in use’ and ‘disposal’ respectively); however, there are some potential conflicts with respect to the technology choices available to reduce CO\textsubscript{2} emissions and the impacts on recycling and recovery. Many measures that can increase vehicle fuel efficiency can make subsequent recycling and recovery at the end-of-life stage more challenging. For example, increasing use of plastics and advanced materials (for weight reduction) can make recycling more challenging. That is, while the recycling of these materials may be technically feasible, recycling of plastics and composites is particularly challenging due: to the lack of clear and developed recycling routes (logistics, infrastructure and recycling technologies) relative to other material industries,
the lack of clear end products/markets for recycled materials and lower quality of the recyclates compared to virgin materials (Ricardo-AEA, 2015). There are some promising examples of post-shredder technologies that are able to produce high quality recyclates – for instance, in the Netherlands one ASR processing plant can produce a plastics pre-concentrate consisting of polypropylene, polyethylene, ABS and polystyrene a mixture that is processed by the company Galloo Plastics and returned in a closed-loop to automotive applications. However, technological processes and the possibilities for recycling are different for different polymers and composite materials. The development of technology to improve separation and recycling of plastics and composites from shredder residue is essential, but proven technologies are not yet available in all Member States (Ricardo-AEA, 2015).

Additionally, the treatment of batteries (used in hybrid and electric vehicles) may pose challenges for reaching high levels of recycling in the future, although significant progress has been achieved in recent years, with a particular focus on recovering the valuable rare earth elements and a number of developments in Japan, France, Belgium, Germany, the USA and Norway (Optimat, 2013). For example, an industrial-scale battery recycling operation (for Li-ion and NiMH batteries) has been opened in Belgium (Umicore website, accessed January 2015).

5.8.5 Air quality and noise
There is potential for conflict whilst trying to achieve targets for both local air quality pollutants/noise and CO₂ emissions from vehicles. The Fuel Quality Directive (assessed in Section 5.8.3), also aims to facilitate lower air pollutant emissions.

The most relevant air quality and noise policies are as follows:

- **Regulation 715/2007/EC on Type Approval (“Euro standards”):** This Regulation sets out the Euro 5 and 6 Emission standards for light passenger and commercial vehicles. Vehicle manufacturers are required to achieve the limit values (in mg/km) that have been set out for emissions of carbon monoxide (CO), total hydrocarbons (THC), non-methane hydrocarbons (NMHC), oxides of nitrogen (NOx) and particulate matter (PM).
- **Air Quality Directive on Ambient Air Quality (2008/50/EC):** This Directive regulates concentrations of a range of pollutants, including sulphur dioxide (SO₂), nitrogen dioxide (NO₂), PM₁₀, PM₂.₅, CO, ozone (O₃), benzene and lead. Local and regional Member State administrations must develop and implement air quality management plans in areas where exceedances occur in the air quality limit and target values as set out by the Directive.
- **Environmental Noise Directive (END) (2002/49/EC):** The key aim of the END is to “define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise”. The Directive aims to provide a basis for developing Community measures to reduce noise emitted by major sources, and specifically identified from road vehicles (in addition to other sources of noise).
- **Regulation on sound level of motor vehicles and replacing silencing systems (540/2014):** The main objective of this regulation is to “ensure a high level of health and environmental protection; to safeguard internal market for motor vehicles”. The targets are to decrease noise limit values by 4 dB(A) for passenger cars and LCVs (also buses and coaches).

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41 Euro 5 came into force in September 2009. Euro 6 standards apply from 1st September 2014 for approval and 1st January 2015 for the registration and sale of new types of cars.
There are no direct overlaps between the objectives of the Euro Emissions Standards and CO₂ Regulations as they are aimed at reducing emissions from different pollutants; however the means of meeting the Euro standards may require the use of technologies that increase fuel consumption. Nevertheless, although some technologies can result in a trade-off between reductions of CO₂/NOx emissions where manufacturers aim to meet the requirements of both Regulations, any increases in pollutants must be compensated for due to the emission limits. The Euro 6 standards have a greater focus on emissions of NOx than previous standards – NOx emissions from vehicles often present challenges for manufacturers of diesel vehicles when trying to limit/reduce emissions, as they are higher than for petrol vehicles of an equivalent Euro Standard.

Member States will use a variety of measures to reduce local transport air pollutant emissions and meet Air Quality Directive targets. It is up to the Member States to determine how the reductions in pollutant emissions required to meet the Air Quality Directive targets are achieved, so this is where particular conflicts may occur. As mentioned above, tailpipe air pollutant emissions from vehicles (one of the sources) are dealt with under the Euro Emission Standards. Member States must still achieve national and local air quality standards, and are therefore required to implement a range of other complementary measures/instruments to further reduce emissions from transport, such as low emission zones (access restrictions placed on more polluting vehicles), economic incentives (e.g. fees, taxes, road pricing schemes etc.), promotion of general awareness raising on air pollution (e.g. targeted campaigns, internet-based info on air quality etc.) etc. However, these measures/instruments are not likely to affect tail-pipe CO₂ emissions from vehicles, but may affect demand for certain vehicle/fuel types.

Whilst the LDV CO₂ Regulations and vehicle noise Regulations both aim to increase environmental protection, several stakeholders consulted in the course of this study queried whether the measures that are used to achieve the reductions in noise from vehicles may result in conflicts with the achievement of CO₂ Regulation objectives, e.g. the use of quieter tyres, and the impact on CO₂ emissions that this move would have was uncertain. However, a study conducted by the Forum of European National Highway Research Laboratories (FEHRL) revealed that use of quieter tyres would not jeopardise the braking performance of tyres on wet surfaces or the rolling resistance of tyres on the road, which also has a great influence on fuel consumption and CO₂ – the study concluded that reductions in tyre noise limits (as have been set out in Regulation 540/2014) should not affect overall values of tyre rolling resistance, and it is therefore not expected that there will be any noticeable effect on vehicle fuel economy and emissions of GHGs.

Synergies with noise reductions have been identified for the following measures related to powertrain development: downsized engine and turbo changer, encapsulation, reduced friction, increased damping, stop-start, hybridisation, electrification and quiet and low rolling resistance tyres (T&E, 2012).

The vehicle noise Regulation recognises that technical measures to reduce the sound level of motor vehicles have to comply with a set of competing requirements, such as those of reducing noise and pollutant emissions and improving safety whilst keeping the vehicle in question as cheap and efficient as possible. Through attempting to meet all of these requirements, the vehicle industry can run up against the limits of what is technically feasible, and vehicle designers have reacted by using new, innovative materials and methods. The Regulation sets out a framework for innovation that can be achieved in a realistic timeframe.

5.8.6 Safety

The main safety policy of relevance is Regulation 78/2009 on the Type Approval of Motor Vehicles with regards to the protection of pedestrians and other
vulnerable road users: This Regulation sets out the requirements for the construction and functioning of motor vehicles and frontal protection systems in order to reduce the number and severity of injuries to pedestrians and other vulnerable road users who are hit by the fronts of vehicles and in order to avoid such collisions.

Whilst there are no explicit conflicts related to the objectives, the measures that are used in achieving the requirements of the safety regulation may lead to increased fuel consumption. For example, if additional weight is added to the vehicle in order to meet the requirements of the Regulation (e.g. changes to the bonnet form etc), then there are potential contradictions in terms of reducing CO$_2$ emissions from vehicles, and to a lesser extent improving the EU energy security of supply, as additional vehicle weight tends to increase vehicle CO$_2$ emissions. Conversely, if safety-related measures contribute to weight reduction (e.g. removal of bull bars), there are co-benefits with respect to CO$_2$ emission reductions and energy security.

It has been argued that there are possible negative safety consequences of using a mass rather than footprint approach for the utility parameter in the car and LCV CO$_2$ Regulations, which may conflict with vehicle safety strategies. As discussed earlier, the use of ‘mass’ as the utility parameter potentially promotes the development of heavier vehicles in order to avoid more stringent CO$_2$ targets, whereas lighter vehicles are considered to be more ‘friendly’ for other vehicles in the event of a crash, since less crash energy needs to be absorbed (EAA, 2013; ICCT, 2010). Furthermore, US analysis has indicated that it is feasible to design light-weight vehicle body structures that also comply with crashworthiness legislation, although it should be noted that this analysis is based on US-market vehicles and US crashworthiness legislation (Ricardo-AEA, 2014).

5.8.7 Conclusions
Overall, the objectives of the LDV CO$_2$ Regulations are generally coherent with objectives of other related GHG reduction policies, particularly when considered in high level terms. In terms of overarching strategies, the Regulations are a key part of the Commission’s policy package to reduce GHGs from transport as part of Europe’s 2020 goals, the Transport White Paper and the Sustainable Development Strategy. The objectives of the Regulations are also coherent when considering interactions with overarching policies relevant to competitiveness and energy security, including the 2020 goals for smart, sustainable and inclusive growth, the cars 2020 action plan and the European Strategy on Energy Security.

Furthermore, the LDV CO$_2$ Regulations work coherently with demand-side policies including the car CO$_2$ labelling Directive, green public procurement (the Clean Vehicle Directive) and national fiscal incentives, all of which help to stimulate demand for low carbon vehicles.

The objectives of the relevant fuel, energy carrier and infrastructure policies are generally coherent with the objectives through the same mechanisms, particularly in promoting the use of alternatively-fuelled vehicles and decarbonising fuel. One potential conflict with the objective of achieving real world lifecycle GHG reductions concerns the use of biofuels promoted under the Biofuel Directive and the Renewable Energy Directive policies, which have come under recent scrutiny, particularly considering the issue of Indirect Land Use Change (ILUC).

Finally, the main potential conflicts were found at the interface with non-GHG polices. The issues mainly relate to specific technology choices that may have trade-offs between CO$_2$ and air pollutant emissions, noise or recyclability/recoverability. In addition, the means of improving safety may lead to increased fuel consumption in some cases. However, these trade-offs do not currently appear to compromise compliance with multiple Regulations at the same time. Improved coordination may be required as
future targets become more stringent both for the LDV CO₂ Regulations and other targets.
5.9 EU added value: What is the EU added value of the Regulations? To what extent could the changes brought by the Regulations have been achieved by national or individuals' measures only?

The assessment of ‘EU added value’ focuses on identifying the benefit of developing the Regulations at the EU level (so that they apply equally across all Member States) compared to Member States developing (or not developing) their own comparable legislation.

5.9.1 Justifying intervention at the EU level

The single market provides grounds to act at the EU level rather than Member State level, so as to ensure common requirements across the EU and thus minimise costs for manufacturers. In relation to the question of EU added value, the great majority of stakeholders consulted for this study were of the view that EU-wide Regulations are the most appropriate approach, with both industry and non-industry stakeholders generally expressing support (see Annex I).

The analysis of Relevance (see Section 5.1) showed that there is still a need to address climate changes and cut GHG emissions from transport in a way that delivers cost effectively, whilst still ensuring the competitiveness of the industry. The assessment of the effectiveness of the Regulations in ensuring these objectives are met (see Section 5.2 and 5.4) found that the Regulations have overall been effective in contributing to reductions in CO₂ emissions from cars and LCVs while supporting the other objectives related to competitiveness, environmental protection and social equity. On their own, Member States would represent too small a market to achieve the same level of results and therefore an EU wide approach is needed to drive industry level changes.

Policymakers have considered a wide range of instruments to reduce carbon emissions from transport. Currently, there are widely varying break points employed in differentiation of taxes, fiscal incentives and fuel economy labels developed by different Member States, since these policies are subject to national sovereignty. Hence it seems unlikely that national policies would create the same level playing field. The automotive industry requires as much regulatory certainty as possible if it is to make the large capital investments necessary to maximise the fuel economy of new vehicles, and even more so for shifting to new primary energy sources. Hence, standards can provide this certainty over a long planning horizon (ITF, 2010). Poor coordination will raise compliance costs for manufacturers as well as weakening the incentive to design fuel efficient cars and LCVs because of the fragmentation of the European market (ITF, 2010).

Furthermore, the analysis of the efficiency of the Regulations (see Section 5.5) clearly shows that the Regulations have been more cost-effective than originally anticipated. The harmonisation of the market is the most crucial aspect of added-value and it is unlikely that uncoordinated action would have been as efficient. Indeed, vehicle manufacturers and component suppliers are identified as those who would be particularly disadvantaged by Member State rather than EU level action, due to differences in ambition levels and design parameters that may emerge from national-level action (European Commission, 2012a).

Considering the coherence of the Regulations (see Section 5.8) demonstrates that there are many other examples of legislation that aims to improve the performance of cars and LCVs that are based on EU-level action, including for noise, safety and air pollutant emissions. In all of these cases, it has been deemed preferable to act at the EU-level – and it could be argued that taking action to improve CO₂ emissions is no different.
5.9.2 Achieving changes brought about by the Regulations through other measures

As discussed above, the harmonisation of national measures between Member States would be very challenging, particularly if action was based on taxes or incentives, and uncoordinated action risks creating a fragmented market.

The diversity and unpredictability of national taxes create difficulties for manufacturers, and the harmonisation of taxes is generally perceived as being more difficult than the harmonisation of standards (ITF, 2010). Previous attempts to harmonise taxation have been unsuccessful – notably in 2005, the Commission adopted a draft for a Directive on car taxation addressing CO\textsubscript{2} emissions, but this draft was never adopted by the European Council. The draft proposed that all or a major part of the taxation of cars should be based on the CO\textsubscript{2} emissions of the vehicle, and the taxes on vehicles should be based on ownership and annual taxes, rather than on purchase (ITF, 2010). This uncoordinated situation forces vehicle manufacturers to implement short-term adaptations in marketing for CO\textsubscript{2} improvements that are not cost-effective for industry (ITF, 2010).

An alternative to national actions or EU Regulation would be to implement EU-wide voluntary agreements, similar to those agreed with manufacturers prior to the introduction of the car Regulation. The analysis of the effectiveness of the Regulations compared to the voluntary standards (see Section 5.3) showed that the Regulations have been more effective in terms of reducing test-cycle CO\textsubscript{2} emissions – indeed, the Regulations have overachieved compared to what was expected by this point in time, which demonstrates the benefit of taking EU-level co-ordinated action. This is generally supported by stakeholders (see Annex I), who on average view voluntary standards as being less effective than Regulations.

A further alternative that has been debated is the possibility of including road transport into the EU Emissions Trading Scheme (ETS). Modelling carried out by Cambridge Econometrics (2014) aimed to compare the performance of including road transport was included in the EU ETS. The results showed that in the absence of the LDV CO\textsubscript{2} Regulations and road transport was instead included in the EU ETS, the carbon price would have to average €217/tCO\textsubscript{2} over the period 2020-2030\textsuperscript{42} in order to achieve the level of emissions abatement in the road transport sector required to meet the EU’s long-term goals (approximately 60g/km for cars in 2030). This very high carbon price was considered politically infeasible due to the heavy burden it would place on energy-intensive industries and, indirectly, on other industries and consumers. The study found that fuel efficiency standards on new vehicles could achieve the same level of emissions reduction in the road transport sector as a whole but at a much lower cost to consumers and industry (Cambridge Econometrics, 2014).

By contrast, if road transport was included in the EU ETS without tightening the cap to a level that would be comparable to the Regulations, the credit price would be too modest (at €19.4/tCO\textsubscript{2}) to drive any significant CO\textsubscript{2} emission reductions, thus rendering the policy ineffective at reducing net CO\textsubscript{2} (Cambridge Econometrics, 2014).

Aside from the issue of cost-effectiveness, inclusion of transport in the EU ETS faces a number of other obstacles in meeting the objectives of the Regulation. It is likely that such a scheme would lead to transport becoming a net purchaser of credits (i.e. that emission cuts would take place in other sectors), with the costs being passed on to the

\textsuperscript{42} The full effect of the carbon price on road transport emissions is only realised in the long run. Therefore, the average price over the period 2020-2030 is considered by the authors of the report to be a better reflection of the price required to meet the level of road transport emissions reported in 2030.
consumers (T&E, 2014b). Hence the scheme would not meet the objectives to reduce transport CO\textsubscript{2} emissions, to contribute to increased energy security or to increase innovation in low carbon technologies in the automotive sector. Furthermore, consumers would not be able to benefit from fuel expenditure savings, which are suggested to lead to net savings overall (see Section 4.5).

In conclusion, there do not appear to be any plausible alternatives to achieving the same level of CO\textsubscript{2} emission reductions in a more cost-effective manner compared to the LDV CO\textsubscript{2} Regulations.
5.10 EU added value: Are there other technological, economic or administrative issues that are not covered by the existing Regulations and that could be introduced in view of their potential added value?

The aim of this section is to discuss other technological, economic or administrative issues that are not covered by the existing Regulations, but which could be introduced as they would potentially bring added value. This section does not seek to reach conclusions on the other evaluation questions, only to discuss potential additions to the Regulations in the respective areas. Hence, issues that have been discussed under other evaluation questions already are not covered here.

From a technological/technical perspective, the most obvious additional issue arises around the test cycle and the technologies that are covered and the technical approaches used. These might be summarised as:

- The coverage of technologies on the test cycle;
- The treatment of CO₂ reducing (and potential CO₂ increasing) technologies that are not covered on the test cycle; and
- Technical issues relating to the test cycle itself.

As discussed in Section 3.4.1, one of the causes between the discrepancy between CO₂ emissions as measured on the NEDC test cycle and real-world emissions is the increased use of energy consuming devices that are used in the real-world, but which are not operational when emissions are measured on the test cycle. As discussed in Section 5.2.3, the fact that the existing NEDC test cycle is not sufficiently representative of real-world driving conditions is one of the main weaknesses of the Regulations. Currently, the provisions relating to eco-innovations are meant to address this issue, at least to some extent (see Section 2.4; for stakeholders views on eco-innovations, see Section 15.3). In the longer-term, the development of a revised test procedure, which will be part of a new worldwide harmonised test protocol (or WLTP), will bring more of these technologies under consideration on the test cycle. However, it is unlikely to be able to account for all potential technologies that have an impact on the in-use CO₂ emissions of a vehicle.

Consequently, for the future development of the Regulations, it will be necessary to consider how best to cover as many of these technologies as possible – and consequently to incentivise improvements to their energy efficiency – through the mechanisms associated with the Regulations. In addition to the need for a thorough understanding of the implications of moving to the new test cycle for such technologies, the following might also be considered:

- An extension of the coverage of eco-innovations to ensure that they cover – and incentivise improvements to – as wide a range of technologies as possible that can be used to reduce real-world CO₂ emissions. Any extension would need to be supported by robust evaluation procedures.
- Accounting for technologies that have higher real-world impacts on CO₂ emissions compared to their contribution as measured on the WLTP test cycle. As above, any such accounting would need to be supported by robust evaluation procedures.
- Reviewing the approach to eco-innovations to see whether it might be made more efficient from an administrative perspective, e.g. by, for example, reviewing the approach taken to similar provisions in the US (see Annex G).

As the aim of such provisions is to try to cover as many technologies as possible in order that the emissions values used in the Regulations are as close to real-world emissions as possible, consideration might also be given to in-use testing of CO₂ to complement
the Regulation. Alternatively, real-world emissions (as measured using Portable Emissions Measurement Systems (PEMS)) might be used as the basis of the Regulations. It might be worth exploring the feasibility and desirability of such changes in the context of the Regulations.

With respect to the technical details of the test, a number of issues were raised which it was not possible to explore further in this project, e.g. a lack of common equipment and standards in relation to the way in which tests are carried out, that IT tools can be used to optimise vehicles for the test cycle and that competition between type approval authorities has the potential to undermine the testing procedure (see Section 15.3). When the new test procedure and protocol is transposed into EU law, it will be important to identify the extent to which such concerns are a problem and to address the main issues as far as possible.

From an economic perspective, one additional issue that might be considered for inclusion in the Regulations in subsequent periods is the introduction of additional flexibility for manufacturers in terms of meeting their targets. In a review of the various standards around the world, IEA (2012) identified the banking of credits, under which overachievement in a particular year can be ‘banked’ for (usually a limited number of) future years, and trading of credits, where a manufacturer that overachieves in a particular year can trade the overachievement with a manufacturer that has underachieved, as potential additional flexibilities. As noted in Annex G, in the equivalent legislation in the USA, the banking, borrowing and trading of credits is allowed in order to allow manufacturers greater flexibility with respect to meeting their targets. In the EU context, TNO et al (2011) also considered that allowing the banking and borrowing (but not trading) of credits would be a flexibility that enabled the overall target to be met in a more cost-effective and efficient manner. The use of banking and borrowing (and perhaps trading) could be used to facilitate the introduction of annual declining targets from 2021, instead of the current less frequent targets, which would address a perceived weakness of the Regulations (see Section 5.2.3).

From an administrative perspective, a potential means of incentivising ultra-low carbon vehicles that do not weaken the targets in the way that super-credits do might be considered, e.g. some sort of flexible mandate under which manufacturers are rewarded and penalised according to the extent to which they meet a target for supplying such vehicles (see Section 15.3).
6 Conclusions and recommendations

6.1 Conclusions

This section presents the overall conclusions of the study. In each case, the main research findings on which the conclusion is based are summarised, which provides the link back to the evidence presented in the main body of the report.

6.1.1 Relevance

The evaluation of relevance has concluded that the four needs that were the basis of the Regulations were valid and will remain so for the period beyond 2020, as follows:

1. **All sectors needed, and still need, to contribute to the fight against climate change:** there appears to be strong support of the need to fight climate change. International scientific bodies, the European Commission and stakeholders are in general agreement on this issue. The need for transport to use less oil (and energy) is also widely agreed upon.

2. **The CO\textsubscript{2} performance of new vehicles needs to improve at a faster rate:** Since LDVs account for the majority of CO\textsubscript{2} emissions from transport, reductions in their emissions are required in order to contribute to overall GHG reductions. Scenarios under which LDVs do not contribute to emission reductions would require unrealistic reduction efforts in other areas.

3. **Road transport also needed to, and will continue to need to, use less oil.** In order to be consistent with long-term CO\textsubscript{2} reduction targets, the transport sector needs to use less oil. Since the vast majority of oil used in the EU is imported, the respective general objective of the Regulations, i.e. to improve the security of energy supply in the EU. Even if the trends towards the increasing diversification of the fuels and energy sources used by transport continued, it would still be prudent to improve the security of energy supply in relation to these fuels and energy sources.

4. **CO\textsubscript{2} reductions must be delivered cost-effectively without undermining either sustainable mobility or the competitiveness of the automotive industry.** The importance of maintaining sustainable mobility is clear and was emphasised in the Transport White Paper. The importance of the EU automotive sector to the EU economy is also widely recognised, both in terms of the direct and indirect jobs it creates and the contribution it makes to the EU economy.

6.1.2 Effectiveness

The analysis suggests that the car CO\textsubscript{2} Regulation is likely to have had a positive impact in terms of contributing to the CO\textsubscript{2} emission reductions achieved following the introduction of the Regulation, accounting for between 65-85% of the reductions seen in tailpipe emissions. Furthermore, the analysis indicates that the Regulations have been more successful in reducing CO\textsubscript{2} emissions compared to voluntary agreements from industry, which achieved an estimated rate of annual improvement in CO\textsubscript{2} of 1.1 to 1.9 gCO\textsubscript{2}/km compared to the rate achieved by the Regulations of 3.4 to 4.8 gCO\textsubscript{2}/km. In addition, the targets required under the Regulations have been met two years early, whereas the targets under the voluntary agreement were missed.

Similarly for LCVs, monitoring data shows that the fleet wide average emissions have already exceeded the required target for 2017, and place manufacturers in a strong position to meet their 2020 targets. The rapid rate of CO\textsubscript{2} emission reductions seen in recent years suggests that the Regulations have played an important role in speeding up specific emission reductions from LCVs. For LCVs, there were no equivalent voluntary agreements, but the rate of recent CO\textsubscript{2} emission reductions and the fact that the fleet
average emission targets have been met four years early suggests that the Regulations are more effective than voluntary targets would otherwise have been.

The analysis also highlighted some key weaknesses that may need to be addressed in future policy proposals, particularly issues around the unrepresentativeness of the test cycle and the current focus on tailpipe emissions.

- **Test cycle:** The CO₂ emissions per kilometre as measured on the test cycle are not an accurate reflection of real-world emissions per kilometre, which is at least partially caused by the impact and use of more energy consuming devices to vehicles that are used in the real-world, but not measured on the test cycle. This is a significant concern as the increasing discrepancy between test cycle and real-world emissions performance has eroded the benefits of the Regulations.

- **Well-to-tank emissions:** The Regulations incentivise the use of powertrains that have zero CO₂ emissions as measured on the test cycle, but which have higher indirect emissions associated with their production than fossil fuels. These emissions are not considered within the Regulations.

- **Embedded emissions:** The Regulations incentivise the use of vehicles that have higher GHG emissions associated with their production and disposal than more conventional vehicles, which are also not considered within the Regulations.

- **Other potential weaknesses (super-credits and phasing in of the targets) do not appear to result in significant weakening of the targets in practice.** The impact of derogations for small volume and niche manufacturers have been relatively small.

The goal to **provide for a high level of environmental protection** was assessed in terms of the impact on life cycle emissions, which does not indicate that there have been environmental trade-offs to date between types of pollutants or life cycle stages, due to the fact that improvements to ICE technology do not entail large changes to production processes and these have accounted for the major part of emission savings so far. In the longer term, the potential for burden-shifting is much greater, particularly considering batteries in hybrid and electric vehicles. At the same time, technological developments in production processes, battery lifetimes and the decarbonisation of the electricity sector mean that the overall impact is still likely to be positive. In most cases the technologies and fuels with the greatest potential reductions in lifecycle GHG emissions (such as BEVs and FCEVs), generally also have the greatest potential to reduce NOx and PM emissions.

In terms of **energy security**, the Regulations have contributed to lifetime reductions in oil-based road transport fuel consumption. The calculated reductions in oil-based fuel consumption from new cars registered between 2006 and 2013 were around 35.9 Mtoe lower compared to what would have been expected in the absence of the Regulations. The impacts of the LCV CO₂ Regulation to date are likely to be much smaller, estimated at 1.4 Mtoe between 2010 and 2013 under the Regulations compared to the baseline situation for new LCVs registered between 2010 and 2013. This is in part because the net reductions in oil consumption are accumulated according to the distance driven and the LCV legislation was adopted later. The impact of the Regulations on diversification of fuels to date has been low, although recently the market penetration of these vehicles has been increasing. Hence, the impacts of the Regulation on energy security have generally followed expectations; that is, current impacts are relatively minor and Regulations are expected to contribute further to energy security in future years.

Impacts on **competitiveness and innovation** also generally appear to be positive. There are promising signs that research and development of fuel-efficient technologies has ramped up, as well as clear trends towards increased market uptake of fuel efficient technologies both in cars and LCVs.
It can be concluded that the Regulation was not in contradiction to its **competitive neutrality** objective, although there have been changes in the market context since the introduction of the Regulations. Targets in 2013 were over-achieved by most manufacturers, including manufacturers in all vehicle segments. Furthermore it cannot be shown that manufacturers of premium segments have circumvented targets by shifting their production to lighter segments.

The shape and slope of the limit curve have been designed to address potential issues of competitive neutrality, but it is possible that the slope may not currently be sufficiently shallow to completely eliminate the possibility for manufacturers to “game” the system by increasing the mass of their vehicles. For passenger cars, the average vehicle mass has slightly increased over the period 2006-2013; the market share of smaller vehicle segments has decreased (mainly to the advantage of the Sport-Utility Vehicle (SUV) segment) and the average mass per vehicle segment has slightly but steadily increased over the same period. The latter suggests a possible “gaming” approach by car manufacturers, meaning that vehicle masses are slightly increased as long as the impact of the resulting less stringent CO₂ emission target is less than the impact of the increased mass on CO₂ emissions. The analysis for LCVs is more limited due to a lack of data, but tentative conclusions suggest that manufacturers of smaller LCVs are under higher pressure to comply with their emission targets since (i) their market shares decreased over the period 2009-2013 and (ii) their average vehicle masses increased over the same period.

From the perspective of **social equity**, overall the impacts of the Regulations can be considered positive. In terms of the impacts on fuel expenditure, it is clear that the car and LCV CO₂ Regulations have led to significant reductions in annual fuel expenditure. For new cars registered in 2013, the expected lifetime (discounted) fuel savings are €1,336 for petrol cars and €981 for diesel cars compared to the baseline counterfactual scenario. For passenger cars, it is likely that changes in the affordability of new vehicles will affect higher income consumers (as these consumers are more likely to purchase new vehicles) and in any case market data do not show increases in average retail prices for relevant vehicle segments. As these more fuel efficient vehicles move into the second-hand car market, where lower income consumers are more likely to purchase them, the rapid depreciation of car values in the first few years is likely to ensure that second-hand owners are able to benefit more from fuel cost savings compared to the first owners since they can reap the fuel savings without the fuel efficiency being fully reflected in the prices they pay for used cars. Similarly for LCVs, SMEs typically only purchase used vehicles, and they will similarly benefit from the overall fuel efficiency improvements. The lifetime (discounted) fuel savings for new LCVs registered in 2013 are expected to be €1,466 for petrol LCVs and €982 for diesel LCVs compared to the baseline counterfactual scenario.

### 6.1.3 Efficiency

In terms of **efficiency** both of the Regulations have generated net economic benefits to society. The car CO₂ Regulation has proved to be more efficient than expected with reductions in societal costs (the ex-ante impact assessment predicted that there would be net costs) and the Regulation is also more cost effective than predicted, with abatement costs of -€46.4 per tonne of CO₂ abated, compared to central ex-ante estimates of +€32.4/tCO₂ to +€38.7/tCO₂. The LCV CO₂ Regulation has also generated net economic benefits and emissions savings, although these are smaller than anticipated in the ex-ante Impact Assessment, primarily because the baseline emissions estimates used are likely to have been overestimated. The overall cost effectiveness of the LCV Regulations has been estimated at -€172/tCO₂, which compares favourably with the ex-ante estimates of -€38.9/tCO₂ to €32.6/tCO₂.
In terms of costs to manufacturers, the analysis has shown that the costs have been much lower than originally anticipated, because the costs of emissions abatement technologies have, in general, proved to be less costly than expected. For passenger cars, the average ex-post unit costs associated with meeting the 130 gCO\textsubscript{2}/km target have been estimated at €183 per car. By contrast, the average ex-ante estimates of manufacturer costs prior to the introduction of the Regulation ranged from €430 to €984 per car.

For LCVs, the costs to manufacturers have also been lower than originally anticipated; ex-post costs have been estimated at €114 per vehicle, as opposed to the ex-ante average cost estimate of €1,037 per vehicle. However, it should be stressed that part of the reason that the ex-ante costs were so high is because the level of effort required to reduce emissions to 175 gCO\textsubscript{2}/km is likely to have been over-estimated for the original Impact Assessment.

Lifetime fuel expenditure savings for cars have been lower than originally anticipated in the Impact Assessment, primarily because of the increasing divergence between test cycle and real-world emissions performance. Similarly, for LCVs, the fuel lifetime expenditure savings have also been significantly affected by this divergence from test cycle performance. Linked to these fuel expenditure savings are losses in fuel tax revenues. For passenger cars, fuel tax revenues are estimated to have reduced by €22 billion over the time period 2006 to 2013, whilst for LCVs, the reduction in fuel tax revenue over the period 2010 to 2013 is estimated to be €1 billion. Whilst overall, the Regulations have been cost efficient in achieving CO\textsubscript{2} emissions reductions, a key weakness relates to the test cycle not being representative of real-world emissions. The analysis carried out for this evaluation has shown that the increasing discrepancy between test cycle and real-world emissions performance has eroded the expected emissions benefits and fuel expenditure savings of both the car and LCV CO\textsubscript{2} Regulations.

The analysis suggests that some design elements (modalities) of the Regulations are likely to have had an impact on the efficiency of the Regulations. The main sources of inefficiency are considered to be aspects that relate to whether the CO\textsubscript{2} emissions reduction that have been delivered could have been achieved at lower costs, rather than considering the actual level of CO\textsubscript{2} emissions achieved.

In particular, the use of mass as the utility parameter penalises the use of vehicle weight reduction as an emissions abatement option. The analysis suggests that for weight reduction options, having ‘mass’ as the utility parameter could be less than half as efficient as having ‘footprint’ would have been. However, this only applies to the introduction of weight reduction options and not to fuel efficient technologies in general. Since manufacturers are starting to use mass reduction options, a continued use of ‘mass’ as the utility parameter risks increasing the inefficiency of the car Regulation.

With respect to the assumptions about the average annual distances, recent research indicates that that larger and heavier petrol cars are driven farther than smaller petrol cars over their lifetime, although there were no such differences identified for diesel cars. Taking this into account in the Regulation through mileage-weighting has the potential to improve the cost efficiency of the Regulations because the current approach does not accurately reflect the real-world lifetime mileages associated with different types of vehicles. Mileage-weighting would reduce the costs associated with delivering the same level of CO\textsubscript{2} emissions reduction overall by between 1.62% and 1.75%, depending on, respectively, whether ‘footprint’ or ‘mass’ was the utility parameter. For LCVs, there would be no improvements in efficiency by using mileage-weighting.
**6.1.4 Coherence**

It can be concluded that the two Regulations are largely coherent internally and with each other, with some important caveats as follows:

- **The derogation for niche manufacturers** potentially weakens the delivery of CO₂ emissions reductions, and also potentially has issues for competitive neutrality. However, less than one third of the manufacturers eligible actually benefit from a derogation, as it is not needed by these manufacturers to meet their targets. If all of the other manufacturers that were eligible for a niche derogation applied for it, the numbers of cars covered could increase by five times, which could have a not insignificant impact on the overall level of CO₂ emissions reductions achieved.

- **Super-credits** provide an additional incentive for manufacturers to develop and market low CO₂ emitting cars, but they potentially weaken the respective targets, although their application is capped for the first LCV target and the second car target. The use of super-credits does not seem to have weakened the targets in 2013, particularly as monitoring data indicates that all major manufacturers met their targets even without taking super-credits into account.

- In relation to the **phase-in period**, that for the second car target is not coherent as it potentially weakens the Regulation and delivers little with respect to any other objective, as manufacturers will have had sufficient time to develop their cars in order to deliver the targets. This does however highlight the importance of setting a post 2020 target as soon as possible in order to give manufacturers sufficient time to plan to meet this target.

In relation to the coherence between the two Regulations, the main issue is the different level of stringency between the targets in the two Regulations and the potential to move car-derived LCVs to the car CO₂ Regulation. If the targets in the respective Regulations were set so as to be equivalent, which included a recognition of the fact that some LCVs are car-derived and therefore would benefit from technology applied in order to deliver the targets in the passenger car CO₂ Regulation, the Regulations would be far more coherent with each other.

Overall, the objectives of the LDV CO₂ Regulations are generally coherent with objectives of other related GHG reduction policies. In terms of overarching strategies, the Regulations are a key part of the Commission’s policy package to reduce GHGs from transport as part of Europe’s 2020 goals, the Transport White Paper and the Sustainable Development Strategy. The objectives of the Regulations are also coherent with overarching policies relevant to competitiveness and energy security. Furthermore, the LDV CO₂ Regulations work coherently with EU-level demand-side policies and national fiscal incentives, all of which help to stimulate demand for low carbon vehicles.

The objectives of the relevant fuel, energy carrier and infrastructure policies are generally coherent, particularly in aiming to promote the use of alternatively-fuelled vehicles and decarbonising fuel. One potential conflict with the objective of achieving real world lifecycle GHG reductions concerns the use of biofuels promoted under the Biofuels Directive and the Renewable Energy Directive policies, which have come under recent scrutiny, particularly considering the issue of Indirect Land Use Change (ILUC).

Finally, the main potential conflicts with other legislation were found at the interface with non-GHG polices. The issues mainly relate to **specific technology choices** that may have trade-offs between CO₂ and air pollutant emissions, noise or recyclability/recoverability. In addition, the means of improving safety may lead to increased fuel consumption in some cases. However, these trade-offs do not currently appear to compromise compliance with multiple Regulations at the same time.
6.1.5 EU added value

The harmonisation of the market is the most crucial aspect of added-value and it is unlikely that uncoordinated action would have been as efficient. The Regulations ensure common requirements across the EU and thus minimise costs for manufacturers, whereas on their own, Member States would represent too small a market to achieve the same level of results and therefore an EU wide approach is needed to drive industry level changes.

The automotive industry requires as much regulatory certainty as possible if it is to make the large capital investments necessary to maximise the fuel economy of new vehicles, and even more so for shifting to new primary energy sources. Performance standards can provide this certainty over a long planning horizon.

Furthermore, there are many other examples of legislation that aim to improve the performance of cars and LCVs that are based on EU-level action, including for noise, safety and air pollutant emissions. In all of these cases, it has been deemed preferable to act at the EU-level – and it could be argued that taking action to improve CO₂ emissions is no different.

In addition, there do not appear to be any plausible alternatives to achieving the same level of CO₂ emission reductions in a more cost-effective manner compared to the LDV CO₂ Regulations. The main alternatives considered included:

- **National policies:** Currently, there are widely varying break points employed in differentiation of taxes, fiscal incentives and fuel economy labels developed by different Member States. Hence it seems unlikely that national policies would create the same level playing field, and uncoordinated action risks creating a fragmented market.

- **EU-wide voluntary agreements:** Similar agreements reached with manufacturers prior to the introduction of the Regulations have been shown to have been less effective compared to the Regulations.

- **Including road transport into the EU Emissions Trading Scheme (ETS):** Although the same level of emissions reduction in the road transport sector as a whole could be achieved under an ETS, it would be at a very high carbon price that is considered politically infeasible due to the heavy burden it would place on energy-intensive industries and, indirectly, on other industries and consumers. Furthermore, this scheme would not help to overcome the barriers to decarbonisation of LDVs.

6.2 Recommendations

Overall, the evaluation of the Regulations has been largely positive – they are still relevant, they are broadly coherent, they have generated significant emissions savings and they have been more cost effective than expected. They also generate significant EU added value that could not be achieved to the same extent through national measures.

There are however, some aspects that could be improved and some recommendations that would ensure the Regulations remain relevant, coherent, effective and efficient.

With respect to relevance, while the four needs that were originally identified are still relevant and expected to continue to be relevant, a potential additional need post 2020 could be considered. Namely, that road transport needs to use less energy, in order to take account of the increasing range of fuels and energy sources that the transport is likely to be using. That is, energy efficiency will become a more important metric as the LDV fleet moves to a more diverse mix of powertrains.
Concerning **effectiveness**, the Regulations have clearly been successful in improving the specific CO\textsubscript{2} emissions of cars and LDVs. The analysis also highlighted some key weaknesses that may need to be addressed in future policy proposals:

- The most significant of these appears to be the current **test cycle**: there is an increasing discrepancy between real-world and test cycle emissions which has eroded a significant portion of the originally expected benefits of the Regulations. This issue has been recognised by policy-makers and will be addressed – at least in part – by the development of a revised test procedure, which will be part of a new worldwide harmonised test protocol (WLTP).

- The lack of consideration of the **lifecycle and embedded emissions** of vehicles is currently a relatively minor issue due to the low penetration of electric and plug-in hybrid vehicles; however, as the proportion of electric vehicles is expected to increase, this issue will become more significant. This aspect may therefore need to be included in future legislation.

With respect to **efficiency**, whilst the Regulations have generated net economic benefits to society and have provided consumers with savings in fuel expenditure, both of these metrics have been adversely affected by the problems with the test cycle. This means that the benefits have been smaller than they would otherwise have been if the divergence between test cycle and real-world performance had not been increasing over the last few years. It is recommended that the new WLTP test cycle should address this issue, but it is important that sufficient checks are included to ensure that the new test does not in future years become subject to the problems experienced with the NEDC.

In addition, there is a need to look at how to **improve the ex-ante assessment of costs** associated with the Regulations. It is clear from this evaluation that the costs to manufacturers assumed prior to the introduction of the Regulations were much higher than has been the case in reality. Work is already ongoing to improve the cost assessment approach, but further assessment may be needed.

Considering the **internal coherence** of the Regulations, one recommendation could be considered with respect to the use of **super-credits** in future periods, as their use may not be needed to incentivise the uptake of low emission vehicles. If an additional incentive to develop low CO\textsubscript{2} emission vehicles is required – although the respective targets should be set to be cost-effective and therefore provide a sufficient incentive – one that does not potentially weaken the target might be explored (see, for example, Section 5.2.3).

With respect to the **coherence of the LDV CO\textsubscript{2} Regulations with other policy instruments**, it is clear that any trade-offs do not currently appear to compromise compliance with multiple Regulations at the same time. However, improved coordination may be required as future targets become more stringent both for the LDV CO\textsubscript{2} Regulations and other targets such as those in the End-of-Life Vehicle Directive, Euro emission standards, noise Directives etc.
7 Annex A: Cross-cutting issues

7.1 Test cycle CO₂ emissions as an accurate reflection of real-world emissions

The three main reasons for the observed discrepancies are discussed in turn below:

1. The NEDC test cycle is not representative of real-world driving;
2. Manufacturers are increasingly using flexibilities within the test cycle; and
3. The increased fitting and use of energy consuming devices to cars that are used in the real-world, but which are not operational when measuring emissions on the test cycle (2013a); T&E, (2013d).

While devising a test procedure that is representative of driving conditions and styles across all Member States, while still being replicable, is clearly challenging, the NEDC has a number of issues that might be improved. The cycle has low accelerations, constant cruising speeds and many idling events, which are not representative of real-world driving conditions. Furthermore, the way in which the cycle is defined, e.g. the fixed speeds, gear shift points and accelerations, make it possible for manufacturers to optimise the performance of vehicles for the test cycle (ICCT, 2012d).

There are many flexibilities that are present within the NEDC that potentially have an impact on a vehicle’s CO₂ emissions. An analysis undertaken on behalf of the European Commission suggested that manufacturers have increasingly been making use of these flexibilities to lower a vehicle’s type approved CO₂ emissions rating (TNO et al, 2012b). The report concluded that out of a total reduction of 26.8 gCO₂/km that had been observed for cars on the test cycle between 2002 and 2010, 15.7 gCO₂/km could be due to the deployment of flexibilities. For LCVs, the equivalent figure was estimated to be 10.7 gCO₂/km out of a total reduction of 35.5 gCO₂/km. The analysis also suggested that there may be further scope for the use of flexibilities, which could reduce test cycle emissions by another 5-10 gCO₂/km between 2010 and 2020. As Figure 3-10 shows, the gap between test cycle and real-world emissions has continued to grow since 2010, which might suggest that some of the remaining flexibilities have now been used.

One of the major sources of flexibility is the determination of the ‘road load coefficients’, which are needed to simulate the effects caused by a vehicle actually moving (as the vehicle is tested in the laboratory while stationary) (ICCT, 2013a). Issues that affect the determination of the road loads include allowed adjustments to the vehicle (e.g. to the wheel alignment, brakes, transmission, etc), the ambient conditions (e.g. temperature), the type, pressure and extent of wear of the tyres, the specifics of the test track used and the actual tested weight of the vehicle. Other major sources of flexibility that relate to the test cycle itself include using a higher gear than necessary in the test, the running-in period of the test vehicle (i.e. the minimum distance that a test vehicle has to have been used for before the test) and the implementation of laboratory instrument flexibilities (e.g. by calibrating the instruments to utilise any tolerance allowed) (TNO al, 2012b).

The NEDC does not require energy consuming devices to be switched on during the test. Although not used all of the time when a vehicle is used in the real-world, lights, heating systems, entertainment systems and air conditioning will all increase the CO₂ emissions used when they are switched on. The use of all electrical equipment could increase a vehicle’s CO₂ emissions by around 15%, while air condition could increase CO₂ emissions by up to 50% (T&E, 2013d); (ICCT, 2014e); TNO al, 2012b). TNO (2013) suggests that all models have had an increasing deviation between real-world and type approved emissions, the value of which can be as high as 50 g/km for some petrol cars. At the time of writing, TNO is doing further work in this area, which is expected to shed more
light on the issue, as presented at the Commission’s stakeholder event in December 2014.

7.2 The potential “rebound effect” resulting from the improved fuel efficiency of vehicles

The principal or direct “rebound effect” results from the fact that improving fuel efficiency makes driving the same distance cheaper, which may stimulate additional demand that offsets (at least partially) the increased efficiency. The way in which consumers adjust to lower travel costs is therefore an important issue in determining the impacts of fuel efficiency standards.

Typically, direct rebound effects are empirically estimated using price or operating cost elasticities of demand and there is a wide literature estimating the magnitude of such effects. Although the mechanism of the rebound effect is widely accepted, the precise magnitude is still highly contested (Frondel et al., 2011). Nevertheless, the existing literature does not suggest that the rebound effect is large enough to reverse energy efficiency gains (Gillingham et al, 2014).

Based on 17 studies in OECD countries, the “best guess” direct rebound effect for personal automotive transport is estimated to be between 10-30% (Maxwell et al., 2011). However, the findings show a very wide variation (between 5% and 87%) and depend on the model specifications applied, as well as variation in the quality of data and varying definitions (Gillingham et al, 2014). Furthermore, studies with greater credibility (based on the robustness of techniques used such as panel data methods, experimental designs, and quasi-experimental approaches) tend to provide estimates of the rebound effect that lie toward the lower end of the range (between 5 and 40 per cent), although these refer to short- or medium-run effects (Gillingham et al, 2014). Even so, the highest estimates found in the literature are typically less than 100%; hence even in the worst case the rebound effects cannot negate the overall improvement in emissions. The rebound effect is also unlikely therefore to negate the improvement in air quality emissions (due to reduced fuel consumption).

There are comparably fewer studies on the elasticity of demand for LCVs. Different studies that analyse the rebound effect of energy efficiency improvements for commercial transportation show measurements between 30% and 80% (Maxwell et al., 2011). Graham & Glaister (2002) reviewed international literature on road traffic and fuel demand, and found that 42% of the estimates fall within the range of a direct rebound effect of 40-80%. However, it is important to bear in mind that these estimates are not of general equilibrium elasticities and, therefore, will not equate to full system-wide rebound estimates. Anson & Turner (2009) used a computable general equilibrium (CGE) model of the Scottish economy to examine a 5% increase in energy efficiency in the freight transport sector. They found that this leads to rebound effects of 36.5% in the short run and 38.3% in the long run. It is thought that the rebound effect should be smaller for commercial transport than for private transport as it is less sensitive to price, whilst the economy-wide rebound effect should theoretically be greater than the direct rebound effect alone. Hence, the results of Anson & Turner (2009) suggest that the direct rebound effects are more likely to lie at the lower end of the range predicted by Graham & Glaister (2002).

The impact of purchase price increase and a decrease in fuel cost per kilometre on purchasing behaviour is complex. Consumers respond to purchase price changes as well as to changes in the total cost of ownership (TCO). Hence, there are a number of potential rebound effects that could occur other than changes in the amount of driving

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43 http://ec.europa.eu/clima/events/articles/0103_en.htm
per vehicle. Fuel efficiency improvements may lead to changes in the price of the vehicle and/or changes in other attributes (such as size, weight, power), which may have knock-on consequences on consumer behaviour. For example, increased vehicle prices as a result of the CO₂ Regulation could lead to a shift towards purchasing smaller vehicles and a reduced demand for new vehicles. Conversely, the reduced total cost of ownership per kilometre (taking account of increased purchase costs and reduced fuel costs) could lead to a shift towards larger vehicles, an increased demand for vehicles, and an increase in the use of vehicles (AEA et al, 2012a). These are shown schematically in Figure 7-1.

**Figure 7-1: Mechanisms through which changes in vehicle price and usage costs resulting from CO₂ legislation lead to knock-on consequences with respect to the net CO₂ emission reduction**

While it is difficult to quantify the magnitude of these various effects, it has been estimated that there could be a small negative impact on the effectiveness of the car CO₂ Regulation in the context of the 130 gCO₂/km target for 2015 (AEA et al, 2012a). That is, there may be a small reduction in the effectiveness due to knock-on effects. The equivalent analysis with respect to the rebound effects associated with the 95 gCO₂/km target was sensitive to assumptions about the costs (and payback periods) of the technologies needed to meet the targets: if these were as high as suggested by the main cost curves in TNO et al (2011), the knock-on effects could lead to an overall positive effect (increasing the effectiveness of the Regulation). However, if the cost of the technologies needed to meet the 95 gCO₂/km target is lower than anticipated in TNO et al (2011), as has been suggested by other literature, the net impact of the above effects was considered to be similar to those associated with the 130 gCO₂/km target, i.e. a small negative impact on effectiveness of the Regulation (AEA et al, 2012a).

**7.3 The way in which vehicles are used**

If all vehicles were driven the same distances in the real-world, and indeed were driven in a similar manner, the CO₂ emissions as measured on the test cycle would be a good proxy for the relative contribution of different vehicles to overall CO₂ emissions...
reductions. Hence, the decline in test cycle emissions would be a good indicator of the expected decline in real-world emissions, all else being equal.

The way in which vehicles are driven has an impact on the CO₂ emissions of a vehicle. Many different actions affect the CO₂ emissions of vehicles, including when gears are changed, the severity of braking and acceleration and the pressure and resistance of the tyres. It has been estimated that improvements in driving style – as a result of taking on board the principles of eco-driving, for example – could reduce CO₂ emissions by 10% (Kampman, Rijkee, Pridmore and Hulsotte, 2009). As a result of legislation implemented as part of the EU’s Integrated Approach to reducing CO₂ emissions from cars and LCVs, tyre pressure monitoring systems and gear shift indicators are now compulsory for new cars, all new cars have to be fitted with low rolling resistance tyres. Additionally, in the longer-term, advanced vehicle technologies are expected to automate many eco-driving techniques, thus reducing this source of discrepancy (European Commission, 2010a).

In relation to the distances that vehicles are driven, a report for the Commission has identified that different types of vehicle are driven differently. On average, over their lifetime diesel cars were found to be driven nearly 50% further than petrol cars. While there was no significant difference between the way in which different masses and sizes (measured in terms of their respective footprints) of diesel cars and LCVs are driven, larger and heavier petrol cars are driven further than smaller petrol cars over their lifetime. There is also evidence that newer vehicles tend to be driven farther than older vehicles (Ricardo-AEA & TEPR, 2014; also see Section 9.2).

### 7.4 Well-to-tank CO₂ emissions associated with different fuels and energy sources

The LDV CO₂ Regulations are currently based on the specific tailpipe CO₂ emissions of a vehicle, measured in gCO₂/km on the test cycle. These are also known as the tank-to-wheel (TTW) emissions. However, emissions are generated over the car’s life cycle as illustrated by Figure 7-2.
From the perspective of well-to-tank CO₂ emissions, the use of the specific CO₂ emissions of a vehicle as the metric in the Regulations has largely been appropriate to date. This is because the vast majority of vehicles that have been put on the market since the Regulations came into force are vehicles that use internal combustion engines (ICEs). For these vehicles, the emissions measured on the test cycle correlate well with the direct in-use (or tank-to-wheel (TTW) emissions) CO₂ emissions (notwithstanding the difference between NEDC test cycle and real-world emissions).

However, as measured on the NEDC test cycle, some vehicles using alternative powertrains are measured as having zero CO₂ emissions, e.g. battery electric vehicles (BEVs) or fuel cell electric vehicles (FCEVs) and, to a lesser extent plug-in hybrid vehicles (PHEVs). This reflects that there are no TTW emissions from the vehicle when it is in use, but this presents a misleading picture of the actual emissions associated with the use of the vehicle. For example, this ignores any CO₂ emissions generated upstream in the course of the production of electricity or hydrogen. For the UK, it has been estimated that the CO₂ emissions associated with electricity production (i.e. its well to tank (WTT) emissions) for an electric car are smaller in absolute and relative terms than the CO₂ emissions associated with the combustion of petrol or diesel in ICE vehicle. However, they can still amount to over half of the CO₂ emissions associated with the lifetime of a mid-sized electric car (depending on the assumptions made) (Ricardo, 2011). Figure 7-3, again with reference to the UK, illustrates the CO₂ equivalent emissions associated with a car’s fuel or energy source, including upstream emissions, compared to those associated with embedded emissions.
**Figure 7-3: Relative importance of fuel consumption in contributing to life cycle CO₂-equivalent emissions for petrol ICE, PHEV and BEV cars**

Notes: ICE = internal combustion engine; PHEV = plug-in hybrid electric vehicle; REEV = range extended electric vehicle; BEV = battery electric vehicle. Manufacture and disposal emissions from Ricardo-AEA (2013). 160 g CO₂/km tailpipe emissions assumed for ICE (see Table 4-3), plus 20% upstream emissions (JRC, 2014). 77 gCO₂/km upstream emissions assumed for BEV (as well as PHEV and REEV in EV mode), based on real-life energy consumption of 22 kWh/100km and the European average electricity mix of 352 g/kWh.

Source: (Ricardo-AEA, 2013)

The well-to-plug emissions of PHEVs and BEVs are crucial to their overall life cycle emissions. The upstream emissions associated with electricity production will also vary between EU Member States, as there are large differences in average electricity...
emission factors (i.e. as measured in gCO₂ per kWh generated) between different countries (see Figure 7-4).

**Figure 7-4: Average emission factors from electricity generation across Member States in kg per kWh<sub>el</sub>**

[Graph showing average emission factors across Member States]

*Source: (DEFRA, 2014)*

Moreover, these average electricity emission factors will not necessarily tend to be representative of the emissions arising from the additional electricity demand created for powering plug-in vehicles – output will not increase evenly across all types of power plant in the energy mix. Therefore, the marginal emissions are of interest, i.e. the emissions generated from the additional electricity generation required to charge the vehicle. The type of plant responding to changes in grid load will tend to be affected by current demand in the grid (varying constantly throughout the day) as well as supply (e.g. weather affecting the output of wind and solar PV sources). Figures for marginal emission factors are therefore mostly not readily available. Moreover, in the longer term, the electricity demand created by plug-in vehicles will affect the electricity generation infrastructure: the timing, type and amount of generation plant built and retired.

Figure 7-5 illustrates how the e-Golf’s life-cycle emissions can vary depending on the electricity source. The Regulation only captures the NEDC tank-to-wheel emissions. Well-to-plug emissions will of course vary in proportion to the vehicle’s plug-to-wheel energy consumption.
In practice, vehicle manufacturers often offer a green electricity tariff along with the purchase of their plug-in vehicle (Volkswagen, 2014) (GM, 2011) (Good Energy, 2013). Green electricity tariffs can reduce emissions if they provide additional investment into new green generation capacity that would have otherwise not taken place. However, this ‘additionality’ can be difficult to prove (Pehnt, Seebach, Irrek, & Seidfried, 2008). UK GHG accounting for companies initially requires using the standard average grid emission factors regardless of what electricity tariff the company purchases. However, a green tariff can then be used to offset some emissions as long as it meets ‘good quality’ criteria proving additionality (DEFRA, 2009) (The Environmentalist, 2012).

TNO et al. (2013) compare in detail the current approach of tailpipe emission regulation to a variety of alternative approaches incorporating elements of upstream and embedded emissions, as well as lifetime mileage. Vehicles’ life-cycle CO\(_2\) performance is also affected by the gap between test cycle and measured real-world emissions per km which has been growing in recent years.

The emissions from the combustion of biofuels are counted as zero, as growing energy crops removes an equivalent amount of CO\(_2\) from the atmosphere. However, the well-to-tank GHG emissions associated with biofuels tend to be about double those associated with mineral petrol and diesel, around 31-33 g CO\(_2\)/MJ on average, to a large extent due to methane and nitrous oxide emissions (TNO et al., 2013). Emissions from biofuels are also regulated under the Fuel Quality Directive.

A detailed analysis of the emissions from production of hydrogen is not considered since the market availability and uptake of hydrogen-powered vehicles has been extremely low to date. Overall lifecycle emissions are significantly affected by the hydrogen production pathway. The majority of hydrogen today is produced from fossil fuels – natural gas reformation and coal gasification (AEA et al., 2012c). It is anticipated that in the long term hydrogen would be produced exclusively from renewable/low carbon sources (primarily from electrolysis of water) (AEA et al., 2012c).

---

**Figure 7-5: Comparison of life-cycle emissions of conventional VW Golf models versus e-Golf**

<table>
<thead>
<tr>
<th></th>
<th>Manufacture</th>
<th>NEDC tank-to-wheel</th>
<th>Well-to-tank emissions</th>
<th>Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>e-Golf (using electricity from lignite power station)</td>
<td>8.5</td>
<td>28.5</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>e-Golf (using average European electricity mix)</td>
<td>8.5</td>
<td>10.6</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>e-Golf (using 100% renewable electricity)</td>
<td>8.5</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golf Diesel (Mk VII 1.6 TDI)</td>
<td>5.0</td>
<td>14.9</td>
<td>3.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Golf Petrol (Mk VII 1.2 TSI)</td>
<td>4.5</td>
<td>17.0</td>
<td>4.0</td>
<td>0.2</td>
</tr>
</tbody>
</table>

*Source: Volkswagen (2014), DEFRA (2014)*
7.5 Embedded CO₂ emissions associated with vehicle manufacture and disposal

As with the discussion of the previous section, the existing metric has largely been appropriate to date, as the difference between the embedded emissions in different types of ICE vehicle, e.g. those using petrol and diesel, are similar. For example, Ricardo (2011) estimated that the total lifetime emissions associated with a mid-sized petrol car are similar to those of a similar sized diesel car, although the latter has slightly higher production emissions, which are counteracted by fewer fuel-related emissions. TNO et al (2011) estimate that vehicle production is responsible for around 9-13% of total lifecycle GHG emissions for petrol cars, and around 10-20% higher than this for diesel cars. This implies that the in-use phase is currently much more important in the lifecycle compared to the production phase. While the use phase emissions are expected to decrease over the next decade, the production phase emissions are expected to remain constant.

The situation changes with an increasing proportion of vehicles using alternative powertrains entering the market, as for electric vehicles, emissions associated with production increase the more the vehicle relies on the use of electricity (see Figure 7-6).

**Figure 7-6: Lifetime CO₂ emission associated with production, fuel and energy use and disposal for mid-size cars with different technologies**

![Figure 7-6](image)

Source: (Ricardo, 2011)

A significant proportion of this increase in production emissions associated with electric vehicles is due to battery production. Ricardo (2011) estimate that the non-battery CO₂ emissions in production are slightly lower for a BEV than for a conventional petrol car. Over 40% of the total production emissions from a mid-size battery electric vehicle are associated with the production of its battery. There are various estimates in the literature on the carbon intensity of lithium battery production, ranging between 50 and
160 kg CO$_2$/kWh capacity, with most estimates being close to the latter value (Messagie et al, 2013); Ricardo (2011) assumed 120 kg CO$_2$/kWh.

Given the energy intensity of the battery, production emissions from BEVs will tend to be very sensitive to the battery size. While most BEVs on the market tend to have batteries of around 17-25 kWh of capacity (e.g. Nissan Leaf, BMW i3, Smart ForTwo electric drive, Renault Zoe, VW e-Golf, VW e-up), the Tesla Model S is available with batteries with up to 85 kWh capacity, suggesting that battery production alone may result in production emissions of up to 14t CO$_2$ per vehicle.

A further complication is the increased use of alternative materials in cars and LCVs, high strength steel, aluminium, plastics, carbon fibre reinforced plastic composites and magnesium (Ricardo-AEA et al, 2015). These will have different GHG intensities in the production phase, although lighter vehicles will use less energy, and therefore be responsible for emitting less associated CO$_2$. According to figures used by the respective industries, primary aluminium has a GHG intensity of nearly five times that of primary steel, although the margin and absolute values fall significantly when recycled metal is used. However, for electric vehicles, the use of aluminium, even though it is more expensive and GHG-intensive, would be beneficial in terms of both, as the cost (and GHG emissions associated with the production) of the battery could be reduced (FKA, 2012).

On the other hand, end-of-life disposal and recycling do not generally make a significant contribution to life cycle CO$_2$ emissions, with estimates of the order of a few percent at most (Ricardo, 2011; Ricardo-AEA, 2013).

### 7.6 Share of diesel vehicles

There are many factors that may have contributed to the trend towards dieselisation seen in Europe. This section summarises the evidence from literature.

The increased uptake of diesel as a fuel for cars and LCVs has been an ongoing trend for over 20 years. Comparisons with other major vehicle markets (such as the USA and Japan) show that diesel shares in those markets are comparatively much lower in the passenger car fleet (ICCT, 2014b). Additionally, the adoption of diesel-fuelled vehicles in Member States is also very heterogeneous, ranging from 29% (Netherlands) to around 70% (Belgium, France, and Spain) (ICCT, 2014b).

It is difficult to precisely determine the relative contribution of different factors to the trends in diesel vehicle uptake in Europe. For example, simple static charts depicting the difference in petrol tax versus diesel tax against diesel share, as shown in Figure 7-7, may lead to conclusions that it is fuel taxes that have driven the uptake of diesel.
This can be misleading, as econometric studies find that the effect of differences in fuel prices only have a small effect on fuel choice (as discussed below). Rather, some of the Member States with high levels of fuel taxes have high levels of other taxes as well, such as registration taxes – and these other taxes tend to have a larger effect (ETC/ACM, 2012).

Therefore in our analysis we have included only studies that are based on statistical analysis of empirical data, as opposed to descriptive analyses (such as simple graphs), since the results are considered more robust.

Linn (2014) uses an econometric model to assess the effect of the Regulation on diesel share. The study estimates the impact on the diesel share in Austria, Belgium, France, Germany, Italy, the Netherlands and Spain if a fleet average of 130 gCO₂/km were required, using car models available on the market in 2010, instead of the 2010 fleet average across these countries of 141 gCO₂/km. It is assumed that manufacturers would adjust market shares by charging a €57 premium for every gram CO₂ in excess of 130 gCO₂/km and an equivalent subsidy for cars with emissions below 130g CO₂/km. This amount is exactly sufficient to induce consumers to shift to models whose total European fleet average is 130 gCO₂/km. Consumers shift both to lower emitting models of a given fuel type, as well as from petrol to diesel models. The resulting estimated average increase in diesel share in Europe is of 8.6% (or 5 percentage points), with significant variations between countries. Given that this analysis only allows for shifts within the 2010 model range it is almost certainly an over-estimate of the effect of the Regulation on the diesel share by 2015 as manufacturers appear to have responded to the Regulation with the introduction of new models with lower fuel consumption, especially among petrol models. The regression analysis (Annex E) has not found no effect of the Regulation on the uptake of diesel vehicles; diesel share was therefore included in the regression as independent variable.

- National vehicle taxes: Registration taxes appear to be an effective means of changing the shares of diesel and petrol cars, while annual road taxes and fuel taxes only have small and highly unreliable effects (ETC/ACM, 2012). Using a registration tax to increase the sales price of a diesel car relative to its petrol
counterpart by €1,000, decreases the share of diesel cars in new car sales by 3%.

- **Fuel prices and taxes:** In Europe, fuel taxes generally favour diesel in European countries, although both the levels of fuel prices and the relative prices of gasoline and diesel fuel differ considerably. However, a large body of economic literature using econometric models finds that in Europe, the market shares of diesel are not strongly correlated with fuel prices or taxes either in cross section or over time (Linn, 2014); (Klier and Linn, 2013a); (Cambridge Econometrics, 2013); (ETC/ACM, 2012).

- **Supply of vehicles and vehicle characteristics:** Overall, there has been an increase in the number of diesel fuel models on offer (particularly for French brands) since 2007 (Klier and Linn, 2013b). However, some Member States may enjoy a greater variety of diesel models available compared to others. Econometric analysis suggests that the characteristics of vehicles supplied to each market do not appear to explain a large part of the variation in diesel shares between European countries (Linn, 2014).

- **Consumer preferences:** Using a data set with vehicle characteristics and registrations figures for Austria, Belgium, France, Germany, Italy, the Netherlands, and Spain, Linn (2014) builds a model to explain the diesel share in these European countries through a vehicle cost parameter (including vehicle taxes), a fuel cost parameter (including fuel consumption and prices) and a parameter for other vehicle characteristics. He finds that the coefficients on these parameters vary significantly between European countries, e.g. Germans tend to be more responsive to a change in vehicle costs than other countries in the sample, while French, Belgians and Italians tend to be more than twice as responsive to fuel price changes compared to Germans. Consequently, Linn (2014) finds that these differences in consumer preferences for fuel economy explain a very large share of the variation in diesel share between countries.

Whilst the contribution of the Regulations to this trend is difficult to quantify, it is likely that other factors (especially national vehicle registration taxes and consumer preferences) have had a large impact. While structural imbalances in the transport fuel market may not necessarily pose security of supply issues as long as a sufficiently diverse number of suppliers is maintained, an increasing (worldwide) imbalance in demand may lead to higher fuel prices.
8 Annex B: Baseline counterfactual scenario and methods for quantifying the effectiveness and efficiency of the Regulations

In order to assess the impacts of the Regulation, it was necessary to construct counterfactual baseline scenarios that define what would have happened in the absence of the two Regulations. The development of a baseline scenario is an important element of any ex-post evaluation and is critical for the purposes of being able to assess the effectiveness and efficiency of an intervention.

The baseline represents the starting point for any analysis of ex-post impacts, and can be used as the basis for quantifying the effects of the intervention on costs, emissions, energy consumption, and other key indicators. However, it is important to stress that the presence of differences between the baseline scenario and the actual outcomes, do not, on their own, indicate direct causal relationships between the intervention and the actual outcomes.

In the context of this study, two baselines are required: one for evaluating the passenger car CO$_2$ Regulation and one for the LCV CO$_2$ Regulation. Furthermore, in order to quantify the effectiveness of the Regulations (in terms of impacts on total CO$_2$ emissions) and the efficiency of the Regulations (costs associated with achieving the reductions in CO$_2$ emissions), it was necessary to construct a model of the EU’s fleet of new cars registered between 2006 and 2013 and a model of the fleet of new LCVs registered between 2009 and 2013. The following sections describe each of these tools in turn:

- Section 8.1 describes the development of a baseline scenario for passenger cars
- Section 8.2 describes the development of a baseline scenario for LCVs
- Section 8.3 describes the development and use of the fleet models for quantifying emissions reductions and costs

8.1 Development of a baseline scenario for passenger cars

The passenger car CO$_2$ Regulation came into force in 2009 and was originally announced in 2007 as a replacement for the previous industry-developed voluntary agreement on car CO$_2$ emissions. The voluntary agreement was designed to reduce fleet-average new car emissions to 140 gCO$_2$/km by 2008, and whilst year-on-year reductions were achieved, by 2006 it was clear that the target was going to be missed. The baseline scenario for passenger cars needs to take into account the existence of the voluntary agreement whilst also recognising that on its own it was not sufficient to deliver the levels of emissions reductions required. In the absence of the car CO$_2$ Regulation, it is unlikely that the voluntary agreement would have continued to deliver year-on-year emissions reductions at the same level achieved in the years immediately preceding the announcement of the Regulation. By contrast, given that car manufacturers had already invested to a certain extent in developing and implementing new technologies for passenger cars to reduce vehicle CO$_2$ emissions as part of their voluntary agreement commitments, it is highly unlikely that in the absence of the Regulations, annual improvements in fuel efficiency would have completely ceased.

As the Regulation was introduced across the whole of the EU at the same time, it is not possible to identify a control group to compare against. Furthermore, as cars designed for the EU market are also sold in non-EU European countries, it is not possible to examine trends in these other countries as they will have benefited from spillover effects of the Regulation.
As an alternative, it has been necessary to investigate historic trends in vehicle fuel consumption in the absence of measures for incentivising and regulating improvements. In the early 1990s, annual fuel efficiency improvements amounted to around 0.1% per year until the Voluntary Agreement was introduced. In the United States, in the absence of more stringent Corporate Average Fuel Economy standards in between 1985 and 2000, new car fleet fuel efficiency remained static, and in some years got worse (National Research Council of the National Academies, 2014). Hence, in the absence of regulatory standards or other measures for improving car fuel efficiency, a reasonable assumption would be that average fuel economy and tailpipe CO₂ emissions remain static year-on-year. However, in the case of passenger cars, the existence of the Voluntary Agreement complicates the picture. For this reason, the study team decided that a baseline scenario where CO₂ emissions remain static would not be appropriate. Instead, baseline improvements of 0.5 gCO₂/km per year have been assumed. This level of improvement equates to a 0.31% average annual reduction in car CO₂ emissions and is 10% of the actual levels of reduction achieved. This level of annual improvement is an assumption and it is not possible to validate its accuracy. However, it is reasonable to assume that if there had been no car CO₂ Regulation, there would have been residual effects from the voluntary agreement that would have had an impact on car fuel efficiency and tailpipe CO₂ emissions over the full period from 2007 to 2013. Hence, in the baseline counterfactual scenario, fleet-average new car NEDC emissions are assumed to decrease from 158.7 gCO₂/km in 2007 to 155.7 gCO₂/km in 2013 (with the Regulation in place, actual NEDC emissions declined from 158.7 gCO₂/km to 126.7 gCO₂/km over the same time period).

NEDC emissions performance does not accurately reflect real-world emissions performance and hence for both the baseline counterfactual scenario and for the actual outturn performance under the Regulation, real-world uplift factors are required to convert NEDC CO₂ figures to real-world figures. Research carried out by the ICCT (ICCT, 2014e), indicates that the divergence between NEDC test-cycle emissions performance and real-world performance has been increasing for the last several years. These data were used as the basis for translating the outturn NEDC figures to real-world figures; the level of real-world uplift applied to the outturn NEDC figures increased from 11% in 2006 to 31% in 2013. For the baseline counterfactual scenario, the level of divergence between test cycle and real-world emissions was also assumed to increase, but at a much slower rate. This reflects the likelihood that without the car CO₂ Regulation in place, there would have been less need for manufacturers to make use of test-cycle flexibilities to the same extent as has been the case with the Regulation in place. Under the baseline counterfactual scenario, a real-world uplift factor of 11% was applied for new cars registered in 2006, rising to 15% for new cars registered in 2013.

Table 8-1: Outturn emissions performance with the car CO₂ Regulation in place and baseline counterfactual performance assuming no car CO₂ Regulation

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Outturn emissions performance due to the car CO₂ Regulation (gCO₂/km)</th>
<th>Baseline counterfactual emissions performance (assumes no Regulation (gCO₂/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NEDC</td>
<td>Real-world</td>
</tr>
<tr>
<td>----------------------------</td>
<td>------</td>
<td>------------</td>
</tr>
<tr>
<td>2006</td>
<td>161.3</td>
<td>179.1</td>
</tr>
<tr>
<td>2007</td>
<td>158.7</td>
<td>176.9</td>
</tr>
<tr>
<td>2008</td>
<td>153.6</td>
<td>172.0</td>
</tr>
</tbody>
</table>

In addition to data on average CO₂ performance across all fuel types for each year, data on average performance for vehicles by powertrain type were also collected. The NEDC CO₂ figures for petrol, diesel and alternatively fuelled passenger cars are presented in the table below alongside the overall average NEDC figures for each year.

Table 8-2: Average actual outturn NEDC CO₂ emissions performance by fuel type and by year of registration

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Outturn emissions performance due to the car CO₂ Regulation (gCO₂/km)</th>
<th>Baseline counterfactual emissions performance (assumes no Regulation (gCO₂/km))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NEDC</td>
<td>Real-world</td>
</tr>
<tr>
<td>2009</td>
<td>145.7</td>
<td>172.0</td>
</tr>
<tr>
<td>2010</td>
<td>140.3</td>
<td>169.8</td>
</tr>
<tr>
<td>2011</td>
<td>135.7</td>
<td>168.3</td>
</tr>
<tr>
<td>2012</td>
<td>132.2</td>
<td>165.2</td>
</tr>
<tr>
<td>2013</td>
<td>126.7</td>
<td>166.3</td>
</tr>
</tbody>
</table>

Baseline counterfactual emissions performance by fuel type were generated taking into account the overall assumed annual reduction in fleet average CO₂ emissions of 0.5 gCO₂/km and changes in the split of new car sales between petrol, diesel and alternatively fuelled vehicles over the period 2006 to 2013.
Table 8-3: Average baseline counterfactual NEDC CO₂ emissions performance by fuel type and by year of registration

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Baseline counterfactual emissions performance for passenger cars (gCO₂/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fleet average</td>
</tr>
<tr>
<td>2006</td>
<td>161.3</td>
</tr>
<tr>
<td>2007</td>
<td>158.7</td>
</tr>
<tr>
<td>2008</td>
<td>158.2</td>
</tr>
<tr>
<td>2009</td>
<td>157.7</td>
</tr>
<tr>
<td>2010</td>
<td>157.2</td>
</tr>
<tr>
<td>2011</td>
<td>156.7</td>
</tr>
<tr>
<td>2012</td>
<td>156.2</td>
</tr>
<tr>
<td>2013</td>
<td>155.7</td>
</tr>
</tbody>
</table>

Real-world emissions factors for each fuel type were calculated using the uplift factors presented in Table 8-1.

8.2 Development of a baseline scenario for LCVs

For LCVs, a similar baseline counterfactual scenario was constructed, but in this case it was assumed that without the presence of a CO₂ Regulation, NEDC emissions performance would have stayed flat between 2009 and 2013. The reason for the assumed difference between cars and LCVs is that for LCVs there was no voluntary agreement on reducing CO₂ emissions prior to the introduction of the CO₂ Regulation. Furthermore, whilst there could have been some spillover effects on car-derived vans from the passenger car voluntary agreement, these have been assumed to be counteracted by the negative impacts of the Euro 5 Regulation on fuel economy and CO₂ emissions (some forms of exhaust after-treatment for air pollutants used to meet the Euro 5 standards can lead to increases in fuel consumption and CO₂ emissions).

As for passenger cars, it is also necessary to take into account the divergence between test cycle and real-world CO₂ emissions performance for both the baseline counterfactual and outturn performance scenarios. For LCVs, no detailed research has been carried out to analyse the level of divergence between test cycle and real-world performance and how this varies over time. Hence, it was assumed that prior to the introduction of the LCV CO₂ Regulation, the level of divergence was the same as for passenger cars prior to the car CO₂ Regulation – i.e. 11%. Analysis of real-world fuel consumption data from for a selection of 2013-model LCVs indicate that that on average, there is a 15% divergence between test-cycle and real-world performance for LCVs registered that year, and hence it has been assumed that the level of divergence increases from 11% in 2009 to 15% in 2013. However, it must be stressed that the amount of real-world data available on LCVs is very limited. For the baseline counterfactual scenario, it was assumed that the level of divergence does not increase so rapidly; the level of divergence is assumed to increase from 11% in 2009 to 13% in 2013.
Table 8-4: Outturn emissions performance with the LCV CO\textsubscript{2} Regulation in place and baseline counterfactual performance assuming no LCV CO\textsubscript{2} Regulation

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Outturn emissions performance due to the car CO\textsubscript{2} Regulation (gCO\textsubscript{2}/km)</th>
<th>Baseline counterfactual emissions performance (assumes no Regulation (gCO\textsubscript{2}/km))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NEDC</td>
<td>Real-world</td>
</tr>
<tr>
<td>2009</td>
<td>185.0</td>
<td>205.4</td>
</tr>
<tr>
<td>2010</td>
<td>181.5</td>
<td>203.3</td>
</tr>
<tr>
<td>2011</td>
<td>180.9</td>
<td>205.5</td>
</tr>
<tr>
<td>2012</td>
<td>180.2</td>
<td>206.4</td>
</tr>
<tr>
<td>2013</td>
<td>173.3</td>
<td>199.7</td>
</tr>
</tbody>
</table>

As for passenger cars, data on average performance for vehicles by powertrain type were also collected. These are presented in the table below.

Table 8-5: Average actual outturn NEDC CO\textsubscript{2} emissions performance by fuel type and by year of registration

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Outturn emissions performance due to the LCV CO\textsubscript{2} Regulation (gCO\textsubscript{2}/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fleet average</td>
</tr>
<tr>
<td>2009</td>
<td>185.0</td>
</tr>
<tr>
<td>2010</td>
<td>181.5</td>
</tr>
<tr>
<td>2011</td>
<td>180.9</td>
</tr>
<tr>
<td>2012</td>
<td>180.2</td>
</tr>
<tr>
<td>2013</td>
<td>173.3</td>
</tr>
</tbody>
</table>

Given that the baseline counterfactual scenario for LCVs consists of average emissions performance remaining flat over the period 2009 to 2013, the baseline disaggregated emissions performance by fuel type for each year are the same as the 2009 data from Table 8-5 above.

8.3 Development of fleet models for quantifying total emissions reductions and costs

8.3.1 Design and operating principles of the fleet models

In order to quantify the total reductions in CO\textsubscript{2} emissions due to the Regulations, the baseline counterfactual emissions scenario and the actual outturn emissions scenario for each type of vehicle (i.e. for cars and for LCVs) were overlaid onto spreadsheet-based models of the new car fleet and new LCV fleet for the relevant time period of interest. The models were designed to calculate the emissions, fuel consumption, fuel

costs and vehicle technology costs for the new car and LCV fleet on a year-by-year basis for new vehicles that entered the EU fleet up to 2013. Calculations within the model were carried out for (a) the actual outturn scenarios and (b) the baseline counterfactual scenarios. By subtracting the baseline results from the actual outturn results, the impacts of the Regulations were quantified.

The basic principle underpinning the car and LCV fleet models is that total CO₂ emissions for any given vehicle type can be calculated according to Equation 1 below.

**Equation 1:**

\[
\text{Total emissions}_{(a,b,c)} = \text{Number of vehicles}_{(a,b,c)} \times \text{Emission factor}_{(a,b,c)} \times \text{Vehicle km travelled}_{(a,b,c)}
\]

Notes:

- **a** = Year of first registration for the vehicle
- **b** = Vehicle fuel type (e.g. petrol, diesel, etc)
- **c** = Year of interest

The fleet models were designed to allow analysis to be carried out using both the NEDC and real-world CO₂ emission factors for each vehicle type to be used. However, the main results are based on using the real-world emissions factors (described in Sections 8.1 and 8.2) as these are more representative of actual operating conditions.

Fuel costs associated with the use of each vehicle are calculated using the following equation:

**Equation 2:**

\[
\text{Total fuel costs}_{(a,b,c)} = \text{Number of vehicles}_{(a,b,c)} \times \text{Fuel consumption factor}_{(a,b,c)} \times \text{Fuel price} \times \text{Vehicle km travelled}_{(a,b,c)}
\]

The fuel consumption factors (in litres per kilometre) for each vehicle were derived directly from the equivalent vehicle CO₂ emission factors. Using this equation, the impacts of the Regulations on costs to consumers was calculated, as well as the contributions of changes in fuel expenditure to the net costs to society associated with the Regulations. Additionally, the impacts of the Regulations on tax revenues were also calculated by comparing total pre-tax and post-tax fuel costs.

Vehicle costs were calculated taking into account the adoption and market penetration of new technologies over the time period of interest (2006-2013 for cars; 2009-2013 for LCVs), and the costs of these technologies.

**Equation 3:**

\[
\text{Total vehicle costs}_{(a,b)} = \text{Number of vehicles}_{(a,b)} \times \text{Market penetration rate}_{(a,b,d)}
\]

Note: **d** = market penetration of technology type d.
The original ex-ante Impact Assessments for the car and LCV CO₂ Regulations were carried out on the basis of analysing impacts out to 2020 (and 2030 in the case of LCVs). At this point in time (i.e. 2015) it is not possible to carry out an equivalent ex-post evaluation that covers the full impacts to 2020 and 2030. However, it is possible to estimate the lifetime emissions impacts and cost impacts of those vehicles that have entered the fleet up to 2013, including accounting for the future costs and benefits of these vehicles, given that they are already on the road. Hence, for the purposes of the evaluation, the lifetime costs and emissions impacts of new passenger cars that entered the fleet between 2006 and 2013, and LCVs that entered the fleet between 2009 and 2013 have been calculated and compared to the baseline counterfactual scenario for the same vehicles.

The simple calculations described above are repeated over and over to account for the lifetime emissions and costs associated with all new vehicles that entered the fleet over the full time period of interest (i.e. 2006-2013 for new passenger cars and 2009-2013 for new LCVs).

Whilst the fleet models are based around a simple set of equations, a wide range of supporting data was required in order to populate the models. The data on tank-to-wheels emissions used for the emissions analysis has already been described in Sections 8.1 and 8.2, but the fleet models also required on the following datasets:

- Data on annual new vehicle registrations, split by fuel type (petrol, diesel and alternative fuel vehicle)
- Data on annual and lifetime mileage by fuel type (including changes in annual mileage over the lifetime of the vehicle)
- Vehicle survival rates by age
- Well-to-tank emissions factors
- EU-average pre-tax and post-tax fuel prices covering 2006 to 2013
- Data on market penetration of CO₂ abatement technologies for cars and LCVs
- Data on the unit costs of CO₂ abatement technologies for cars and LCVs

The following sections describe each of the datasets used to support the development of the new vehicle fleet models.

### 8.3.2 Data on new vehicle registrations

Knowing how many vehicles were covered by the scope of the Regulations is fundamental to the task of quantifying both the emissions impacts and cost impacts. Data on new car and LCV sales in the EU27 were gathered from ACEA’s annual statistics. The figures used for the analysis are presented below.

#### Table 8-6: Data on new car and LCV annual registrations, 2006-2013

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Numbers of new cars registered</th>
<th>Numbers of new LCVs registered</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>15,423,209</td>
<td>2,026,749</td>
</tr>
<tr>
<td>2007</td>
<td>15,573,611</td>
<td>2,201,174</td>
</tr>
<tr>
<td>2008</td>
<td>14,331,792</td>
<td>1,978,743</td>
</tr>
<tr>
<td>2009</td>
<td>14,157,752</td>
<td>1,369,455</td>
</tr>
<tr>
<td>2010</td>
<td>13,372,917</td>
<td>1,482,178</td>
</tr>
</tbody>
</table>
Data on the split between petrol, diesel and alternatively fuelled vehicles for new car and LCV sales were also required. For passenger cars, these data were obtained from ACEA statistics and from the EEA CO2 monitoring reports. For LCVs, less data were available and a combination of different sources and assumptions had to be used. For 2012 and 2013, data from the annual EEA CO2 monitoring reports on new LCV sales disaggregated by powertrain type were used (EEA, 2014). For 2009 to 2011, research carried out by the ICCT was used (ICCT, 2014c). For all prior years, the split of LCV sales by powertrain type was assumed to be the same as for 2009.

Table 8-7: New car sales split by powertrain type (2006-2013)

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Petrol</th>
<th>Diesel</th>
<th>Alternative fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>49.4%</td>
<td>50.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>2007</td>
<td>47.3%</td>
<td>51.9%</td>
<td>0.7%</td>
</tr>
<tr>
<td>2008</td>
<td>47.4%</td>
<td>51.3%</td>
<td>1.3%</td>
</tr>
<tr>
<td>2009</td>
<td>51.2%</td>
<td>45.2%</td>
<td>3.7%</td>
</tr>
<tr>
<td>2010</td>
<td>45.3%</td>
<td>51.3%</td>
<td>3.4%</td>
</tr>
<tr>
<td>2011</td>
<td>43.4%</td>
<td>55.2%</td>
<td>1.3%</td>
</tr>
<tr>
<td>2012</td>
<td>43.0%</td>
<td>54.9%</td>
<td>2.2%</td>
</tr>
<tr>
<td>2013</td>
<td>45.2%</td>
<td>52.6%</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

Table 8-8: New LCV sales split by powertrain type (2006-2013)

<table>
<thead>
<tr>
<th>Year of first registration</th>
<th>Petrol</th>
<th>Diesel</th>
<th>Alternative fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>3.0%</td>
<td>96.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>2007</td>
<td>3.0%</td>
<td>96.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>2008</td>
<td>3.0%</td>
<td>96.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>2009</td>
<td>3.0%</td>
<td>96.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>2010</td>
<td>2.0%</td>
<td>96.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>2011</td>
<td>2.0%</td>
<td>97.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>2012</td>
<td>1.8%</td>
<td>96.5%</td>
<td>1.7%</td>
</tr>
<tr>
<td>2013</td>
<td>2.0%</td>
<td>96.5%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>
8.3.3 Data on annual and lifetime distances travelled

Data on annual and lifetime distances travelled by vehicles are necessary in order to quantify the total emissions impacts of new vehicles that enter the fleet. Ricardo-AEA carried out detailed research on this topic as part of a separate study for the European Commission (Ricardo-AEA & TEPR, 2014) which was used as the basis for that data on passenger car and LCV mileage. These data were originally sourced from the UK’s MOT database of periodic technical inspection data for vehicles and it has been assumed that the figures are representative of the wider European fleet (equivalent comprehensive data for other countries do not currently exist).

For passenger cars, the study investigated annual mileage for petrol and diesel cars, but no data were collected for alternatively fuelled vehicles. In the absence of any other data, and given the very low percentage of alternatively fuelled vehicles as a proportion of new car sales (in the range 0.3-3.7%, depending on year of registration), to simplify the analysis it was assumed that the annual mileage for these types of vehicles is the mean of the distance travelled by the average petrol car and the average diesel car.

Table 8-9: Annual average distances travelled by passenger cars by powertrain type and age

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Annual distance travelled (km)</th>
<th>Petrol</th>
<th>Diesel</th>
<th>Alternative fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td></td>
<td>13,045</td>
<td>25,665</td>
<td>19,355</td>
</tr>
<tr>
<td>1-2</td>
<td></td>
<td>13,045</td>
<td>25,665</td>
<td>19,355</td>
</tr>
<tr>
<td>2-3</td>
<td></td>
<td>13,045</td>
<td>25,665</td>
<td>19,355</td>
</tr>
<tr>
<td>3-4</td>
<td></td>
<td>12,245</td>
<td>17,586</td>
<td>14,256</td>
</tr>
<tr>
<td>4-5</td>
<td></td>
<td>12,096</td>
<td>16,494</td>
<td>14,325</td>
</tr>
<tr>
<td>5-6</td>
<td></td>
<td>11,869</td>
<td>15,255</td>
<td>13,804</td>
</tr>
<tr>
<td>6-7</td>
<td></td>
<td>11,608</td>
<td>14,206</td>
<td>12,808</td>
</tr>
<tr>
<td>7-8</td>
<td></td>
<td>11,316</td>
<td>13,296</td>
<td>12,849</td>
</tr>
<tr>
<td>8-9</td>
<td></td>
<td>10,993</td>
<td>12,493</td>
<td>12,089</td>
</tr>
<tr>
<td>9-10</td>
<td></td>
<td>10,640</td>
<td>11,774</td>
<td>11,313</td>
</tr>
<tr>
<td>10-11</td>
<td></td>
<td>10,257</td>
<td>11,122</td>
<td>11,157</td>
</tr>
<tr>
<td>11-12</td>
<td></td>
<td>9,845</td>
<td>10,527</td>
<td>10,815</td>
</tr>
<tr>
<td>12-13</td>
<td></td>
<td>9,404</td>
<td>9,979</td>
<td>10,253</td>
</tr>
<tr>
<td>13-14</td>
<td></td>
<td>8,936</td>
<td>9,472</td>
<td>9,267</td>
</tr>
<tr>
<td>14-15</td>
<td></td>
<td>8,439</td>
<td>8,999</td>
<td>8,744</td>
</tr>
<tr>
<td>15-16</td>
<td></td>
<td>7,915</td>
<td>8,556</td>
<td>8,799</td>
</tr>
<tr>
<td>16-17</td>
<td></td>
<td>7,363</td>
<td>8,140</td>
<td>7,901</td>
</tr>
<tr>
<td>17-18</td>
<td></td>
<td>6,785</td>
<td>7,747</td>
<td>6,775</td>
</tr>
<tr>
<td>18-19</td>
<td></td>
<td>6,181</td>
<td>7,376</td>
<td>6,430</td>
</tr>
</tbody>
</table>

For LCVs, the study only investigated annual mileage for diesel-powered vehicles, and hence an additional source of data was required for petrol-powered LCVs. Data on annual mileage for petrol LCVs was based on analysis from the TRACCS study on
transport data collection for supporting the quantitative analysis of measures relating to transport and climate change (Papadimitriou, 2013). In particular, data on annual mileage for petrol and diesel LCVs were reviewed from the TRACCS study, the relationship between petrol and diesel usage intensity was used to factor the diesel LCV mileage data from (Ricardo-AEA & TEPR, 2014) as a means of estimating petrol LCV mileage. This is an imperfect method of quantifying petrol LCV mileage figures, but given the very low percentage of new LCVs powered by petrol engines (3% or less for all years from 2006 onwards), this was viewed as an acceptable compromise. As for passenger cars, annual mileage for alternatively fuelled LCVs was calculated as the mean of the values for petrol and diesel LCVs (alternatively fuelled LCVs account for between 1% and 2% of new LCV sales).

Table 8-10: Annual average distances travelled by LCVs by powertrain type and age

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Annual distance travelled (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Petrol</td>
</tr>
<tr>
<td>0-1</td>
<td>26,644</td>
</tr>
<tr>
<td>1-2</td>
<td>26,644</td>
</tr>
<tr>
<td>2-3</td>
<td>26,644</td>
</tr>
<tr>
<td>3-4</td>
<td>17,760</td>
</tr>
<tr>
<td>4-5</td>
<td>15,603</td>
</tr>
<tr>
<td>5-6</td>
<td>14,797</td>
</tr>
<tr>
<td>6-7</td>
<td>13,264</td>
</tr>
<tr>
<td>7-8</td>
<td>11,839</td>
</tr>
<tr>
<td>8-9</td>
<td>10,965</td>
</tr>
<tr>
<td>9-10</td>
<td>10,065</td>
</tr>
<tr>
<td>10-11</td>
<td>9,499</td>
</tr>
<tr>
<td>11-12</td>
<td>8,685</td>
</tr>
<tr>
<td>12-13</td>
<td>7,642</td>
</tr>
<tr>
<td>13-14</td>
<td>6,563</td>
</tr>
<tr>
<td>14-15</td>
<td>6,153</td>
</tr>
<tr>
<td>15-16</td>
<td>5,359</td>
</tr>
<tr>
<td>16-17</td>
<td>5,367</td>
</tr>
<tr>
<td>17-18</td>
<td>5,049</td>
</tr>
<tr>
<td>18-19</td>
<td>5,328</td>
</tr>
</tbody>
</table>

8.3.4 Data on vehicle survival rates

Vehicle survival rates quantify the percentage of vehicles that leave the fleet each year because they have reached the end of their useful lives. Vehicles can leave the fleet prematurely (e.g. due to severe accident damage), but the majority of vehicles leave the fleet due to a major system failure that means it is no longer economically viable to repair the vehicle. Data on survival rates is important in the context of this evaluation.
study, as in order to quantify the total lifetime CO\textsubscript{2} emissions associated with new vehicles that enter the fleet in any given year, it is necessary to understand how long those vehicles will remain in the fleet, and only take into account emissions from the proportion of vehicles remaining in the fleet each year after first registration.

As part of the Ricardo-AEA study on vehicle mileage for the European Commission (Ricardo-AEA & TEPR, 2014), data on survival rates for passenger cars and LCVs were collected, and these data have now been used to support this evaluation study. As with the information on vehicle mileage, the data on vehicle survival rates were originally sourced from analysis of the UK’s MOT database of periodic technical inspection data and, in the absence of equivalent datasets from other countries, it has been assumed that these data are representative of the wider EU. The survival rates for passenger cars and LCVs are presented in the table below.

Table 8-11: Survival rates for passenger cars and LCVs

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Survival rates</th>
<th>Passenger cars</th>
<th>LCVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>96%</td>
<td>96%</td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>96%</td>
<td>94%</td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td>95%</td>
<td>93%</td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>94%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>4-5</td>
<td>94%</td>
<td>88%</td>
<td></td>
</tr>
<tr>
<td>5-6</td>
<td>92%</td>
<td>86%</td>
<td></td>
</tr>
<tr>
<td>6-7</td>
<td>92%</td>
<td>83%</td>
<td></td>
</tr>
<tr>
<td>7-8</td>
<td>90%</td>
<td>80%</td>
<td></td>
</tr>
<tr>
<td>8-9</td>
<td>87%</td>
<td>74%</td>
<td></td>
</tr>
<tr>
<td>9-10</td>
<td>83%</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>10-11</td>
<td>78%</td>
<td>65%</td>
<td></td>
</tr>
<tr>
<td>11-12</td>
<td>70%</td>
<td>58%</td>
<td></td>
</tr>
<tr>
<td>12-13</td>
<td>59%</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>13-14</td>
<td>48%</td>
<td>34%</td>
<td></td>
</tr>
<tr>
<td>14-15</td>
<td>27%</td>
<td>26%</td>
<td></td>
</tr>
<tr>
<td>15-16</td>
<td>20%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>16-17</td>
<td>12%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>17-18</td>
<td>6%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>18-19</td>
<td>4%</td>
<td>4%</td>
<td></td>
</tr>
</tbody>
</table>

8.3.5 Well-to-tank emission factors

Whilst both the car and LCV CO\textsubscript{2} Regulations are focused on tank-to-wheel CO\textsubscript{2} emissions (i.e. the regulatory metric and the fleet-average targets are expressed purely in terms of tailpipe CO\textsubscript{2} emissions), the overall impacts will affect total well-to-wheel emissions. Hence, the analysis carried out in this study was designed to cover both tank-to-wheel and well-to-tank emissions in order to provide this level of coverage. The

An approach for tank-to-wheel emissions has been covered in Sections 8.1 and 8.2; for well-to-tank emissions, data was gathered from the latest JEC Consortium study on well-to-wheels analysis of fuels and powertrains (JEC, 2014). Well-to-tank emissions factors for petrol, diesel, natural gas and LPG were taken from the JEC study and used in this evaluation. The emissions factors used are presented in the table below.

Table 8-12: Well-to-tank emission factors

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Well-to-tank emission factor (gCO₂e/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>13.8</td>
</tr>
<tr>
<td>Diesel</td>
<td>15.4</td>
</tr>
<tr>
<td>Natural gas</td>
<td>13.0</td>
</tr>
<tr>
<td>LPG</td>
<td>8.0</td>
</tr>
</tbody>
</table>

8.3.6 EU-average pre-tax and post-tax fuel prices covering 2006 to 2013

Pre-tax and post-tax fuel prices were needed in order to analyse the economic impacts of the Regulations and to answer the questions on how efficient the Regulations have been. Fuel prices covering the period of interest were obtained from the European Commission’s EU Oil Bulletin (European Commission, 2006-2014). The EU Oil Bulletin provides detailed prices covering each week in any given year of interest. The weekly figures were averaged to provide annual average prices for the 2006-2013 time period, and were also adjusted for inflation so that all prices were presented in a common reporting year (i.e. 2014 prices). Total fuel costs for each year were calculated using fuel consumption factors (in litres per kilometre) derived from the real-world CO₂ emissions factors, vehicle activity data (average kilometres travelled per vehicle per year) and numbers of vehicles in the fleet affected by the Regulations. Changes in taxation revenues were calculated by subtracting total pre-tax fuel costs from total post-tax fuel costs for each year of interest. The fuel prices for each year are presented in the tables below.

Table 8-13: Average EU fuel prices (excluding taxes), 2006-2013

<table>
<thead>
<tr>
<th>Year</th>
<th>Petrol (€)</th>
<th>Diesel (€)</th>
<th>LPG (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>0.557</td>
<td>0.604</td>
<td>0.426</td>
</tr>
<tr>
<td>2007</td>
<td>0.558</td>
<td>0.591</td>
<td>0.419</td>
</tr>
<tr>
<td>2008</td>
<td>0.610</td>
<td>0.741</td>
<td>0.467</td>
</tr>
<tr>
<td>2009</td>
<td>0.454</td>
<td>0.482</td>
<td>0.336</td>
</tr>
<tr>
<td>2010</td>
<td>0.567</td>
<td>0.595</td>
<td>0.421</td>
</tr>
<tr>
<td>2011</td>
<td>0.673</td>
<td>0.735</td>
<td>0.481</td>
</tr>
<tr>
<td>2012</td>
<td>0.738</td>
<td>0.788</td>
<td>0.499</td>
</tr>
<tr>
<td>2013</td>
<td>0.697</td>
<td>0.740</td>
<td>0.478</td>
</tr>
</tbody>
</table>
Table 8-14: Average EU fuel prices (including taxes), 2006-2013

<table>
<thead>
<tr>
<th>Year</th>
<th>Petrol (€)</th>
<th>Diesel (€)</th>
<th>LPG (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>1.455</td>
<td>1.292</td>
<td>0.671</td>
</tr>
<tr>
<td>2007</td>
<td>1.459</td>
<td>1.279</td>
<td>0.654</td>
</tr>
<tr>
<td>2008</td>
<td>1.476</td>
<td>1.428</td>
<td>0.703</td>
</tr>
<tr>
<td>2009</td>
<td>1.273</td>
<td>1.111</td>
<td>0.540</td>
</tr>
<tr>
<td>2010</td>
<td>1.437</td>
<td>1.262</td>
<td>0.648</td>
</tr>
<tr>
<td>2011</td>
<td>1.563</td>
<td>1.435</td>
<td>0.720</td>
</tr>
<tr>
<td>2012</td>
<td>1.656</td>
<td>1.524</td>
<td>0.746</td>
</tr>
<tr>
<td>2013</td>
<td>1.597</td>
<td>1.463</td>
<td>0.719</td>
</tr>
</tbody>
</table>

8.3.7 Data on market penetration of CO\(_2\) abatement technologies

In order to estimate the costs to manufacturers associated with applying CO\(_2\) abatement technologies to cars and LCVs for meeting the Regulatory CO\(_2\) targets, it was necessary to obtain data on actual market penetration of the various technologies and compare this to a counterfactual baseline scenario for technology deployment if the Regulations had not been introduced. As part of a separate study for the European Commission on vehicle technology costs for the European Commission (Ricardo-AEA et al, forthcoming), data on the market penetration of the relevant technologies was gathered. These data, covering 2002, 2010 and 2013 were used to estimate the levels of technology penetration for the outturn scenarios for cars and LCVs. For all intervening years, estimates of market penetration were developed by interpolation, assuming that the adoption rates between 2002 and 2010, and between 2010 and 2013 for each technology are linear. This is a simplification, but was necessary given the absence of any other data on actual market adoption rates.

For the baseline counterfactual scenario, it was necessary to make assumptions about the levels of market penetration in each year, given that there is no data on what would have happened in the absence of the Regulations. These assumptions, by their very nature, will be imperfect as it is not possible to know for sure what would have happened in the absence of the Regulations.

For passenger cars, it was assumed that the market penetration of technologies between 2002 and 2006 was the same in the baseline as in the outturn scenario, but that after 2006, the levels of technology adoption would have been lower. Technology adoption rates for the period between 2006 and 2013 were scaled in accordance with the assumed rate of CO\(_2\) reduction for the baseline scenarios. For cars, the baseline assumes that NEDC CO\(_2\) emissions reduce by 0.5 gCO\(_2\)/km per year between 2006 and 2013, which is around 16% of the actual CO\(_2\) reductions achieved over the same time period with the Regulation in place. For LCVs, the baseline counterfactual scenario assumes that without the Regulation, CO\(_2\) emissions would have remained flat between 2010 and 2013, and hence for the baseline it was assumed that the market penetration of CO\(_2\) abatement technologies in LCVs did not change over this time period.

Table 8-15 to Table 8-18 provide details of the baseline and counterfactual scenarios for market penetration of abatement technologies for passenger cars and LCVs. These scenarios were used in conjunction with the data on new vehicle registrations (Section 8.3.2) for each year to quantify the numbers of vehicles entering the fleet equipped with each type of technology. These vehicle numbers were then used in conjunction with
estimates of the unit costs of each technology in order to estimate the total costs to manufacturers associated with meeting the car and LCV CO₂ targets.
## Table 8-15: Outturn market penetration of CO₂ abatement technologies in new passenger cars

<table>
<thead>
<tr>
<th>Vehicle technology</th>
<th>Market penetration (percentage of new cars equipped with each technology by year of registration)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
</tr>
<tr>
<td>Gasoline - Gas wall heat transfer reduction</td>
<td>5.0%</td>
</tr>
<tr>
<td>Gasoline - direct injection (homogeneous and stratified charge)</td>
<td>1.7%</td>
</tr>
<tr>
<td>Gasoline - Downsizing and turbocharging</td>
<td>34.1%</td>
</tr>
<tr>
<td>Gasoline - Variable Valve Actuation and Lift</td>
<td>7.2%</td>
</tr>
<tr>
<td>Gasoline - Cam phasing</td>
<td>42.7%</td>
</tr>
<tr>
<td>Gasoline - low friction design and materials</td>
<td>34.1%</td>
</tr>
<tr>
<td>Gasoline - cylinder deactivation</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - 6-speed dual clutch transmission</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - automated manual transmission</td>
<td>2.2%</td>
</tr>
<tr>
<td>Gasoline - CVT</td>
<td>1.3%</td>
</tr>
<tr>
<td>Gasoline - Belt alternator starter HEV (micro-hybrid)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Belt-driven starter generator start-stop system</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - mild hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Power split hybrid</td>
<td>0.1%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (replacing uncooled)</td>
<td>3.7%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (no EGR in baseline)</td>
<td>3.7%</td>
</tr>
<tr>
<td>Gasoline - Electrical air conditioning (auxiliary system improvement)</td>
<td>4.9%</td>
</tr>
<tr>
<td>Gasoline - Electric / electro-hydraulic power steering</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - downsizing</td>
<td>12.4%</td>
</tr>
</tbody>
</table>
### Market penetration (percentage of new cars equipped with each technology by year of registration)

<table>
<thead>
<tr>
<th>Vehicle technology</th>
<th>2002</th>
<th>2006</th>
<th>2010</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel - advanced high pressure fuel injection</td>
<td>5.0%</td>
<td>27.5%</td>
<td>50.0%</td>
<td>66.9%</td>
</tr>
<tr>
<td>Diesel - VVT</td>
<td>0.0%</td>
<td>4.9%</td>
<td>9.8%</td>
<td>10.3%</td>
</tr>
<tr>
<td>Diesel - high pressure, low pressure cooled EGR</td>
<td>0.0%</td>
<td>0.5%</td>
<td>1.0%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Diesel - automated manual transmission</td>
<td>1.5%</td>
<td>2.1%</td>
<td>2.6%</td>
<td>3.6%</td>
</tr>
<tr>
<td>Diesel - CVT</td>
<td>0.7%</td>
<td>1.2%</td>
<td>1.6%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Diesel - dry 6-speed dual clutch transmission</td>
<td>0.0%</td>
<td>2.8%</td>
<td>5.5%</td>
<td>12.5%</td>
</tr>
<tr>
<td>Diesel - Belt alternator starter HEV (micro-hybrid)</td>
<td>0.0%</td>
<td>0.2%</td>
<td>0.4%</td>
<td>6.5%</td>
</tr>
<tr>
<td>Diesel - Belt-driven starter generator start-stop system</td>
<td>0.0%</td>
<td>11.3%</td>
<td>22.6%</td>
<td>55.2%</td>
</tr>
<tr>
<td>Diesel - mild hybrid</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Power split hybrid</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Diesel - Electrical air conditioning (auxiliary system improvement)</td>
<td>6.0%</td>
<td>28.0%</td>
<td>50.0%</td>
<td>66.5%</td>
</tr>
<tr>
<td>Diesel - Electric / electro-hydraulic power steering</td>
<td>0.0%</td>
<td>43.3%</td>
<td>86.6%</td>
<td>87.6%</td>
</tr>
<tr>
<td>Weight reduction - whole vehicle: At least 2.5% reduction</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 5% reduction</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>52.2%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 7.5% reduction</td>
<td>0.0%</td>
<td>0.2%</td>
<td>0.3%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 10% reduction</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Aerodynamic improvements - mild</td>
<td>0.0%</td>
<td>14.1%</td>
<td>28.1%</td>
<td>41.5%</td>
</tr>
<tr>
<td>Aerodynamic improvements - strong</td>
<td>0.0%</td>
<td>4.4%</td>
<td>8.8%</td>
<td>25.1%</td>
</tr>
<tr>
<td>Low rolling resistance tyres</td>
<td>0.0%</td>
<td>6.1%</td>
<td>12.2%</td>
<td>29.8%</td>
</tr>
</tbody>
</table>
Table 8-16: Baseline counterfactual market penetration of CO₂ abatement technologies in new passenger cars

<table>
<thead>
<tr>
<th>Vehicle technology</th>
<th>Market penetration (percentage of new cars equipped with each technology by year of registration)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
</tr>
<tr>
<td>Gasoline - Gas wall heat transfer reduction</td>
<td>5.0%</td>
</tr>
<tr>
<td>Gasoline - direct injection (homogeneous and stratified charge)</td>
<td>1.7%</td>
</tr>
<tr>
<td>Gasoline - Downsizing and turbocharging</td>
<td>34.1%</td>
</tr>
<tr>
<td>Gasoline - Variable Valve Actuation and Lift</td>
<td>7.2%</td>
</tr>
<tr>
<td>Gasoline - Cam phasing</td>
<td>42.7%</td>
</tr>
<tr>
<td>Gasoline - low friction design and materials</td>
<td>34.1%</td>
</tr>
<tr>
<td>Gasoline - cylinder deactivation</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - 6-speed dual clutch transmission</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - automated manual transmission</td>
<td>2.2%</td>
</tr>
<tr>
<td>Gasoline - CVT</td>
<td>1.3%</td>
</tr>
<tr>
<td>Gasoline - Belt alternator starter HEV (micro-hybrid)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Belt-driven starter generator start-stop system</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - mild hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Power split hybrid</td>
<td>0.1%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (replacing uncooled)</td>
<td>3.7%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (no EGR in baseline)</td>
<td>3.7%</td>
</tr>
<tr>
<td>Gasoline - Electrical air conditioning (auxiliary system improvement)</td>
<td>4.9%</td>
</tr>
<tr>
<td>Gasoline - Electric / electro-hydraulic power steering</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - downsizing</td>
<td>12.4%</td>
</tr>
</tbody>
</table>
### Vehicle technology

<table>
<thead>
<tr>
<th></th>
<th>Market penetration (percentage of new cars equipped with each technology by year of registration)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
</tr>
<tr>
<td>Diesel - advanced high pressure fuel injection</td>
<td>5.0%</td>
</tr>
<tr>
<td>Diesel - VVTI</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - high pressure, low pressure cooled EGR</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - automated manual transmission</td>
<td>1.5%</td>
</tr>
<tr>
<td>Diesel - CVT</td>
<td>0.7%</td>
</tr>
<tr>
<td>Diesel - dry 6-speed dual clutch transmission</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Belt alternator starter HEV (micro-hybrid)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Belt-driven starter generator start-stop system</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - mild hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Power split hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Electrical air conditioning (auxiliary system improvement)</td>
<td>6.0%</td>
</tr>
<tr>
<td>Diesel - Electric / electro-hydraulic power steering</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction - whole vehicle: At least 2.5% reduction</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 5% reduction</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 7.5% reduction</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 10% reduction</td>
<td>0.0%</td>
</tr>
<tr>
<td>Aerodynamic improvements - mild</td>
<td>0.0%</td>
</tr>
<tr>
<td>Aerodynamic improvements - strong</td>
<td>0.0%</td>
</tr>
<tr>
<td>Low rolling resistance tyres</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
Table 8-17: Outturn market penetration of CO₂ abatement technologies in new LCVs

<table>
<thead>
<tr>
<th>Vehicle technology</th>
<th>Market penetration (percentage of new cars equipped with each technology by year of registration)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
</tr>
<tr>
<td>Gasoline - Gas wall heat transfer reduction</td>
<td>5.0%</td>
</tr>
<tr>
<td>Gasoline - direct injection (homogeneous and stratified charge)</td>
<td>1.7%</td>
</tr>
<tr>
<td>Gasoline - Downsizing and turbocharging</td>
<td>17.8%</td>
</tr>
<tr>
<td>Gasoline - Variable Valve Actuation and Lift</td>
<td>2.6%</td>
</tr>
<tr>
<td>Gasoline - Cam phasing</td>
<td>47.8%</td>
</tr>
<tr>
<td>Gasoline - low friction design and materials</td>
<td>17.8%</td>
</tr>
<tr>
<td>Gasoline - cylinder deactivation</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - 6-speed dual clutch transmission</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - automated manual transmission</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - CVT</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Belt alternator starter HEV (micro-hybrid)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Belt-driven starter generator start-stop system</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - mild hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Power split hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (replacing uncooled)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (no EGR in baseline)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Electrical air conditioning (auxiliary system improvement)</td>
<td>4.9%</td>
</tr>
<tr>
<td>Gasoline - Electric / electro-hydraulic power steering</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - downsizing</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
### Evaluation of Regulations 443/2009 and 510/2011 on CO₂ emissions from light-duty vehicles

#### Market penetration (percentage of new cars equipped with each technology by year of registration)

<table>
<thead>
<tr>
<th>Vehicle technology</th>
<th>2002</th>
<th>2006</th>
<th>2010</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel - advanced high pressure fuel injection</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - VVTl</td>
<td>0.0%</td>
<td>4.2%</td>
<td>8.4%</td>
<td>11.7%</td>
</tr>
<tr>
<td>Diesel - high pressure, low pressure cooled EGR</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - automated manual transmission</td>
<td>2.2%</td>
<td>2.1%</td>
<td>2.0%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Diesel - CVT</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - dry 6-speed dual clutch transmission</td>
<td>0.2%</td>
<td>1.2%</td>
<td>2.1%</td>
<td>3.9%</td>
</tr>
<tr>
<td>Diesel - Belt alternator starter HEV (micro-hybrid)</td>
<td>0.0%</td>
<td>0.5%</td>
<td>1.0%</td>
<td>8.6%</td>
</tr>
<tr>
<td>Diesel - Belt-driven starter generator start-stop system</td>
<td>0.0%</td>
<td>8.2%</td>
<td>16.4%</td>
<td>28.7%</td>
</tr>
<tr>
<td>Diesel - mild hybrid</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Power split hybrid</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Diesel - Electrical air conditioning (auxiliary system improvement)</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Electric / electro-hydraulic power steering</td>
<td>0.0%</td>
<td>7.8%</td>
<td>15.5%</td>
<td>40.6%</td>
</tr>
<tr>
<td>Weight reduction - whole vehicle: At least 2.5% reduction</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 5% reduction</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 7.5% reduction</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 10% reduction</td>
<td>0.0%</td>
<td>1.8%</td>
<td>3.5%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Aerodynamic improvements - mild</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Aerodynamic improvements - strong</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Low rolling resistance tyres</td>
<td>0.0%</td>
<td>2.9%</td>
<td>5.7%</td>
<td>12.0%</td>
</tr>
</tbody>
</table>
### Table 8-18: Baseline counterfactual market penetration of CO₂ abatement technologies in new LCVs

<table>
<thead>
<tr>
<th>Vehicle technology</th>
<th>Market penetration (percentage of new cars equipped with each technology by year of registration)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
</tr>
<tr>
<td>Gasoline - Gas wall heat transfer reduction</td>
<td>5.0%</td>
</tr>
<tr>
<td>Gasoline - direct injection (homogeneous and stratified charge)</td>
<td>1.7%</td>
</tr>
<tr>
<td>Gasoline - Downsizing and turbocharging</td>
<td>17.8%</td>
</tr>
<tr>
<td>Gasoline - Variable Valve Actuation and Lift</td>
<td>2.6%</td>
</tr>
<tr>
<td>Gasoline - Cam phasing</td>
<td>47.8%</td>
</tr>
<tr>
<td>Gasoline - low friction design and materials</td>
<td>17.8%</td>
</tr>
<tr>
<td>Gasoline - cylinder deactivation</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - 6-speed dual clutch transmission</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - automated manual transmission</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - CVT</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Belt alternator starter HEV (micro-hybrid)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Belt-driven starter generator start-stop system</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - mild hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Power split hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (replacing uncooled)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (no EGR in baseline)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Gasoline - Electrical air conditioning (auxiliary system improvement)</td>
<td>4.9%</td>
</tr>
<tr>
<td>Gasoline - Electric / electro-hydraulic power steering</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - downsizing</td>
<td>0.0%</td>
</tr>
<tr>
<td>Vehicle technology</td>
<td>Market penetration (percentage of new cars equipped with each technology by year of registration)</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>2002</td>
</tr>
<tr>
<td>Diesel - advanced high pressure fuel injection</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - VVT</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - high pressure, low pressure cooled EGR</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - automated manual transmission</td>
<td>2.2%</td>
</tr>
<tr>
<td>Diesel - CVT</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - dry 6-speed dual clutch transmission</td>
<td>0.2%</td>
</tr>
<tr>
<td>Diesel - Belt alternator starter HEV (micro-hybrid)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Belt-driven starter generator start-stop system</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - mild hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Power split hybrid</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Electrical air conditioning (auxiliary system improvement)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Diesel - Electric / electro-hydraulic power steering</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction - whole vehicle: At least 2.5% reduction</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 5% reduction</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 7.5% reduction</td>
<td>0.0%</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 10% reduction</td>
<td>0.0%</td>
</tr>
<tr>
<td>Aerodynamic improvements - mild</td>
<td>0.0%</td>
</tr>
<tr>
<td>Aerodynamic improvements - strong</td>
<td>0.0%</td>
</tr>
<tr>
<td>Low rolling resistance tyres</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
8.3.8 Data on vehicle technology costs

Technology cost data was required in order to assess the overall costs of meeting the regulatory targets and, specifically, the costs to manufacturers associated with the Regulations. Cost data were gathered from a number of sources including work carried out by Ricardo-AEA for the European Commission (Ricardo-AEA et al., forthcoming), analysis carried out for ICCT by the consulting firm FEV (FEV, 2013), and from other sources including research by the National Research Council of the US National Academies (National Academies, 2011). As discussed in the previous section, technology cost data was used in conjunction with outturn and baseline counterfactual data on market penetration of each technology and information on the numbers of new vehicles entering the fleet each year in order to calculate the costs to manufacturers associated with meeting the CO₂ targets for cars and LCVs.
Table 8-19: Technology cost data

<table>
<thead>
<tr>
<th>Vehicle technology</th>
<th>Technology cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small cars</td>
</tr>
<tr>
<td>Gasoline - Gas wall heat transfer reduction</td>
<td>50</td>
</tr>
<tr>
<td>Gasoline - direct injection (homogeneous and stratified charge)</td>
<td>183</td>
</tr>
<tr>
<td>Gasoline - Downsizing and turbocharging</td>
<td>240</td>
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<tr>
<td>Gasoline - Variable Valve Actuation and Lift</td>
<td>140</td>
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<tr>
<td>Gasoline - Cam phasing</td>
<td>81</td>
</tr>
<tr>
<td>Gasoline - low friction design and materials</td>
<td>28</td>
</tr>
<tr>
<td>Gasoline - cylinder deactivation</td>
<td>172</td>
</tr>
<tr>
<td>Gasoline - 6-speed dual clutch transmission</td>
<td>442</td>
</tr>
<tr>
<td>Gasoline - automated manual transmission</td>
<td>72</td>
</tr>
<tr>
<td>Gasoline - CVT</td>
<td>72</td>
</tr>
<tr>
<td>Gasoline - Belt alternator starter HEV (micro-hybrid)</td>
<td>580</td>
</tr>
<tr>
<td>Gasoline - Belt-driven starter generator start-stop system</td>
<td>135</td>
</tr>
<tr>
<td>Gasoline - mild hybrid</td>
<td>1626</td>
</tr>
<tr>
<td>Gasoline - Power split hybrid</td>
<td>4748</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (replacing uncooled)</td>
<td>62</td>
</tr>
<tr>
<td>Gasoline cooled low pressure EGR (no EGR in baseline)</td>
<td>105</td>
</tr>
<tr>
<td>Gasoline - Electrical air conditioning (auxiliary system improvement)</td>
<td>184</td>
</tr>
<tr>
<td>Vehicle technology</td>
<td>Technology cost</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td></td>
<td>Small cars</td>
</tr>
<tr>
<td>Gasoline - Electric / electro-hydraulic power steering</td>
<td>60</td>
</tr>
<tr>
<td>Diesel - downsizing</td>
<td>-125</td>
</tr>
<tr>
<td>Diesel - advanced high pressure fuel injection</td>
<td>14</td>
</tr>
<tr>
<td>Diesel - VVTL</td>
<td>138</td>
</tr>
<tr>
<td>Diesel - high pressure, low pressure cooled EGR</td>
<td>124</td>
</tr>
<tr>
<td>Diesel - automated manual transmission</td>
<td>72</td>
</tr>
<tr>
<td>Diesel - CVT</td>
<td>72</td>
</tr>
<tr>
<td>Diesel - dry 6-speed dual clutch transmission</td>
<td>402</td>
</tr>
<tr>
<td>Diesel - Belt alternator starter HEV (micro-hybrid)</td>
<td>448</td>
</tr>
<tr>
<td>Diesel - Belt-driven starter generator start-stop system</td>
<td>589</td>
</tr>
<tr>
<td>Diesel - mild hybrid</td>
<td>1626</td>
</tr>
<tr>
<td>Diesel - Power split hybrid</td>
<td>4748</td>
</tr>
<tr>
<td>Diesel - Electrical air conditioning (auxiliary system improvement)</td>
<td>184</td>
</tr>
<tr>
<td>Diesel - Electric / electro-hydraulic power steering</td>
<td>60</td>
</tr>
<tr>
<td>Weight reduction - whole vehicle: At least 2.5% reduction</td>
<td>0</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 5% reduction</td>
<td>0</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 7.5% reduction</td>
<td>0</td>
</tr>
<tr>
<td>Weight reduction on whole vehicle: At least 10% reduction</td>
<td>31</td>
</tr>
<tr>
<td>Aerodynamic improvements - mild</td>
<td>53</td>
</tr>
</tbody>
</table>
### Evaluation of Regulations 443/2009 and 510/2011 on CO₂ emissions from light-duty vehicles

<table>
<thead>
<tr>
<th>Vehicle technology</th>
<th>Technology cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small cars</td>
</tr>
<tr>
<td>Aerodynamic improvements - strong</td>
<td>172</td>
</tr>
<tr>
<td>Low rolling resistance tyres</td>
<td>33</td>
</tr>
</tbody>
</table>
9 Annex C: Issues affecting the design of the Regulations

This Annex contains more detail on the aspects of the Regulations that potentially contradict the principles of cost-effectiveness and technological neutrality, i.e.:

- Choice of the utility parameter, which is relevant in the context of both cost-effectiveness and technological neutrality;
- The assumptions about annual mileages; and
- The treatment of vehicles with alternative powertrains.

9.1 Choice of utility parameter

As noted in Section 2.4, both LDV CO₂ Regulations relate a vehicle’s CO₂ emissions to a measure of a vehicle’s utility and in both cases ‘mass’ was chosen as the utility parameter. This means that each manufacturer’s CO₂ emissions target in any one given year is a function of the average mass of its new vehicle fleet. However, ‘mass’ was only one of many utility parameters that were considered in the studies that supported the development of the Regulations (see, for example, IEEP et al, 2005).

By the time of the Commission’s proposal for the passenger car CO₂ Regulation in 2007, the utility parameters considered the most promising were ‘mass’ (defined as the mass in running order and measured in kg) and ‘footprint’, which is defined as ‘wheelbase’ multiplied by ‘track width’ and is measured in m². The European Commission’s Impact Assessment accompanying the proposal concluded that ‘mass’ should be chosen as the utility parameter for the Regulation ahead of ‘footprint’ as it scored better on a number of assessment criteria, i.e. “data availability”, “understandability” and “international compatibility”. On the other hand, ‘footprint’ was considered to be a better measure of the actual utility of a car, to be less likely to cause perverse effects and not to discriminate against some CO₂ reduction options (i.e. those that reduce weight). Largely as a result of the lack of data, mass was chosen to be the utility parameter relative to which manufacturers’ CO₂ reduction targets would be met (European Commission, 2007b).

For the 2020 targets, the retention of ‘mass’ as the utility parameter was justified on the basis of certainty, as manufacturers would have planned their compliance pathways to 2020 on the basis of ‘mass’ being the utility parameter, and of a more even distribution of costs between segments. It was, however, noted that ‘mass’ did not treat all CO₂ reduction options (particularly those that reduce weight) equally and that ‘footprint’ was more cost-effective (European Commission, 2012). This reflected the issues raised in the supporting study (TNO et al, 2011).

It is worth noting that two of the three original arguments in favour of ‘mass’ as the utility parameter are no longer valid. The relevant data to calculate ‘footprint’ are now collated as part of the monitoring requirements of both LDV CO₂ Regulations, so these data are now available. In the US, Canada and Mexico, ‘footprint’ is used as a utility parameter in LDV fuel efficiency legislation, so ‘mass’ can no longer be viewed as “internationally incompatible”.

For LCVs, the use of ‘pan area’ was considered along with ‘mass’ in the Impact Assessment that accompanied the original proposal, but again ‘mass’ was chosen as the utility parameter for LCVs for reasons of data availability and practicality (European Commission, 2009b). For the proposal to confirm the 2020 CO₂ targets for LCVs, an assessment was again undertaken as to the most appropriate utility parameter for LCVs, but this time the analysis compared ‘mass’ to ‘footprint’. It was concluded that average costs under both were similar, while the choice between the two parameters had no
significant direct environmental or social impacts. ‘Mass’ was considered to be the preferred option, as with ‘footprint’ there was an increased risk of perverse incentives, a large distributional impact and a need to use a non-linear limit function (European Commission, 2012). In the supporting study, TNO et al (2012) had concluded that ‘mass’ was a better utility parameter for LCVs than either ‘footprint’ or ‘payload’, as it correlated better with CO₂ and had less potential for gaming.

The choice of utility parameter for the passenger car CO₂ Regulation, has been the subject of much debate since the Regulation came into force (e.g. ICCT, 2011). The main argument has centred on the relative cost-effectiveness of ‘mass’ compared to ‘footprint’ as the utility parameter, particularly in relation to technological options that reduce the weight of a vehicle. Although, often mentioned as a secondary point, this also raises issues of the technological neutrality of the current utility parameter. It is important to underline that both of these issues where already raised in the respective impact assessments, as noted above.

From a mathematical perspective, it is clear that, if the average mass of a manufacturer’s new fleet declines, the manufacturer would be closer to its CO₂ emissions target if ‘footprint’ was the utility parameter than when ‘mass’ is the utility parameter (Ricardo-AEA et al, 2015). This is because when ‘mass’ is the utility parameter, the manufacturer’s position relative to the target line changes both horizontally to the left as well as vertically downwards (see Figure 9-1).

**Figure 9-1: Change in position of an ‘average’ manufacturer relative to the target line, where ‘mass’ is the utility parameter (resulting from a 10% decline in the average mass of the manufacturer)**

![Figure 9-1: Change in position of an ‘average’ manufacturer relative to the target line, where ‘mass’ is the utility parameter (resulting from a 10% decline in the average mass of the manufacturer)](source: Developed from graphs presented in Ricardo-AEA et al (2015))

On the other hand, if ‘footprint’ was the utility parameter the manufacturer’s position would only change vertically downwards (see Figure 9-2). Both of these figures assume that the only action taken to reduce CO₂ emissions is weight reduction in order to illustrate the point.
Figure 9-2: Change in position of an ‘average’ manufacturer relative to the target line, where ‘footprint’ is the utility parameter (resulting from a 10% decline in the average mass of the manufacturer)

Source: Developed from graphs presented in Ricardo-AEA et al (2015)

Under the assumptions used in Ricardo-AEA et al (2015), if ‘footprint’ was the utility parameter, an average manufacturer would be 8.7 gCO₂/km closer to its target as a result of a weight reduction of 10%, whereas if ‘mass’ was the utility parameter, the same 10% reduction would only move the same manufacturer 4 gCO₂/km closer to its target. Hence, if ‘footprint’ was the utility parameter, manufacturers would benefit in full from the application of weight reduction technologies in terms of moving closer to their targets, unlike the case where ‘mass’ is the utility parameter.

As the costs would be the same in each case, then clearly, from a mathematical perspective, ‘footprint’ is more cost-effective from the manufacturers’ perspective as the cost of a gram of CO₂ reduction is less than it would be if ‘mass’ was the utility parameter. Consequently, from a manufacturers’ perspective, when ‘mass’ is the utility parameter weight reduction options would be farther down the list of cost-effective options to implement than they would have been in a ‘footprint’-based system. This brings into question the technological neutrality of the existing approach.

Ricardo-AEA et al (2015) estimated that, if available weight reductions technologies were applied to cars (in the context of a hypothetical post 2020 target), all but one manufacturer would face costs that were between 8% and 20% lower under a footprint-based system compared to a system where ‘mass’ was the utility parameter. However, the stakeholder engagement that was undertaken as part of the development of the report showed that many manufacturers supported the retention of ‘mass’ as the utility parameter – in spite of the issues discussed above.

9.2 Assumptions about annual vehicle mileage

As noted in Section 7.3, diesel cars are on average driven further than petrol cars, while the heavier and larger petrol cars are on average driven farther than lighter and smaller petrol cars. The first difference was recognised in the development of the passenger car CO₂ Regulation, as a higher annual mileage figure – 16,000 km – was assumed for diesel cars than petrol cars (i.e. 14,000 km). These numbers were used in relation to the
supporting analysis, e.g. particularly in relation to the cost-effectiveness of the Regulations. However, the analysis supporting the development of the Regulations did not take account of the differences in the distance travelled between small and large petrol vehicles. Furthermore, the average annual distances used in the analysis supporting the Regulations were marginally less than those suggested by other datasets for diesel, but greater than those suggested by other datasets for petrol. For example, the average annual distance for a medium-sized petrol car over the first 10 years of its life was estimated to be just over 12,300 km instead of the 14,000 km used for the Regulation (Ricardo-AEA & TEPR, 2014).

Ricardo-AEA and TEPR (2014) also estimated the impacts on cost-effectiveness if the targets in the Regulations were weighted by the lifetime distances that vehicles were expected to be used. As there were no size-related differences identified for LCVs (see Section 7.3), this analysis was only undertaken for cars. Mileage-weighting in this case could be implemented, for each manufacturer, by weighting the CO₂ emissions of each type of car, not just by sales, as is currently the case in Annex I of the Regulation, but also by the distance that a car of that type typically travels. This has the effect of imposing a proportionately more stringent target on larger (or heavier) vehicles in recognition of the relationships between vehicle footprint (or mass) and lifetime mileage discussed that had been identified in the report. This analysis suggested that the introduction of a mileage-weighted system of this form into a post-2020 Regulation would reduce the overall fleet-wide cost of achieving the same CO₂ reduction whether ‘mass’ was retained as a utility parameter or ‘footprint’ was used instead. Indeed the reduction in costs would be marginally greater – at 1.75% – in the case where ‘mass’ was the utility parameter than when ‘footprint’ was, in which case the cost saving was 1.62%.

9.3 Treatment of vehicles with alternative powertrains

As discussed in Sections 3.4.1 and 7.4, for vehicles that use alternative powertrains, such as BEVs, FCEVs and to a lesser extent PHEVs, the CO₂ emissions associated with the production of electricity or hydrogen are not currently taken account of by the Regulations, as these emissions cannot be measured on the test cycle. Additionally, as noted in Section 2.4, the provisions relating to super-credits further incentivise the introduction of these vehicles onto the market.

While on balance these vehicles do generally have fewer CO₂ emissions associated with their lifetime use (i.e. including the generation of energy and the production of the vehicles; see Section 7.5), the existence of these incentives means that these vehicles are incentivised more by the Regulations than would be justified on the basis of their WTW CO₂ emissions. This raises questions about the Regulations’ technological neutrality in this respect. Issues of technological neutrality will also be important when considering how best to include WTT CO₂ emissions in the Regulations (TNO et al, 2013).
10 Annex D: Evidence relating to the need for the CO₂ performance of new vehicles to improve at a faster rate under ‘relevance’

This Annex contains further detailed evidence as to whether the need for the CO₂ emissions performance of new vehicles to improve at a faster rate is still relevant (see Section 5.1.3).

The “EU Transport GHG: Routes to 2050 II” project undertaken for DG Climate Action developed a series of scenarios to explore the importance of specific policy instruments in meeting the targets set out in the Transport White Paper (see Section □). The baseline for these scenarios, which is presented in Figure 10-1 demonstrated that under business as usual (BAU), i.e. no additional measures for transport including no continuation of the Regulations beyond 2020, the White Paper’s 2050 target would not be met. Indeed the total GHG emissions from cars and LCVs in 2050 under the BAU would account for virtually all of the GHG emissions that would be allowed from transport if the 2050 target is to be met. This would mean that emissions from other transport modes would have to be virtually zero by 2050 if no further measures were put in place to reduce GHG emissions from cars and LCVs. The baseline presented in Figure 10-1 takes account of the trends presented in Figure 3-2 and Figure 3-4, i.e. that the use of cars, and the CO₂ emissions of road transport, had begun to decline. The latter was largely due to the implementation of the 2020/2021 targets in the LDV CO₂ Regulations (AEA et al, 2012b).

Figure 10-1: Business as usual (BAU) for transport’s lifetime GHG emissions developed in the “EU Transport GHG: Routes to 2050 II” project

Source: (AEA et al, 2012b)
Notes: The ‘Total WP Targets’ points represent the emissions implied by the targets of reducing maritime GHG emissions by 40% by 2050, as well as the targets for the rest of transport in 2030 and 2050. The error bars on these points represent the range of values for these targets that were indicated in the 2050 Roadmap (see Section 5.1).

Within the project, a scenario was developed to deliver the White Paper target, which took into account the technical potential for GHG reduction across all transport modes, as well as the potential from efficiency gains that could be made from operational
changes (see Figure 10-2). Within this scenario, there would be a reduction in lifecycle GHG emissions of 80% for both cars and LCVs by 2050 compared to 2010 (a rate of reduction of nearly 4% a year). Scenarios were also developed to test the importance of different policy instruments in obtaining the 2050 Transport White Paper reduction target. These showed that if even all of the other measures that were considered in the project – driver training, lower speed limits, modal shift, efficiency improvements in other modes and more tax harmonisation – the rates of decrease of emissions reductions from cars would still need to be 2.3% a year. This assumes that all of these other measures deliver to their maximum potential, which would lead to a significantly lower demand for transport (AEA et al, 2012b). It is important to note, however, that the latter scenario would be particularly challenging. Hence, annual rates of emissions reductions for new LCVs of more than 2.3%, and perhaps as much as 4% on average, are likely to be needed, which is a steeper rate than the Regulations would deliver if they meet their targets (see above).

Figure 10-2: Scenario for transport’s lifetime GHG emissions consistent with meeting the Commission’s Transport White Paper GHG reduction targets for 2050 developed in the “EU Transport GHG: Routes to 2050 II” project

The impact of Regulations can also be seen by looking at periods when there were no standards, as in the case of the EU prior to 2009, or where there were no improvements to existing standards, as in the US. The US Corporate Average Fuel Economy (CAFE) standards first came into force for model year 1978, with a subsequent significant improvement for model year 1985. Between 1985 and 2010, the standard remained broadly constant before new tighter standards came into force in 2010 (National Research Council of the National Academies, 2014). As can be seen in Figure 10-3, the lack of improvement in the standard for 20 years from the mid-1980s was accompanied by worsening fuel consumption in the US car fleet, which contrasts to the tightening of the standards in 1985 and the subsequent progressive tightening since 2010.
Figure 10-3: Historical and projected light duty fuel economy in the US

Source: (National Research Council of the National Academies, 2014).
Notes: All data is new fleet only using unadjusted test values, not in-use fuel consumption.
Annex E: Regression analysis and assessment of drivers of CO\textsubscript{2} emission reductions

11.1 Empirical strategy

Data from the EEA monitoring database has been analysed using a regression model that attempts to quantify the impact of the Regulation while controlling for other factors that may have an impact on new car emissions.

There are several existing studies that attempt to quantify the impact of various factors on vehicle fuel efficiency, using a range of different regression models; therefore we do not attempt to replicate this work here. However, the literature available tends to focus on older datasets (typically covering vehicle sales up to the year 2010) due to the time and cost involved in conducting such detailed studies.

Regression analysis is a statistical technique that provides a measure of the relationship among variables. Specifically, it aims to quantify how a dependent variable changes when one of the independent variables (i.e. explanatory variable) is varied while the other independent variables are held fixed.

The EEA (2014a) dataset includes annual values per Member State, for the following factors:
- Average g\textsubscript{CO\textsubscript{2}}/km;
- Average mass;
- Share of diesel cars; and
- Total new car registrations.

The data covers the period between 2001 and 2013. However, the number of Member States included varies from 14 in 2001\textsuperscript{44} to 27 since 2007. The final dataset includes a total of 264 observations after data validation checks\textsuperscript{45}.

The model is constructed as shown below:

\[
E_{it} = \alpha + \beta P_{it} + \gamma P_{it}t_{i} + \lambda t_{i} + \delta X_{it} + \theta A_{i} + \alpha_{i} + \varepsilon_{it}
\]

Where:
\(E = \text{Average g\textsubscript{CO\textsubscript{2}}/km}\)
\(i = \text{Member State } i\)
\(t = \text{year } t\)
\(\alpha = \text{constant term}\)
\(\alpha_{i} = \text{Member State fixed effect. It captures all time-invariant characteristics of the Member State, including all time-invariant characteristics determined prior to 2001.}\)
\(\beta = \text{estimated constant term for the policy (i.e. the Regulation)}\)
\(\gamma = \text{estimated annual effect of the policy (i.e. the Regulation)}\)
\(\theta = \text{estimated coefficient for the anticipation variable}\)

\textsuperscript{44} EU15 as before the 1\textsuperscript{st} May 2004 expansion, excluding Portugal.

\textsuperscript{45} The mass data for Finland, Italy, Luxembourg, Spain and Czech Republic before 2004 were considered inaccurate and had to be excluded from the analysis.

\( \lambda \) = estimated coefficient of the time trend (autonomous progress)

\( A \) = anticipation variable that captures the effect of the Regulation when it was announced but not yet adopted (a dummy variable taking value 1 in 2007 and 2008 and 0 otherwise)

\( P_t \) = policy variable (a dummy variable taking value 0 before the Regulation and 1 thereafter)

\( X_{it} \) = control variables for each Member State (new car registrations and average share of diesel cars)

\( \delta \) = a vector of estimated coefficients for the control variables

\( \epsilon_{it} \) is the error term, which is robust to heteroscedasticity\(^{46}\) and clustered on Member States in order to allow correlation between observations within each Member State.

### 11.1.1 Control variables

Ideally, data would be available to allow comparisons of observations with and without treatment. This would allow the use of “difference in difference” estimation, which attempts to mimic an experimental setting by estimating the difference in the differences between treatment groups and non-treatment groups over time. However, in this case there is no control group because the Regulation was implemented in all Member States and therefore the analysis needs to rely on the variation in the data before and after the Regulation. As a result, the selection of appropriate control variables is important.

Firstly, any variable that could also be considered an outcome variable of the Regulation is excluded. For example, manufacturers potentially decreased the mass of the vehicles to meet their targets. We tested for this effect and found a negative and statistically significant effect of the Regulation on the average mass of the vehicles. Therefore the mass was excluded from the regression because its inclusion would bias the estimated effect. On the other hand, we could not detect a significant impact of the Regulation on average share of diesel cars, so it was included in the model.

Secondly, it is not possible to include year fixed effects because the treatment (i.e. Regulation) is determined in time. Inclusion of year fixed effects would not allow the estimation of the effects of all fixed effects as well as the Regulation. Instead, a time trend was introduced to control for changes in CO₂ emissions in time not explained by the control variables, i.e. autonomous improvement.

Thirdly, omitted variables that are correlated both with the Regulation and the CO₂ emissions can introduce bias to the estimated effect of the Regulation. For example, consumers’ environmental preferences and technological development are potentially omitted variables. The trend variable likely captures the technological development to an extent, although it is not a perfect proxy. Consumer’s preferences are less clear cut. If consumer preferences have shifted towards cleaner cars, the estimated effect of the policy variable would be biased upward. A possible downward bias is introduced by the fact that the voluntary agreement had been in place prior to the introduction of the regulation. The voluntary agreement may have contributed to the downward trend in emissions observed prior to the introduction of the Regulation, hence the impact due to the Regulation is calculation in addition to this effect.

Another important question relates to the year when the policy change actually took place. The Regulation and targets were announced in 2007 but not officially adopted until 2009. Manufacturers may have started to anticipate the adoption of the Regulation

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\(^{46}\) heteroscedasticity means that the variance of the random variables is not constant.
in 2007, and therefore started to implement measures to comply with any potential future requirement. Alternatively, it is possible that manufactures preferred to maximise the revenue from their less efficient fleet by stepping up their sales until the adoption of the Regulation. Therefore, while assuming the Regulation changed in 2009, an “anticipation” variable was also introduced to capture the effect of the announcement period.

11.1.2 Model results

Two model specifications were tested and the main results are presented in the table below. The first column shows the results including the “anticipation” variable. The second column excludes the anticipation variable and tests for the effects of the Regulation after it was adopted in 2009.

Table 11-1: Results from regression analysis

<table>
<thead>
<tr>
<th></th>
<th>With anticipation</th>
<th>Without anticipation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticipation</td>
<td>-0.524 (1.034)</td>
<td></td>
</tr>
<tr>
<td>Policy2009 * Time</td>
<td>-3.501*** (0.450</td>
<td>-3.409*** (0.346)</td>
</tr>
<tr>
<td>Time</td>
<td>-1.594*** (0.346</td>
<td>-1.684*** (0.252)</td>
</tr>
<tr>
<td>Registrations</td>
<td>-0.004 (0.003)</td>
<td>-0.004 (0.003)</td>
</tr>
<tr>
<td>Share of diesel</td>
<td>-27.672*** (7.183)</td>
<td>-27.701*** (7.165)</td>
</tr>
<tr>
<td>Policy2009</td>
<td>23.402*** (2.825)</td>
<td>23.096*** (2.669)</td>
</tr>
<tr>
<td>Constant</td>
<td>187.769*** (3.668)</td>
<td>188.067*** (3.601)</td>
</tr>
<tr>
<td>Observations</td>
<td>264</td>
<td>264</td>
</tr>
</tbody>
</table>

Robust standard errors in parenthesis  
* p<0.1, ** p<0.05, *** p<0.01

The data suggests that, ceteris paribus, an annual reduction of 3.5 gCO₂/km is attributable to the Regulation while autonomous improvement is around 1.6 gCO₂/km per year. A 10 percentage point increase in the average share of diesel cars is associated with a reduction in CO₂ emissions of 2.8 g/km. However, given that the diesel share has not changed much since the introduction of the Regulation its effect on the observed reductions has been small. On the other hand, the anticipation variable and the number of cars registered annually did not have a statistically significant impact on

Note that this also includes the effect of the voluntary agreements, which could not be disaggregated in the model. Investigation of this aspect is carried out in Section 5.3.
the emissions. The findings suggest that the effects of the voluntary agreements along with autonomous improvement are together around 1.6 gCO₂/km per year.

The results of the two models thus suggest that there is a strong likelihood that the Regulation has contributed to the CO₂ reductions. However, given the limited number of control variables and data resolution available the numerical values should be interpreted with some caution. The results suggest that around two-thirds of the reductions observed since 2009 can be attributed to the Regulation and around one-third to other factors. A more detailed, qualitative exploration of factors contributing to the observed emission reductions has been undertaken in Evaluation Question 3 (Section 4.3).

The results presented here give an important insight on the likely impacts. However, there are some options for improving the analysis further. For example, inclusion of member state policies, or improved data at manufacturer level would enable exploiting the variation in the Regulatory targets by manufacturers.

11.2 Analysis of other driving forces for CO₂ emission reductions

In this section, other potential driving forces which could not be captured in the regression are discussed.

11.2.1 Voluntary agreement and autonomous improvements

Autonomous improvements are improvements that would have occurred, all other things being equal, given general improvements to knowledge, technologies and manufacturing techniques not attributable to particular policies or circumstances. The time trend assessed in the regression analysis also implicitly includes the effect of the voluntary agreement.

Generally, the assumed level of autonomous improvement used in studies is heavily dependent upon the reference period analysed. In the modelling carried out for the Regulation’s Impact Assessment (European Commission 2007) the baseline assumption was a stabilisation of CO₂ emissions at the 2006 levels (‘Baseline b1’, see European Commission (2007: 34) and IEEP et al. (2007: 8)). The regression analysis estimated that CO₂ emissions would have improved by around 1.6-1.7 gCO₂/km per year in the absence of the Regulation. This result is largely reflective of the observed 2002-2006 emission reduction trend, and hence includes the impact of the voluntary agreement.

A similar empirical analysis for LCVs was not possible given the short timescales of the available data. However, it could be expected that the CO₂ reductions in cars, along with the need for common powertrains for production cost reasons would drive the application of similar technology into LCVs (TNO et al., 2012), hence leading to some level of CO₂ reductions in LCVs in the absence of the Regulation. Prior to 2007, there was thought to be limited pressure on lowering CO₂ emissions due to a lack of legislation as well as of fiscal incentives, while between 2007 and 2010 some technological improvements were expected to have contributed to CO₂ reductions, especially due to crossovers from passenger car technologies (TNO, 2012). On the other hand, without regulatory pressure to improve CO₂ emissions, these fuel efficiency improvements may have been offset by increases in other vehicle attributes such as footprint/mass or engine power. Thus it is possible to argue that autonomous improvement in the absence of the Regulations would be either positive (decreasing CO₂) or negative (increasing CO₂). Overall, a baseline that assumes no autonomous improvement appears to be a sensible compromise, as was used in the Impact Assessment underlying the proposals for the 2020 modalities (TNO, 2012).


**11.2.2 Changes in vehicle mass**

Increases in vehicle mass would, all else being equal, lead to higher CO₂ emissions. However, mass developments cannot be considered entirely independently of the Regulations – on the one hand, mass reductions are a strategy to reduce CO₂ emissions, while on the other hand mass developments are related to the Regulation due to the mass-based utility parameter.

During the period from 2004 to 2013, the average mass of petrol vehicles overall decreased together with petrol-vehicle emissions, whereas the average mass of diesel vehicles increased despite the decrease of emissions over the same period (see Figure 11-1).

**Figure 11-1: CO₂ emissions versus vehicles' mass in the EU-27**

![CO₂ emissions versus vehicles' mass in the EU-27](Image)

*Source: (EEA, 2014)*

The most recent monitoring data shows that there has been a slight decrease of 11kg in the average mass of the passenger car fleet between 2013 and 2012 – the first decrease observed since 2009 – but overall trends indicate that average mass has increased since 2004 for all fuel types (EEA, 2014). Average vehicle mass values for the conventional passenger car and MPV (multi-purpose vehicle) segments have increased by approximately 2% between 2010 and 2012 (Ricardo-AEA et al, 2015). The impact of mass on average CO₂ emissions, calculated according to the formula \( \Delta \text{CO}_2 / \text{CO}_2 = 0.65 \Delta m/m \) in TNO (2006) is very small, estimated at only -1.1 g/km between 2013 and 2007 using the mass increase across 11 vehicle segments as provided in ICCT (2014c). This is because some vehicle types have reduced in mass over this time period, which offsets the increase in mass seen in other vehicle types.

For LCVs, using the same formula \( \Delta \text{CO}_2 / \text{CO}_2 = 0.65 \Delta m/m \), equates to a change in CO₂ emissions of around -0.7g/km between 2013 and 2010, taking data for each size class. That is, the reduction in mass of Class II vehicles seen in this period counterbalances the increase in mass seen in Class III vehicles over the same period. Since the monitoring data from the EEA only extends back to 2012, different datasets must be combined to retrieve a time series, using EEA (2014) for 2012-2013 data points and Ricardo-AEA et al (2015) and TNO, AEA. Ricardo and IHS Global Insight (2012) for earlier estimates. Hence, the estimated impact is uncertain, particularly given the variation in average mass seen in recent years. Hence, a second estimate of the impact of mass trends was calculated for the difference between 2012 and 2009 using the same
approach. This time, the estimated impact equated to a change in CO₂ emissions of around 3.5 gCO₂/km – an increase as opposed to a decrease.

Mass trends in LCVs appear to be fluctuating due to a combination of factors including a shift in sales towards LCVs with larger load capacities (leading to changes in sales mix), additional safety and comfort features being fitted as standard, and the emergence of new market segments including crew vans, four-wheel drive vans and the availability of rear-wheel drive and front-wheel drive versions of particular LCV models (Ricardo-AEA et al., 2015).

### 11.2.3 Changes in vehicle sales mix

Two key developments in the sales mix of passenger cars can be observed from available data pre-and post- Regulation: changes in new registrations across vehicle segments and changes in the share of diesel vehicles in each segment.

Figure 11-2 shows the changes in new registrations in different segments in 2006 (pre-Regulations) and in 2012 (the latest year for which disaggregated information was available). There has been a marked increase in the relative share of SUVs and crossover vehicles in this period, while most other segments have lost market share. The likely reasons for this include an increased variety of SUVs and crossovers on the market, reflecting consumer preferences, with manufacturers having introduced a number of new crossover models in smaller vehicle segments in particular (FT, 2013). The available data does not provide a separate segmentation by size class among SUVs/crossovers.

**Figure 11-2: Share of new registrations by vehicle segment in 2006 and 2012**

![Graph showing changes in new registrations by vehicle segment in 2006 and 2012](image)

*Source: (ICCT, 2014b)*

In addition, the diesel share has grown more among the larger segments than among the smaller segments (Figure 11-3).
These changes in the sales mix by segment and fuel type are likely to account for only a small fraction of the observed emission reduction – this means most of the reduction is likely to have been achieved by technological change of vehicles within each segment.

Figure 11-4 shows the fleet average emissions in three cases:

A. **Actual** average fleet CO$_2$ emissions;

B. If the **relative market share of diesel vehicles within each vehicle segment had remained at 2006 levels**, and the CO$_2$ emission performance for petrol and diesel vehicles in each segment had developed to the observed 2012 levels. This shows that emissions would have increased on average by 1g/km between from 2006 to 2012;

C. If the **relative market share of each vehicle segment and the relative market share of petrol vs diesel** had remained at 2006 levels, but CO$_2$ emission performance had developed to the observed 2012 levels. This shows that emissions would have fallen by around 1.5g in net terms, despite the upward effect on emissions of the lower 2006 diesel share.
This analysis therefore suggests that if the sales mix (from both the vehicle segment perspective and the fuel type perspective) had remained at pre-Regulation levels, the fleet average emissions achieved in 2013 would have been lower (Figure 11-4). However, this result may be downward biased as the share of SUVs has more than doubled between 2006 and 2012.

The shift towards smaller vehicle sizes is obscured in Figure 11-2 as all SUV / crossover models are lumped into one segment regardless of size. The EEA monitoring database allows more detailed vehicle segmentation for the years 2010 to 2012. Analysis indicates that the composition of the SUV segment has changed substantially with a larger variety of smaller SUVs having entered the market post-regulation. This can be seen from the chart below, where SUV / crossover vehicles are represented by segments BX, CX, DX and EX. As can be seen, there have been significant increases in market penetration for the smaller BX and CX crossover and SUV segments from 2010 onwards.
Evaluation of Regulations 443/2009 and 510/2011 on CO\textsubscript{2} emissions from light-duty vehicles

Figure 11-5: Market share by segment

![Market share by segment](image)

Notes: A = mini cars; B = small cars (superminis); C = medium cars (lower-medium); D = Large cars (upper medium); E = executive cars; F = Luxury cars; S = sports coupés; M = multi-purpose; J = Sport utility vehicles (including off-road vehicles); LAV = Leisure activity vehicles, X = cross-over vehicles.

Source data: (EEA, 2013a)

While it is difficult to tell whether changes in the sales mix on their own have led to a net increase, or a net decrease in average emissions, it is clear that the effect in terms of changes in segment shares and dieselisation have been rather small and are likely to account for significantly less than 10% of the total reduction in average CO\textsubscript{2} from passenger cars of 28g/km that took place between 2006 and 2012.

For LCVs, there has been a shift in the relative sales of Class I, Class II and Class III LCVs in recent years. Since 2009, the LCV market appears to have been shifting towards higher classes, and therefore heavier vehicles (Ricardo-AEA et al, 2015). Hence, the impact on CO\textsubscript{2} emissions, all else being equal, will be to increase CO\textsubscript{2} emissions due to increased vehicle mass.

Registrations of Class I vehicles (i.e. those below 1305 kg), have declined in market share from 27% in 2009 to 7% in 2012. The reasons for this are not entirely clear-cut: part of the reason may be that vehicles previously classified as Class I have increased in mass enough to move into the Class II category, as shown in Figure 11-6, as opposed to changes in sales mix.
Figure 11-6: LCVs Class I, II and III sales (100 kg bins).

![Diagram showing LCV sales by mass class and year]

**Note:** Class I = Reference mass ≤ 1305 kg; Class II = 1305 kg < Reference mass ≤ 1760 kg; Class III = 1760 kg < Reference mass ≤ 3560 kg

Source: (Ricardo-AEA et al., 2015)

Figure 11-7 shows the fleet average emissions in 2013 as measured by EEA monitoring data. On the right, the chart shows the emissions if the sales mix (in terms of size class and fuel type) had remained at 2010 levels and the CO₂ emission performance for LCVs in each size class had developed to the observed 2013 levels. This shows that emissions would have been lower by around 10 g/km in 2013.

**Figure 11-7: Analysis of fleet average LCV emissions (gCO₂/km)**

![Chart showing comparison between actual 2013 emissions and emissions with 2010 sales mix]

Source data: (EEA, 2014), TNO, AEA. Ricardo and IHS Global Insight (2012)

This analysis therefore suggests that if the sales mix (size class distribution) had remained at 2010 levels, the fleet average emissions achieved in 2013 would have been lower. However, this result should be interpreted with some caution as the evolution of average emissions in each size class could have developed differently, and it is not entirely clear to what extent the trends seen are due to changes in mass or purchasing...
behaviour or both. Similarly as for mass, there is some uncertainty in this estimate due to the need to combine different sources, as well as the uncertainty over the extent to which the changes in fleet characteristics are long-term trends as opposed to short-term fluctuations caused by the economic crisis.

11.2.4 Economic crisis

The economic crisis appears to have directly affected total new car registrations in Europe; however there does not appear to be strong evidence that this has affected average new car CO₂ emissions

Before the recession of 2007-2008, car registrations had been growing in the EU-27 but have since been in decline. In 2013 new registrations were almost 25% below the peak of 2007 (ICCT, 2014). The possible impact of the Regulations on new car registrations was examined in the empirical analysis (see Annex D), which suggests that the total number of vehicle registrations has no significant impact on fleet average CO₂ emissions. Moreover, changes to sales by segment can only explain a small amount of the reduction in average CO₂ emissions between 2006 and 2012.

An exception was the year 2009 where a significant one-off increase in the share of smaller cars sold was observed. This can mainly be attributed to scrappage schemes in Member States, most notably in Germany, intended to mitigate the effects of the reduction in sales on the auto industry (Kaul, Pfeifer, & Witte, 2012). In Greece, where the recession was exacerbated by a government debt crisis, there appears to have been a more permanent shift towards smaller cars. Greece recorded one of the steepest falls in CO₂ emissions amongst new car registrations. However, it is not clear whether reductions in average income would necessarily lead to greater fuel economy, at least over the long term.

Studies on the income elasticity of demand for fuel economy are not entirely conclusive. Bonilla & Foxon (2007) find that in the long run, a 10% increase in income may in fact reduce fuel consumption per 100 km by 3%. In the short run no significant impact on fuel consumption was found. Of the other studies reviewed in Bonilla & Foxon (2007) analysing European, OECD or US data, some find positive and others negative income elasticities for fuel economy.

LCV sales are highly cyclical, their sales fall more in times of economic downturns as compared to passenger cars. On the other hand, they profit more in times of economic recovery (T&E, 2010). New LCV volumes were close to the two million mark for much of 2000 to 2007, dropping to 1.8 million in 2008 at the outset of economic downturn, and to 1.36 million units in 2009 as the recession hit (BCA, 2012). Registrations in Europe have seen a decline to around 1.4 million in 2012-2013, as shown in Figure 11-8.
11.2.5 Fuel (oil) price increases

Although demand for vehicles in general is relatively inelastic, demand for fuel efficient models might be expected to increase when fuel prices increase. Overall, oil prices have been volatile and increased at a higher rate than inflation over the past decade. This has been reflected in volatile and increased road fuel prices.

Although a number of recent studies have found large effects of fuel prices on fuel economy in the United States, studies in Europe have reached widely varying conclusions (Klier & Linn, 2011). For example, an econometric study of the impact of fuel prices in Europe suggested that consumer responses in different countries varied, but overall, even substantial changes in fuel prices would be expected to have relatively small effects on the average fuel economy of new vehicles sold in Europe (Klier & Linn, 2011). An elasticity of fuel economy to fuel prices at 0.03 was estimated, i.e. the 10% increase in real fuel prices observed between 2006 and 2013 would result in a 0.3% improvement to fuel economy. A long-run analysis in OECD countries from 1973-2007 finds an elasticity of 0.3 using an ordinary least squares (OLS) model (fuel price becomes insignificant to fuel economy if a fixed effects model is used) (Schipper, Hand, & Gillingham, 2010). A meta review also finds a variety of estimates within the 0.03 to 0.3 range (Bonilla & Foxon, 2007). Vance & Mehlin (2009) suggest that consumers are very sensitive to fuel prices and find elasticities of between 1.7 and 3.3 of fuel economy to vehicle market share, depending on segment, i.e. a 1% fuel economy improvement will tend to increase a vehicle’s market share between 1.8% and 3.3%.

In the literature, there is a wide variety of estimates on consumer response to fuel price changes, and little agreement between studies on which range is most likely. Consequently, estimates in the literature differ by around an order of magnitude. Fuel price increases may thus explain between 0.5 to 5 gCO₂/km reduction based on a 10% price increase.
Fuel is an important business cost, accounting for a significant proportion of the operating costs of LCVs (around one third of the total costs of ownership), although this share decreases as fuel efficiency increases. The empirical evidence on elasticities for LCVs is rather scarce. Therefore, most studies applying an elasticity approach to estimate the behavioural impacts of cost changes for LCVs use elasticity values derived from elasticities for Heavy Duty Trucks (TNO, 2012). Typical values of fuel cost elasticity with respect to fuel efficiency are around 0.05, with a range of 0.025 to 0.075 (TNO, 2012).

In terms of fuel taxation policies, there have been few major changes in European countries since the Regulation was introduced. Road fuel excise duties are volume based; therefore, the proportionate net increase in fuel prices before tax has been far higher than the proportionate increase in price after tax (DG ENER, 2014).

11.2.6 Other national policies and incentives

Various country case studies provide evidence that changes to vehicle taxation policy have indeed helped reduce emissions in recent years. Nijland et al. (2012) identify the following categories of taxes and incentives applied across European Member States:

- Registration taxes;
- Annual road taxes;
- Fuel taxes;
- Scrapping schemes;
- Congestion charges;
- Tolls;
- Subsidies for consumers (e.g. on cars with a diesel particulate filter or on commuting); and
- Subsidies for industry (R&D).

The majority of EU Member States including Germany, France, Spain, Belgium, the Netherlands, the UK and Sweden have adjusted vehicle-specific taxes and incentives to vary partially or entirely with the vehicle’s CO₂ rating at around the time the Regulation was introduced (Ibid.). The study finds that those European Member States which have reduced their CO₂ emissions above average were generally those which introduced a CO₂ component into their vehicle taxation systems; however, it is not clear from the analysis whether this is due to a direct relationship. The level of tax can vary drastically between member states, especially for registration taxes. Some countries do not charge registration taxes while in other countries registration tax can almost double the purchase cost of the vehicle. Countries which make high (upfront) taxes dependent on CO₂ emissions will also tend to affect fleet average CO₂ emissions to a greater extent.

For example, the Netherlands recorded one of the steepest drops in vehicle emissions between 2006 and 2012. It became the country with the lowest fleet average in 2012 while historically exceeding the EU-27 fleet average until 2009 (ICCT, 2014b). It is also the country with the highest share of hybrids among new registrations (Ibid.). This development not only coincides with the introduction of the Regulation; between 2006 and 2010 vehicle registration taxes were made increasingly dependent on CO₂ emissions. While in 2005 registration taxes for a petrol vehicle would range from around 30% to 40% of the net retail price, in 2012 a car with emissions of 90 gCO₂ per km would incur no registration tax at all, while the rate for a vehicle with 300 gCO₂ per km would exceed 100% (Meerkerk, et al., 2013). A study examining Dutch CO₂ emission reductions between 2007 and 2010 attributes reductions of 6 gCO₂/km to the tax reform (Kok, 2011). This is consistent with the findings of Cambridge Econometrics (2013) who attribute reductions of 6.3g CO₂/km to the Dutch registration tax reform, analysing the period from 2005 and 2012. The same study finds reductions of 3.6g CO₂/km as a result
of change to CO₂-based annual circulation tax. Sales of PHEVs in the Netherlands reached 4% at the end of 2013, and another 1.4% of BEVs due to the phasing out of high rebates, which led to a “last minute run” on these vehicle types (ICCT, 2014c). Sales of these vehicle types subsequently fell to 1% in the first half of 2014.

Further country case studies provide evidence that changes to vehicle taxation policy have indeed helped reduce emissions in recent years, although the estimated level of impacts tend to vary both by country and by source. The introduction of a feebate (‘bonus-malus’) system at vehicle registration in France in 2008 was found to be effective in reducing fleet average emissions. The tax reform was found to have reduced emissions by 8 gCO₂/km in the short run. The long-run impact, with vehicle manufacturers responding to market developments, could potentially be even larger but over the time period analysed, no long-run effects could yet be detected. The same study finds short-run reductions of 1.7 gCO₂/km and 0.6 gCO₂/km due to reforms of annual vehicle tax in Germany and Sweden, respectively. Similarly, a study considering Ireland attributes the steep drop in Irish new car emissions between 2008 and 2009 largely to the CO₂-based taxation reform, but does not explicitly identify what percentage of the 22 gCO₂/km reduction over the period could be attributable to the reform (Rogan, et al., 2011). In both the Irish and the French cases the taxation reforms resulted in a loss in government revenue as the response to the incentive to buy lower emission vehicles was greater than expected. The same is true for the Netherlands (Meerkerk, et al., 2013).

Evidence from literature suggests that consumers are highly sensitive to upfront costs, and less influenced by total cost of ownership, which may explain why schemes which deliver up-front incentives (such as changes to registration taxes and upfront subsidies) tend to be more effective than those which offer savings post-purchase (AEA, 2009b).

Emission reductions in Europe were particularly high in 2009 along with an increase in the share of small vehicles sold. This can mainly be attributed to scrappage schemes in Member States, most notably in Germany, which were intended to mitigate the effects of the reduction in vehicle sales on the car industry (Kaul, et al., 2012). LCV scrappage programmes were typically less generous compared to those introduced for cars following the recession, and attracted fewer participants (BCA, 2012).

### 11.2.7 Consumer attitudes

Apart from overall sensitivity to high fuel prices, there is not much evidence available for a change in consumer attitudes after the Regulation was introduced.

Climate change increased in prominence on the public agenda in the mid-2000 in connection with a series of extreme weather events (Sykes and Fischer, 2009). The increased public and business interest in energy efficiency and managing of carbon footprints is likely to have had positive image implications for greener cars.

While there is much literature on consumer attitudes and valuation of fuel economy (e.g. Allcott & Wozny, 2012), few studies have analysed changes to attitudes over time. One survey of 4,000 German car buyers which was initially undertaken in 2009 and repeated in 2014 found that the proportion of respondents willing to spend more on a car to get lower fuel consumption had increased from 65% to 70% (Auto Nachrichten, 2014).

Both literature and anecdotal evidence highlights differences between the purchasing behaviour of car buyers and LCV buyers. A key different is that commercial buyers place more importance on economic considerations when making vehicle purchasing decisions, including the cost of fuel (AEA, 2010). Purchasing decisions have, until very recently, been constrained by limited information concerning LCV CO₂ emissions and fuel consumption, information which is now monitored as part of the LCV CO₂
Regulations; however the extent to which this affects purchasing decisions is unclear (LowCVP, 2014).
12Annex F: Overview of the main weaknesses of the Regulations

This section provides more detail on the main weaknesses of the Regulations, which is part of the evaluation of effectiveness and is summarised in Section 5.2.3. It also covers the views of stakeholders in this respect, although as the stakeholder question was more general, the stakeholder responses covered in Section 15.3 also cover inefficiencies (that are discussed in detail in Section 5.6) and equity between manufacturers as discussed in Section 5.4.4.

12.1 Phasing in of the targets

As noted in Section 5.2.3, for some of the weaknesses, the theory might be different to the practice. This is true of the phase-in period. In theory, the existence of the phase-in period means that the specified target may not be met as not all of the new vehicles that are put on the market in the years concerned will be taken into account for the purpose of calculating manufacturers’ targets. In order to demonstrate the theoretical weakness of this modality, it is necessary to make a number of assumptions in order to estimate the percentage additional annual, specific CO₂ emissions allowed. These include: that the target is met exactly – rather than over-achieved – as this facilitates the calculation; and the emissions, in terms of the average number of gCO₂/km higher than the target, of the vehicles that do not count for the purpose of the targets. In Figure 12-1, it is assumed that the vehicles that do not count towards meeting the manufacturers’ target in that year reduce their CO₂ emissions in subsequent years at an annual rate equivalent to the reduction for the respective new car and LCV fleets between 2012 and 201348. This demonstrates that the phase-in period has the potential to weaken the target by a few percentage points in each year that it applies. Any weakening has the potential to be greater in the earlier years of the first targets in both Regulations, as the phase-in period for the second CO₂ target for cars is shorter and ignores fewer vehicles (there is no phase in for the second LCV target).

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48 So for cars, 5% was assumed, as this was roughly the decline for the entire new car fleet between 2012 and 2013, and for LCVs it was 4%. The implication of this is that, for example, in 2012 some cars will be 15 gCO₂/km away from their target, as they will not be counted until 2015, whereas some cars will be 10 gCO₂/km and 5 gCO₂/km away from their targets, as they will be counted in 2014 and 2013, respectively. An analogous approach was used for LCVs. It is acknowledged that this is a simplified approach to vehicle emissions reductions, but it is useful to illustrate the potential weakening resulting from the phase-in of the targets.
**12.2 The potential to use super-credits**

Super-credits are another example of a theoretical weakness that may have less of an impact in practice. The application of super-credits effectively increases the number of vehicles that are used to calculate the average CO₂ emissions of a manufacturer – or the entire fleet – and therefore allow the real average CO₂ emissions of a manufacturer to be higher than the target would otherwise imply. Once more, in order to demonstrate the theoretical potential for super-credits to weaken the CO₂ targets in terms of the percentage additional annual, specific CO₂ emissions allowed, it is necessary to make assumptions. In order to estimate the figures represented in Figure 12-2, it was assumed that super-credits were used to their maximum in each year that they are allowed and that with the application of super-credits the targets are met exactly\(^49\). Additionally an assumption has to be made about the proportion of vehicles to which the super-credits can apply – 2.5% was chosen, as this is close to the proportion of alternatively-fuelled vehicles (2.4%) in the 2013 new car fleet (EEA, 2014). Figure 12-2 demonstrates that – even for relatively small numbers of vehicles with CO₂ emissions of less than 50 g/km – super-credits have the potential to increase the CO₂ emissions that are effectively allowed by several percentage points. It is worth noting that for the first LCV CO₂ target and for the second car CO₂ target, a limit is placed on the application

\(^{49}\) For this calculation, it is assumed that no other weaknesses apply, e.g. the phase-in period is not used.
of super-credits (see Table 2-2), although there is no limit on the use of super-credits to meet the first car CO\textsubscript{2} target.

**Figure 12-2: Illustrative percentage additional annual, specific CO\textsubscript{2} emissions allowed (compared to if there were no super-credits) from the new LDV fleet**

![Diagram](image)

*Note: This assumes that 2.5% of the new vehicle fleet were eligible for super-credits each year, on the basis that the proportion of the new car fleet that was an alternatively-fuelled vehicle in 2013 was 2.4% (EEA, 2014).*

Practically, however, super-credits have not yet been needed to meet the targets. As was noted in Section 3.2, the first LCV CO\textsubscript{2} target has been met early, while the first car CO\textsubscript{2} target was met in 2013 – and without the need for super-credits (EEA, 2014).

For manufacturers that were responsible for more than 100,000 new cars in 2013, Table 12-1 shows the difference that super-credits would have made if these had been needed.

**Table 12-1: Potential benefit of super-credits on the performance of larger manufacturers**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Additional gCO\textsubscript{2}/km reduction resulting from super-credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volvo</td>
<td>7.4</td>
</tr>
<tr>
<td>Nissan</td>
<td>5.8</td>
</tr>
<tr>
<td>Renault</td>
<td>3.6</td>
</tr>
<tr>
<td>Daimler</td>
<td>1.8</td>
</tr>
<tr>
<td>Toyota</td>
<td>1.6</td>
</tr>
<tr>
<td>Opel</td>
<td>1.2</td>
</tr>
<tr>
<td>BMW</td>
<td>0.7</td>
</tr>
<tr>
<td>Citroen</td>
<td>0.3</td>
</tr>
<tr>
<td>Volkswagen</td>
<td>0.3</td>
</tr>
<tr>
<td>Peugeot</td>
<td>0.2</td>
</tr>
<tr>
<td>GM Korea</td>
<td>0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Additional gCO₂/km reduction resulting from super-credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyundai</td>
<td>0.0</td>
</tr>
<tr>
<td>Ford</td>
<td>0.0</td>
</tr>
<tr>
<td>Seat</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Source: (EEA, 2014)

Notes: Manufacturers that were responsible for more than 100,000 new cars in 2013 and which are not listed in the above table did not put on the market any vehicles that qualified for super-credits; those indicating '0.0' additional emissions reductions in the table only put very small numbers of qualifying vehicles on the market.

12.3 Derogations for small volume and niche manufacturers and the de minimis

The extent to which the derogations for small volume car and LCV manufacturers and nice car manufacturers are weaknesses depends on the actual numbers of manufacturers that are both eligible and that apply for the derogations, as is the case with the ‘de minimis’. An illustrative example as to the potential extent of the impact of these derogations is provided in Figure 12-3. As with the previous examples in this Annex, assumptions need to be made in order to estimate the percentage additional annual, specific CO₂ emissions allowed. The figures are based on the actual numbers of vehicles put on the market by manufacturers that received the respective derogations in 2013 or, in the case of the ‘de minimis’, benefit from this derogation (EEA, 2014).

An assumption also had to be made as to the extent to which the subsequent, average, specific CO₂ emissions of each of these manufacturers exceeded what would otherwise have been the respective manufacturer’s targets. This figure was assumed to be 50 gCO₂/km, which is on high side, although lower than some LCV manufacturers would have missed their targets by if the derogations had not been in place (and had the target applied) in 2013 (see Table A2.2 of EEA, 2014). This relatively high figure was chosen to demonstrate the very small potential impact of the small volume derogation and the ‘de minimis’, which even with this high figure only risk a relatively small weakening in the order of a fraction of 1%. Even though only four manufacturers benefit from the niche derogation for cars, the comparative impact of this derogation is higher than the other two under the same assumptions⁵⁰.

---

⁵⁰ It is worth noting that in 2013 all bar one of the manufacturers that benefited from a niche derogation met its target. The one that did not was additionally part of a pool, which did meet its target.
Figure 12-3: Illustrative percentage additional annual, specific CO₂ emissions allowed (compared to if there were no respective derogations) from the new LDV fleet

Note: This graph takes the actual numbers of vehicles put on the market by manufacturers that received the respective derogations in 2013 (EEA, 2014). It assumes that the average emissions of these vehicles was 50 gCO₂/km higher than their target would have been if the formula that is used to calculate the targets for larger manufacturers had been applied to these manufacturers.
13 Annex G: Review of legislation on the fuel economy and CO₂ reductions of LDVs implemented elsewhere in the world

A wide range of standards that aim to reduce the GHG emissions and/or increase the fuel economy of LDVs have been introduced elsewhere in the world (see Figure 13-1). The EU regulatory targets for passenger cars in 2021 are currently more stringent than those in other major markets. However, targets in all countries are clearly tightening and it might be expected (given the evidence on climate change discussed in Section □) that they will continue to be tightened.

Figure 13-1: Actual and required CO₂ emissions reductions from cars required by legislation in different parts of the world

![Graph showing CO₂ emissions reductions from cars](image)

Notes: The targets specified have been converted to the European, NEDC test cycle to make them comparable; Switzerland introduced the same targets for passenger cars as the EU in 2012, and plans to introduce the same targets for 2020 in 2016.

Source: ICCT, 2014a

A number of countries have either introduced or plan to introduce targets for LCVs. Mexico and Japan have already done this (for 2016 and 2015 respectively), whereas Switzerland and South Korea have proposed to bring in targets for 2020 for LCVs (see Figure 13-2). The targets set in Europe are the most stringent of those currently planned in 2020 (on the basis of the emission targets, disregarding any flexibilities provided for, such as supercredits); however, without further tightening the standards will be overtaken by the USA and Canada by 2025.
Figure 13-2: Actual and required CO₂ emissions reductions from LCVs required by legislation in different parts of the world

Notes: The targets specified have been converted to the European, NEDC test cycle to make them comparable; Switzerland introduced the same targets for passenger cars as the EU in 2012, and plans to introduce the same targets for 2020 in 2016.
Source: ICCT, 2014a

Figure 13-3 shows the overall and annual reduction rates required under legislation in different parts of the world for passenger cars and LCVs. It can be seen that the annual rate of reductions required for the European passenger car fleet (3.6%) are among the highest (albeit lower than those required in the USA and China, at 4.1% and 4.8% respectively). Targets for passenger cars set in South Korea, India and Latin America require lower annual rates of reduction at around 2.1-2.8%. The European targets for LCVs require the least rapid reductions of those currently enacted, both in terms of the annual rate of reduction and the overall reduction.
Data from the US shows that the rate of technology adoption has increased in recent years – see Figure 13-4. When contrasted with the relatively slow rate of adoption prior to 2004, this suggests that the US light-duty vehicle GHG emissions regulation has played a part in these trends (ICCT, 2013c). Car manufacturers have made substantial technology investments over the 2004–2010 period for compliance with the 2016 standard, while the preparations for and implementation of the 2017-2025 rule has driven the faster diffusion of technologies beyond 2010 (ICCT, 2013c).
Figure 13-4: Trends of technology penetration for car fleet during 2000–2012, and regulatory timeline in the US

Source: (ICCT, 2013c)

Similarly, in China, advanced engine and transmissions technologies have been adopted at a faster pace in recent years, although the fleet still lags behind the US and Europe. This is likely driven by the new Phase 3 fuel consumption standards proposed in 2009 and formally adopted in 2011, as well as various policies incentivising small-engine and efficient vehicle models (ICCT, 2013c). As can be seen in Figure 13-5, the application rates of GDI, VVT, turbo/supercharging, and six-speed or higher transmissions increased from 5%, 44%, 6% and 34% in 2010, to 11%, 51%, 12%, and 51%, respectively, in 2012 (ICCT, 2013c).
Both Switzerland and South Korea have introduced CO₂ emission reduction standards for passenger cars that are similar in design to the EU Regulation. As a result of their proximity to the EU, the Swiss regulations introduced in 2012 are almost identical to those implemented in 2009 in the EU, but they take account of Swiss circumstances. The main differences are that the Swiss regulations allow additional credits for certain powertrains (e.g. those using CNG) and allow the transfer of credits between importers (as Switzerland does not have any vehicle manufacturers based in the country). The Swiss regulations do not have separate provisions for small volume or niche manufacturers (i.e. nothing like the respective EU derogations), which has been controversial as importers of potentially affected vehicles have argued for the same treatment as in the EU.

South Korea’s ‘Corporate Average Fuel Economy and GHG emission standard’ was introduced in 2012 and requires vehicle manufacturers/importers to meet a fuel economy target of 17 km/l or a CO₂ target of 140 gCO₂/km (based on the US CAFE combined test cycle), using mass as a utility parameter. The CO₂ limit is equivalent to 150 gCO₂/km on the NEDC cycle.

The approaches in the United States, Canada and Mexico have used footprint-based corporate average fuel economy standards (see Section 9.1 above). In the United States, the standards use piecewise linear functions linking a vehicle’s footprint and its test cycle GHG emissions value. It allows for different sizes of vehicles to have different standards, whilst constraining the largest vehicles at the upper bend and incentivising vehicles below the lower bend (EPA, 2010). In the US, each manufacturer has a footprint-based standard for 2012-2016 based on sales of vehicles at each vehicle size (Transportpolicy.net, 2013; EPA, 2012a). A range of compliance flexibilities are offered, including:

- Credit banking and trading – The ability to average and bank credits aims to help manufacturers plan and to support the introduction of GHG-reducing technology. Credits can be carried forward (or banked) for five years, or carried back three years to cover deficits in a previous year. Manufacturers can transfer credits across all of the vehicles it produces (including between cars and pick-up trucks). Credits can also be traded between companies.

- Air conditioning improvement credits – Manufacturers can generate CO₂-equivalent credits for use in complying with the standards by improving air
conditioning systems that reduce CO₂ emissions through efficiency improvements; and for reduced refrigerant leakage (better component use/use of refrigerants with lower global warming potential). In the EU, refrigerants in air conditioning systems are regulated separately under the Directive 2006/40 on mobile air-conditioning systems (MACs).

- **Off-cycle credits** – Credits awarded for technologies achieving CO₂ reductions that are not reflected in current test procedures, e.g. solar panels on hybrids, engine start-stop or active aerodynamics. These are directly analogous to the eco-innovation provisions in the EU.

- **Incentives for electric vehicles, plug-in hybrid electric vehicles; fuel cell vehicles, and compressed natural gas vehicles** – An incentive multiplier for these vehicles is currently being developed. Each EV/FCV sold will count for two vehicles each up to 2017 (reducing to 1.5 in 2021), while PHEVs and CNG vehicles will count for 1.6 vehicles in 2017 (reducing to 1.3 in 2021). Prior to 2022, there will be no limits on the number of vehicles to which the multiplier can apply. These incentives are analogous to the super-credits that apply in the EU.

- **Incentives for advanced technologies including hybridisation for full-size pickup trucks** – Credits are awarded if a minimum penetration of these technologies is achieved in a vehicle manufacturer’s pick-up truck fleet, with credits ranging from 10 to 20 gCO₂/mile.

- **Treatment of compressed natural gas (CNG) vehicles, plug-in hybrid electric vehicles (PHEVs), and flexible fuel vehicles (FFVs)** – The EPA is developing a methodology to determine the CO₂ levels for these vehicles, taking account of the time that these vehicles operate using alternative fuels or petrol.

- **Provisions for intermediate and small volume manufacturers** – ‘Intermediate’ manufacturers (that sell less than 50,000 vehicles) are provided with additional lead time flexibility to help ease their transition to achieve the main standards. (They were previously allowed a less stringent CO₂ target). Small volume manufacturers (that sell less than 5,000 vehicles) are able to petition the EPA for alternative CO₂ standards on a case-by-case basis (EPA, 2012a).

Although the current 2016 target was introduced in 2012, the approach used (i.e. using ‘footprint’) was first introduced in the reformed CAFE standards for light trucks that was in place between 2008 and 2011. The standards in Canada and Mexico have been based on the approach taken in the USA.

While ‘footprint’ is used as the utility parameter in North America, in Japan and China ‘mass’ is used as the utility parameter. Japan’s fuel economy standards for petrol and diesel passenger vehicles were set at 16.8 km/l for 2015 and 20.3 km/l for 2020. Japan’s standards were adopted in 2007 (with a 2015 target date), i.e. prior to those in the EU. The Fuel Consumption Regulation Program (introduced August 2009) sets out the GHG emission standards for light duty vehicles in China. In addition to specific fuel consumption limits by weight class, Phase III standards establish a corporate-average fuel consumption (CAFC) target. Credits and flexibilities are likely to be available, including for new energy vehicles (battery electric, fuel cell and plug-in hybrids); for other ultra-low fuel consumption vehicles (i.e. those with fuel consumption less than or equal to 2.8l/100km on combined and extra-urban cycle) and for vehicles equipped with innovative technologies leading to real-world fuel saving (off-cycle technology credits) (ICCT, 2014d). Additionally, the Chinese legislation allows the banking of credits for up to three years (Transportpolicy.net, 2014).
14 Annex H: Analysis relating to the coherence of the Regulations

This Annex contains analysis in support of the discussion of Section 5.7, focusing on:

- Niche derogations
- Phase-in periods; and
- Coherence between the two Regulations.

14.1 Niche derogations

As the range of eligibility for a niche derogation – in terms of the number of new car registrations annually – is large, i.e. between 10,000 and 300,000, the nature of the manufacturers eligible to apply for the derogation is very different. Some of the larger OEMs that are eligible for the derogation have more in common with those that are too large to be eligible for the derogation than with manufacturers of, say, 12,000 cars. As such, these larger niche manufacturers compete with larger manufacturers rather than with the smaller, ‘niche’ manufacturers. However, the larger manufacturers that are eligible for the niche derogation do not utilise it, as is the case with the majority of the smaller niche manufacturers (see Figure 14-1). Indeed, while 20% of the total car registrations in the EU in 2013 were manufactured by companies that were eligible for a niche derogation, only 19% of the registrations of such manufacturers were made by manufacturers that actually had a niche derogation (see Figure 14-3).

To some extent, this lack of use of the niche derogation is linked to the distance that a manufacturer was away from the fleet-wide average in 2007, which is the base year for identifying alternative targets for niche manufacturers, as the greater this original distance, the larger the benefit of using the niche derogation. This is demonstrated in Figure 14-2, as all of the manufacturers that received a niche derogation in 2013 had emissions higher than the fleet-wide average in 2007, although these ranged from being just above the average (less than 5% in Suzuki’s case) to more than 55% above the average in the case of Land Rover. However, there are still four manufacturers that had emission levels more than 10% higher than the 2007 average and which would be eligible for a niche derogation in 2013, which do not have one (although three of those are in pools), including two of the three manufacturers whose emissions differed most from the average. It is also worth noting at this point that of the ‘niche’ manufacturers with more than 200,000 registrations in 2013, only Volvo had emissions levels in 2007 that were significantly higher than the fleet-wide average that year.

Of the four manufacturers that were both in a pool and in receipt of a niche derogation in Figure 14-1, it is important to note that it was the respective pools that received the niche derogation, not the individual manufacturers. However, even for these pools, the total registrations involved were less than 150,000 in each pool.

51 The five ‘niche’ manufacturers with more than 200,000 registrations in 2013 – none of which benefited from a derogation – were Dacia, Kia Motors Corporation, Seat, Hyundai Motor Manufacturing (Czech SRO) and Volvo. Note that there are additional companies with Kia (one other company) and Hyundai (three additional companies) in their names, which are also eligible for, but did not have, a niche derogation (EEA, 2014).

52 See footnote 51

53 The four niche derogations granted in 2013 were to Fuji (for their Subaru cars), Mazda, a pool involving Jaguar Land Rover (JLR) and Tata, and a Suzuki pool. The three companies in the Suzuki pool and JLR would also have been eligible for a niche derogation if they had not have been part of a pool; Tata, which is in the pool with JLR, qualifies for the ‘de minimis’. The total number of
registrations covered by the JLR/Tata and Suzuki pools was 132,400 and 146,600, respectively (EEA, 2014).
Figure 14-2: The difference between a manufacturer’s CO₂ emissions in 2007 and the average fleet-wide CO₂ emissions in 2007 for those manufacturers that were eligible for a niche derogation in 2013 (and so represented in Figure 14-1)


Notes: Figure 14-1 contains 22 manufacturers, while Figure 14-2 only includes 15 manufacturers. This is because the latter 15 were the only manufacturers that could be confidently identified in both lists. Jaguar and Land Rover are included separately in Figure 14-2, as they have separate 2007 emissions figures, but are counted as only one manufacturer in Figure 14-1.
Figure 14-3: Registrations by manufacturer’s eligibility for respective derogations

Source: Developed from data in EEA (2014)

14.2 Phase-in periods

In relation to the phase-in periods, consideration needs to be given with respect to whether these might have been justified for the first car and LCV target and for the second car target. When the proposal for the Regulation was published in 2007, there was only five years until the proposed date of entry into force for the first target in 2012. As manufacturers’ development plans for models are typically up to 10 years ahead (TNO et al., 2011), such a short timescale to implement the targets could have been challenging for some (which, of course, would not have been the case if manufacturers had taken more action to reduce CO₂ emissions under the voluntary agreement). Hence, the phase-in period, which extended the full application of the target to 2015, i.e. eight years from the publication of the initial proposal, could be justified as it brought the first target more in line with manufacturers’ typical planning cycles. Similarly, the original proposal for the LCV CO₂ Regulation set the date for the first target as only five years ahead, as the proposal was published in 2009 proposed and the first target was to apply from 2014. Again, the phase-in period increased the number of years between proposal and the full application of the target to eight years, so might be justified for a similar reason.

The 2020 target for cars was not explicitly mentioned in the original proposal for the passenger car CO₂ Regulation, but it was stated in Article 1 of the eventual passenger car CO₂ Regulation, which came into force in 2009. While the details of the modalities for reaching this target were only confirmed in 2014, the fact that the target was signalled to manufacturers 11 eleven years prior to the date on which it was intended to come into force means that it gave manufacturers’ sufficient time, consistent with typical planning cycles, to meet it. Given that the details of the main modalities were unchanged by the 2011 review of the modalities (TNO et al., 2011), the benefits of the phase-in period for cars for 2020 in relation to facilitating the transition for manufacturers are minimal. There is no phase-in period for LCVs for the 2020 target.
14.3 Coherence between the two Regulations

In relation to the coherence of the two LDV CO₂ Regulations with each other, on paper they should be coherent as they cover distinct types of vehicle:

- The passenger car CO₂ Regulation applies to “M₁ vehicles”, which are vehicles designed and constructed primarily for the transport of people and their luggage and that have no more than 8 seats in addition to the driver’s.
- The LCV CO₂ Regulation covers “N₁ vehicles”, i.e. vehicles designed and constructed primarily for the transport of goods and that have a “technically permissible maximum laden mass” that does not exceed 3.5 tonnes.

In practice, reports suggest that many class I and class II LCVs are derived from passenger cars, so they share a range of components. Indeed, even LCV models that are not derived from a passenger car can share engines and other components with passenger car models (e.g. TNO et al., 2012). It is also possible that many LCVs, particularly those of small traders, could be used as a family car. Hence, there is the potential for an increased use of LCVs instead of cars (or of cars instead of LCVs) if the Regulations lead to significantly different effects for vehicles on, or close to, the boundary between a car and a LCV, which is blurred in practice.

The decision to regulate cars and LCVs separately was made as they represented different markets and it was concluded that the various models were largely unrelated, although it was noted that there were some overlaps. Allowing manufacturers to pool their car and LCV targets was considered in the Impact Assessment accompanying the original proposal for the LCV Regulation, as this could have enabled the minimisation of abatement costs compared to having separate targets. However, it was concluded that manufacturers that only made LCVs might be put at a disadvantage compared to manufacturers that produced both types of vehicle. Additionally, ACEA did not support the pooling of car and LCV targets for individual manufacturers due to concerns about competition (European Commission, 2009b).

The Impact Assessment accompanying the proposal to confirm the modalities for 2020 also rejected the possibility of combining the car and LCV targets. It noted that the 2020 target for cars delivered a 27% reduction in emissions compared to doing nothing by 2020, whereas for LCVs the equivalent figure was 16%. The difference in stringency of the respective targets (and therefore of the costs of meeting the targets) was one of the reasons for rejecting a combined target, as such an approach would benefit manufacturers that produced both types of vehicle and so not be competitively neutral. Additionally, a combined linear target would be unattainable for LCVs (when using ‘mass’) or unachievable for cars (if ‘footprint’ were used), while there was a risk of perverse incentives as a result of the overlap between cars and LCVs (European Commission, 2012a). These conclusions were similar to those in the report that supported the confirmation of the 2020 LCV target (TNO et al., 2012), which also noted that there was potential for some leakage, e.g. if national authorities allowed LCVs to be used mainly for transporting passengers, or cars mainly for transporting goods. Hence, a manufacturer could gain (in terms of reducing the costs of meeting its CO₂ targets) by incentivising some LCV purchases.

TNO and CE (2012), in a report for Transport and Environment, attempted to identify the extent of the difference in the stringencies of the car and LCV targets for 2020 on the basis of an assessment of the marginal costs of additional technologies needed to meet the former. It concluded that a 2020 target for LCVs of around 118 gCO₂/km (as opposed to 147g; see Section 2.4) would have been equivalent to the 95 gCO₂/km target for cars. The report also estimated that additional manufacturer costs for meeting the car target were nearly three times the additional costs of meeting the LCV target.
while the relative price increase for meeting the car target was more than twice that implied by meeting the LCV target.

Even though the reports mentioned above stated that many class I and class II LCVs are car-derived, no attempt was made in any of them to identify which LCVs, and how many, are in fact car-derived. In order to support the analysis within this section, an attempt was made to identify which LCVs might in fact be car-derived. However, looking at the top 10 best-selling models – which accounted for more than half of the registrations in 2013 – it became clear that it was in fact difficult to agree on which models were in fact ‘car-derived’ (see Table 14-1). The Impact Assessment accompanying the proposal to confirm the 2020 targets reached a similar conclusion in that it identified the main barrier to bringing car-derived LCVs into the passenger car CO₂ Regulation as being the challenges of creating a suitable legal definition to set out which LCVs would be covered by the car CO₂ Regulation (European Commission, 2012).

Table 14-1: Best-selling LCV models in the EU, 2013

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Registrations</th>
<th>% of total new LCV fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ford</td>
<td>Transit</td>
<td>134,268</td>
<td>9.8%</td>
</tr>
<tr>
<td>Mercedes</td>
<td>Sprinter</td>
<td>78,742</td>
<td>5.7%</td>
</tr>
<tr>
<td>VW</td>
<td>Transporter</td>
<td>70,134</td>
<td>5.1%</td>
</tr>
<tr>
<td>Citroen</td>
<td>Berlingo</td>
<td>66,628</td>
<td>4.9%</td>
</tr>
<tr>
<td>Renault</td>
<td>Kangoo</td>
<td>63,429</td>
<td>4.6%</td>
</tr>
<tr>
<td>VW</td>
<td>Caddy</td>
<td>61,834</td>
<td>4.5%</td>
</tr>
<tr>
<td>Fiat</td>
<td>Ducato</td>
<td>58,945</td>
<td>4.3%</td>
</tr>
<tr>
<td>Peugeot</td>
<td>Partner</td>
<td>58,818</td>
<td>4.3%</td>
</tr>
<tr>
<td>Renault</td>
<td>Master</td>
<td>57,040</td>
<td>4.2%</td>
</tr>
<tr>
<td>Renault</td>
<td>Trafic</td>
<td>43,754</td>
<td>3.2%</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>50.6%</strong></td>
</tr>
</tbody>
</table>

Source: ICCT (2014)

An additional point worth making is that the definition of LCVs, and of the three classes of LCV, is fluid as it is based on the mass of the vehicle concerned and average masses have been increasing, at least to 2012. Hence, the number of registrations per class is dependent on the mass of the LCVs that are put on the market; as the average mass has increased the number of LCV registrations categorised as Class III (the heaviest class) has been increasing at the expense of the lighter classes (see Figure 14-4). This increase is not necessarily the result of heavier models of LCVs being put on the market, as the mass of different versions of the same model has increased thus changing the class to which the same model might be assigned in different years. It is also worth noting from Figure 14-4 that the trend is also not consistent, as the proportion of the lighter class I LCVs increased to 2009 before declining in more recent years (Ricardo-AEA et al, 2015). This further underlines the difficulties of defining the LCVs that might be incorporated into the car CO₂ Regulation.
Figure 14-4: LCV sales by Class in selected years between 2007 and 2013

15 Annex I: Summary of stakeholder views

15.1 Stakeholder views in relation to “relevance”

This section summarises the results of the stakeholder consultation with respect to the questions relating to ‘relevance’. It reports on the responses to the quantitative questions, and summarises substantial qualitative remarks in support of these responses. It does not contain any analysis; this is provided in Section 5.1.

Stakeholders were asked whether they thought it was likely that there would be any technical developments that would remove or reduce the need for the Regulations. The majority of stakeholders overall felt that there would not be any such developments as shown in Figure 15-1. A much smaller proportion of industry stakeholders felt there would be a development that would remove or reduce the need for the regulations – one out of 17 (6%) compared to the proportion of non-industry stakeholders (11 out of 38, or 23%). Those that thought there would be technical developments that would, at least, reduce the need for the Regulations suggested that by 2030 increased uptake of hybrids and electric vehicles would be driven by market forces and concerns over air quality. Others thought that increased uptake of vehicles with such alternative powertrains had the potential to reduce the need for the Regulations in the longer-term, i.e. after 2035.

Figure 15-1: Stakeholder responses to question: “Is it likely that there will be any technical developments which will remove or reduce the need for the Regulations?”

Notes: N = 55.
Source: Stakeholder survey conducted for this study, 2014

Overall, support for the various different aspects of the Regulations appeared to be higher on average in non-industry stakeholders as might be expected; however overall responses were still positive in both groups – see Figure 15-2.
Figure 15-2: Stakeholder responses to question: “To what extent do you agree or disagree with the following statements?”

<table>
<thead>
<tr>
<th>Overall</th>
<th>Industry</th>
<th>Non-industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

There was a very high degree of similarity between the replies given by each individual regarding the relevance of the Regulations today compared to in 2030. That is each stakeholder’s opinions were similar for both short and long-term timeframes. This is measured by the Spearman Rank correlation coefficients, as shown in Table 15-1.

Table 15-1: Spearman rank correlation coefficients for short- vs long-term relevance of the Regulations

<table>
<thead>
<tr>
<th>Issue</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is a continuing need to tackle climate change</td>
<td>0.93</td>
</tr>
<tr>
<td>Greenhouse gas emissions from cars and LCVs must be reduced to</td>
<td>0.82</td>
</tr>
<tr>
<td>contribute to the EU's long-term climate goals</td>
<td></td>
</tr>
<tr>
<td>Without these Regulations car and LCV CO₂ emissions per km would</td>
<td>0.92</td>
</tr>
<tr>
<td>increase</td>
<td></td>
</tr>
<tr>
<td>Increases in the demand for transport and in vehicle size otherwise</td>
<td>0.84</td>
</tr>
<tr>
<td>offset CO₂ reductions from improved vehicle technology</td>
<td></td>
</tr>
<tr>
<td>The Regulations are needed to encourage a reduction in energy</td>
<td>0.92</td>
</tr>
<tr>
<td>consumed by the LDV sector</td>
<td></td>
</tr>
<tr>
<td>Encouraging the development of increasingly low CO₂ LDVs is</td>
<td>0.89</td>
</tr>
<tr>
<td>beneficial for EU competitiveness</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The correlation coefficient is a measure of the similarity between each individual stakeholder responses to each of the issues, comparing their response for the relevance today vs in 2030. A perfect correlation would score 1.00, meaning that responses to each question were identical.
A more in-depth analysis of stakeholder responses to each issue is provided below.

**All sectors must contribute to the fight against climate change**

Stakeholders were broadly in agreement that there is, and will continue to be, a need to tackle climate change (see Figure 15-3); almost all stakeholders agreed or strongly agreed that there was a need to tackle climate change, with only one stakeholder from industry strongly disagreeing. There were no substantive qualitative comments from stakeholders to support their stated views.

**Figure 15-3: Stakeholder responses to question: “To what extent do you agree or disagree that there is a continuing need to tackle climate change?”**

![Bar chart showing stakeholder responses to climate change question]

Notes: N = 55  
Source: Stakeholder survey conducted for this study, 2014

The majority of stakeholders also agreed that emissions from cars and LCVs must be reduced to meet the EU’s long-term climate goals (see Figure 15-4). Regarding the need to reduce GHGs from LDVs today, all four stakeholders that disagreed or strongly disagreed were representatives from the vehicle manufacturing industry. When considering the longer term, several non-industry stakeholders also disagreed with the need to reduce GHGs from LDVs in 2030.
Figure 15-4: Stakeholder responses to the question: "To what extent do you agree or disagree that GHGs from LDVs must be reduced to contribute to the EU’s long-term climate goals?"

Notes: N = 55  
Source: Stakeholder survey conducted for this study, 2014

The CO₂ performance of new vehicles should improve at a faster rate

Stakeholders were relatively evenly split (excluding those with no opinion) between those which thought that LDV’s CO₂ emissions per km would, and would continue to, increase without the Regulations and those which did not (see Figure 15-5). The explanatory remark from some of those who responded negatively, or had no opinion, was that CO₂ emissions from cars and particularly LCVs would decline anyway as a result of pressure from consumers for increased fuel efficiency in response to higher fuel prices. A number of stakeholders did suggest that the passenger car CO₂ Regulation, in particular, has increased the rate of CO₂ emissions reductions, and so without the Regulation CO₂ emissions would not have declined as fast.
The majority of stakeholders believed that increases in transport demand and vehicle size would continue to offset CO₂ reductions from improved fuel technology (see Figure 15-6). Explanatory remarks from those that did not agree, or who had no opinion, underlined that the Regulations focused only on one means of reducing transport’s CO₂ emissions, i.e. fuel efficiency. Other factors, such as the market and consumer choices, determined vehicle size and transport demand. Some argued that it was difficult to know what the net impact on CO₂ emissions of all of these factors would be, while others suggested that these issues would become less important as, for example, transport demand was unlikely to increase much in the future. Others argued that without the Regulation, manufacturers would aim to compete on car size and performance as well as on fuel efficiency, as all are important for consumers, so improvements in fuel efficiency would be offset by developments in the other areas without the Regulation.

Notes: N = 55
Source: Stakeholder survey conducted for this study, 2014

The word ‘offset’ was used in the question that was asked of stakeholders, and so is retained in the text here. The extent to which stakeholders took this to mean ‘completely negate the CO₂ reductions achieved by the Regulations’ or simply ‘act to counteract some of the benefits of the Regulations’ is not clear. In the interpretation of this information (in Section 5.1.2), we have recognised this issue.
Figure 15-6: Stakeholder responses to the question: “To what extent do you agree or disagree that increases in the demand for transport and in vehicle size otherwise offset technological improvement?”

Notes: N = 55
Source: Stakeholder survey conducted for this study, 2014

Road transport needs to use less oil
A majority of stakeholders agreed that the LDV CO\textsubscript{2} Regulations are, and will continue to be, needed to encourage a reduction in the energy consumed by the LDV sector (see Figure 15-7). Some of those who disagreed argued that the Regulations were not needed to reduce the energy consumed by LDVs, as the market would do this anyway. Others noted that the Regulations did not necessarily lead to a reduction in energy consumption, as they focused on CO\textsubscript{2} emissions.

Figure 15-7: Stakeholder responses to the question: “To what extent do you agree or disagree that the Regulations are needed to encourage a reduction in energy consumed by LDVs?”

Notes: N = 55
Source: Stakeholder survey conducted for this study, 2014
Further reductions in CO₂ emissions must be achieved cost-effectively without undermining sustainable mobility and the competitiveness of the automotive industry

A majority of stakeholders believed that encouraging the development of low CO₂ LDVs is, and will continue to be, beneficial for EU competitiveness (see Figure 15-8).

**Figure 15-8: Stakeholder responses to the question: “To what extent do you agree or disagree that encouraging the development of low CO₂ LDVs is beneficial for EU competitiveness?”**

Notes: N = 55  
Source: Stakeholder survey conducted for this study, 2014

### 15.2 Stakeholder views in relation to “effectiveness”

Stakeholders were questioned about their opinions on the effectiveness of the Regulations on several aspects.

The impact of the Regulations on reducing test cycle CO₂ emissions from LDVs appeared to be a fairly uncontroversial issue with wide support. Most stakeholders (92%) report that they felt the Regulations were very effective or somewhat effective. The remaining stakeholders generally stated that they had no opinion on the issue, whereas only one stated that there was a neutral impact but did not substantiate their response any further. In general, qualitative responses indicated that many stakeholders felt it was too early to assess the impacts on the LCV market, although initial signs were positive.

Around 75% of stakeholders also felt that the Regulations had been somewhat effective in reducing per km CO₂ emissions under real world driving conditions, reflecting awareness of the gap between test cycle and real world performance. That is, many stakeholders felt the overall impacts were still positive, but to a lesser extent for real world emissions.

Several industry stakeholders recognised that the Regulations were a factor influencing manufacturers’ decisions and were therefore somewhat effective in fostering innovation. However, in the short term the potential for mismatches between supply and demand of new technologies could be detrimental to competitiveness.

Representatives of suppliers noted that the reductions in CO₂ emissions seen in the market were likely to be at least partially due to market demand, but also noted that the Regulations would help.

With respect to issues of innovation, competitiveness and R&D, generally industry and non-industry opinions were on average quite similar with slightly higher levels of support among non-industry stakeholders (see Figure 15-9).

**Figure 15-9 Stakeholder responses to the question: “In your opinion, how effective have the Regulations been with respect to the following issues?”**

![Stakeholder responses to the question: “In your opinion, how effective have the Regulations been with respect to the following issues?”](image)

Notes: N = 55  
Source: Stakeholder survey conducted for this study, 2014

There was a high level of similarity (consistency) of opinions from stakeholders on the relationship between the impacts of the Regulations on short- and long-term competitiveness for car manufacturers, component suppliers and the industry as a whole. That is, it appears that stakeholders judge there to be a relatively strong relationship between the impacts on short- and long-term competitiveness. The Spearman rank correlation coefficients between answers for long- and short-term competitiveness were between 0.72 and 0.82, indicating a strong relationship (with 1.00 indicating perfect correlation). Table 15-2 shows the Spearman rank correlation coefficients, which measure the level of similarity between responses from the same stakeholder to different questions. There was also a moderate relationship between impacts on innovation and competitiveness, with Spearman rank correlation coefficients ranging from 0.39 to 0.45. Interestingly, there was only a weak relationship between impacts on R&D spending and innovation and/or competitiveness. Qualitative responses to the survey indicated that several stakeholders felt that spending on R&D did not necessarily contribute to innovations or competitiveness because the outcomes of R&D investment are uncertain.
Table 15-2: Spearman rank correlation coefficients for short- vs long-term relevance of the Regulations

<table>
<thead>
<tr>
<th></th>
<th>Fostering innovation in the automotive sector</th>
<th>Improving short-term competitiveness of European automotive manufacturers</th>
<th>Improving short-term competitiveness of European automotive component suppliers</th>
<th>Improving long-term competitiveness of the European automotive sector</th>
<th>Increasing R&amp;D spending on CO₂-reducing technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fostering innovation in the automotive sector</td>
<td>1</td>
<td>0.39</td>
<td>0.46</td>
<td>0.45</td>
<td>0.14</td>
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<td>Improving short-term competitiveness of European automotive manufacturers</td>
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<td>1.00</td>
<td>0.82</td>
<td>0.78</td>
<td>0.17</td>
</tr>
<tr>
<td>Improving short-term competitiveness of European automotive component suppliers</td>
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<td>1.00</td>
<td>0.72</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
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<td>1.00</td>
<td>0.18</td>
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</tr>
<tr>
<td>Increasing R&amp;D spending on CO₂-reducing technologies</td>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The correlation coefficient is a measure of the similarity between each individual stakeholder responses to each of the issues, comparing their response for each issue. A perfect correlation would score 1.00, meaning that responses to each question were identical.

Equity of the Regulations with respect to industry

Overall around a third of stakeholders felt that the Regulations were very or somewhat equitable by type of manufacturer, with a relatively high proportion (around 40%) of stakeholders responding that they did not know (see Figure 15-10). On average, industry stakeholders indicated that they felt the Regulations were less equitable by type of manufacturer compared to non-industry stakeholders. Several industry stakeholders substantiated their response with the view that manufacturers of premium brands can more easily pass on technology costs to consumers, and also that the volume of production is an important factor that determines the extent to which cross-subsidisation can occur.
With respect to the equity of the Regulations across different vehicle segments, again a high proportion of stakeholders responded that they did not have an opinion (see Figure 15-10). No strong overall consensus is visible, either across all respondents or within industry and non-industry groups. Qualitative responses from stakeholders outlined the relative difficulty in reducing CO₂ emissions from smaller cars, although this aspect is already recognised in the legislation through the use of a limit value curve.
**Impacts on consumers**

Stakeholders were asked whether they felt that the Regulations were equitable in proportion to the income of vehicle users. A slight skew of the responses towards neutral or equitable impacts can be seen, but there was not a strong consensus due to the complexity of assessing the impacts on users by income group.

**Figure 15-12: Stakeholder responses to the question: “In your opinion, do you consider the impacts of the Regulation to be equitable (fair) in proportion to the income of vehicle users?”**

![Bar chart showing responses to the question on equitable impacts]

*Notes: N = 51*

*Source: Stakeholder survey conducted for this study, 2014*

When asked about whether they felt the Regulations had been effective with respect to reducing lifetime running costs of vehicles, there was a mixed response, with slightly more stakeholders feeling that the Regulations had indeed been effective (see Figure 15-3). Support among non-industry stakeholders for this aspect was higher compared to responses from industry stakeholders, but no stakeholders felt that the impact had been highly detrimental.

**Figure 15-13: Stakeholder response to the question: “In your opinion, how effective have the Regulations been with respect to reducing lifetime running costs of vehicles?”**

![Bar chart showing responses to the question on effectiveness]

*Notes: N = 51*

*Source: Stakeholder survey conducted for this study, 2014*
International views on factors that help to improve the effectiveness of CO₂ and fuel economy Regulations

As part of the survey of international government organisations, this group of stakeholders was asked to identify any options used within their own national standards on vehicle CO₂/fuel economy that have been particularly successful and that could be considered when trying to improve the effectiveness of similar legislation elsewhere. The Mexican government identified the use of a tailpipe emissions metric and a fuel consumption metric as being important in ensuring the success of their national standards. Representatives from the South Korean government identified that the use of tailpipe emissions for the regulatory metric, derogations for small-volume manufacturers and special vehicles, banking/borrowing of credits and the use of credits for electric and hydrogen fuel cell vehicles had all been successful. The Swiss government indicated that its legislation is almost identical to the EU Regulations, but that their system allows for vehicle importers to transfer CO₂ credits from one importer to another. This system was set up to take into account the situation in Switzerland where there are no indigenous vehicle manufacturers, and all vehicles enter the country via vehicle importers. The Swiss government representative highlighted this system as a factor that has improved the effectiveness of their national legislation and that could be used elsewhere to improve effectiveness of similar legislation. Other options that the representative from Switzerland identified as being effective in their national legislation included the annual rebasing of the reference mass to take into account year-on-year changes in the fleet-weighted average mass of the new vehicle fleet, and the use of credits for compressed natural gas vehicles to reflect the fact that a proportion of methane supplied by the national gas grid is biogas.

15.3 Stakeholders’ views on the weaknesses of the Regulations

All of the weaknesses discussed in Section 5.2.3 appear in the top eight issues that the respondents to the stakeholder survey considered were detrimental to the effectiveness of the Regulations – i.e. the use of the NEDC, the phase-in period, niche and small volume derogations, super-credits and the focus on the powertrain (which encompasses life cycle fuel emissions and emissions embedded in vehicles) – (see Figure 15-14). The other two are covered in other sections of this report, as they are more to do with efficiency, i.e. the use of ‘mass’ as the utility parameter (see Section 5.6; also see below), or equity between manufacturers, i.e. the slope (Section 5.4.4). It is also interesting to note that the proportion of respondents that consider a particular element to be detrimental is similar for both Regulations.

For both cars and LCVs, the use of the NEDC test cycle was highlighted by stakeholders as the main element that is detrimental to the Regulations. The reasons given for this view reflected the issues discussed in Section 7.1, with one stakeholder noting that the use of tools that can optimise for the test cycle should be banned. For LCVs specifically, it was noted that the fact that commercial vehicles are tested unladen means that the test cycle figures are not representative of real-world use.
Figure 15-14: Percentage of survey respondents who considered that the respective elements were detrimental to the effectiveness of LDV CO\textsubscript{2} Regulations

Notes: Percentages include those with no opinion; the order presented relates to responses in relation to the passenger car CO\textsubscript{2} Regulation; ‘Niche derogations’ is only relevant for cars, while the ‘Treatment of multi-stage LCVs’ is only relevant for LCVs.

With respect to the phase-in periods, most stakeholders that saw these as being detrimental noted that they effectively delayed the implementation of the target, as illustrated in Section 12.1. However, a couple of manufacturers argued that the phase-in periods – particularly the shorter period for the second car target – was not long enough. While it is true that the second phase-in period is shorter than the first, manufacturers have in fact been aware of the actual target for longer.

It was some manufacturers that considered that the slope was detrimental, which is not surprising as this is important in distributing emissions reductions between manufacturers (i.e. it is relevant for the ‘equity’ of the targets between manufacturers, as discussed in Section 5.4.4). A couple of manufacturers that are responsible for more larger cars felt that the slope was too flat, while a manufacturer that is generally responsible for more smaller cars felt that the slope was too steep (another that was responsible for more medium-sized cars thought the slope was about right). These responses are not surprising, as in each case the manufacturer effectively wanted to rebalance the slope to make it more beneficial for their own fleet. Another stakeholder argued that the slope should be steeper as it would be fairer to poorer drivers as these general purchase smaller cars (see Section 5.4.5).

With respect to the derogations for small volume manufacturers and for niche car manufacturers, several commented that while both would reduce the effectiveness of the Regulations their respective impacts would not be significant (as illustrated in Section 12.3) and it might be politically important to have these. It was however noted
that the small volume derogations should not be used as a means of enabling high emitting cars to avoid being regulated. With respect to the derogation for niche car manufacturers, it was noted by a couple of stakeholders that the range defined as ‘niche’ – i.e. those manufacturers that are responsible for between 10,000 and 300,000 cars put on the market each year – potentially covers very different manufacturers. Solutions varied from sub-dividing the range and applying different rules to those manufacturers falling in each sub-division to lowering the upper limit.

The use of ‘mass’ as the utility parameter was considered to be a weakness for both cars and LCVs in spite of the recent suggestion in the report that was undertaken in support of the confirmation of the 2020 target that ‘mass’ was the better utility parameter for LCVs (TNO et al, 2012). The main argument for this conclusion from stakeholders was that mass disincentivises the use of CO2 reduction technologies that reduce the mass of vehicles, as discussed in Section 9.1. This was noted as being a particular issue for some small volume car manufacturers for which mass reduction was important. Other arguments against the use of ‘mass’ was that it was not a good measure of utility (either for cars or LCVs) and provided a greater risk of gaming than ‘footprint’, as also noted in Section 9.1.

As with the phase-in period, super-credits caused concerns for opposing reasons. While some non-industry stakeholders argued that these were detrimental as they reduced the effectiveness of the Regulation, as illustrated in Section 12.2, and so allowed emissions from ICE vehicles to be higher than they would otherwise have been. A manufacturer argued that the lack of super-credits between 2016 and 2019 would delay the introduction of EVs, while another suggested that it would have been better if the factors applied had been higher.

Concern about the focus on the powertrain in the Regulations was linked to some of the issues discussed in Annex A. The lack of consideration of energy consuming devices by the test cycle was the most commonly raised issue in his respect, although the lack of consideration of the CO2 emissions associated with electricity production and the lack of consideration of emissions embedded in the vehicle were also identified as weaknesses.

There were fewer concerns about the other elements of the Regulations. Some noted that the need for eco-innovations further underlined the failures of the test cycle and so argued that these should not be needed once the new cycle had been introduced. Others were more pragmatic, as they considered that it would be difficult for all technologies to be accounted for on any test cycle, so eco-innovations could continue as long as there was also a mechanism to account for technologies that are less beneficial in the real-world than on the test cycle. It was suggested that a potential weakness was that the company proposing the eco-innovation always had the upper hand, so it was important for the Commission’s evaluation to be as robust as possible. Others argued that administratively, the process might simpler, e.g. in the US, there was a much simpler system in relation to off-cycle technologies, as a pre-defined list was drawn up; a credit is then awarded for any technology from that list that was introduced in new vehicles.

With respect to the use of a utility parameter per se, one stakeholder argued that it was not consistent with the need to protect the environment to give more lenient targets to larger cars (i.e. as implied by the slope), which are driven further. Another noted that at some point – although probably not yet – it will be necessary to phase out the use of a utility parameter, as it would become equally easy for all manufacturers to meet the target as a result of improvements in technology.

The few stakeholders that expressed an opinion on the respective targets thought that the second target for cars was more effective than the first as it was more challenging, while another noted that the weakening of the target from 120 gCO2/km to 130 gCO2/km
Evaluation of Regulations 443/2009 and 510/2011 on CO\textsubscript{2} emissions from light-duty vehicles

(see Section 2.2.1) was not necessary as can be seen by the progress that has been achieved (see Section 3.2). For LCVs, the one stakeholder that offered a view argued that both targets were too weak as a result of mistakes in the Commission’s Impact Assessment. Issues raised in relation to the excess emissions premium were actually more to do with other elements, such as concerns about the test cycle (see above), rather than the premium itself.

In relation to multi-stage LCVs, several manufacturers and their representatives argued that the procedure for these LCVs should be simplified and, if retained, should apply only to the vehicles produced and not sold. It was suggested that the Commission identify the number of vehicles affected by this provision and to consider derogating such vehicles if appropriate. The concern with respect to the vehicles covered was that manufacturers were only responsible for the base vehicle and had no responsibility – or ability to influence – the additional equipment that is added to the base vehicle before the vehicle is sold. Hence, they should only be held responsible for the CO\textsubscript{2} emissions associated with the base vehicle, but not the sold vehicle.

In a separate question, respondents were also asked to list three major sources of inefficiency in the Regulations. In many cases, respondents did not directly relate this question to issues of direct costs, but instead mentioned other issues that are covered in responses to other evaluation questions, particularly those on weaknesses discussed above. For example, the use of the NEDC and its flexibilities were highlighted as a major source of inefficiency by many of the non-industry respondents and one manufacturer.

From the industry-perspective, one of the most common sources of inefficiency mentioned was a lack of coherence with other policy initiatives, particularly in relation to safety and air pollutant legislation (which is discussed under ‘coherence’ in Section 5.7). Other inefficiencies related to the fact that details on some of the provisions – such as eco-innovations and super-credits – were not available when the Regulation came into force; this was largely due to the fact that neither of these were included in the Commission’s original proposal (see Section 2.4). A third important concern of industry was that the requirements that were being put on industry – in terms of the development of alternatively-fuelled vehicles – did not yet match the demands of consumers. While this has been the case, many Member States are now taking measures to stimulate consumers’ interest in these vehicles.

The metric used by the respective Regulations was mainly identified as a source of inefficiency – as discussed in Section 5.6 – by non-industry stakeholders. In fact, after the use of the NEDC, the use of ‘mass’ as the utility parameter in the car CO\textsubscript{2} Regulation was the next most frequently mentioned inefficiency by these stakeholders. With respect to LCVs, an industry stakeholder argued that a volume-based metric would have improved the efficiency of that Regulation.

Other sources of inefficiency mentioned by industry stakeholders included:

- Insufficient lead times compared to other countries.
- The administrative costs associated with applying for derogations for small volume manufacturers, which was also mentioned by a Member State administration. This might be addressed – at least in part – by the ‘de minimis’ that was introduced in 2014.
- The lack of consideration of the mileage undertaken by different vehicles - as discussed in Section 5.6.
- Concerns about the implications of manufacturers’ strategies of introducing the WLTP before the 2020 target – it is foreseen that the next test cycle could come into force by 2017.
• Concerns about the accuracy of the monitoring data that had been sent to manufacturers for the purpose of verification.

• That the eligibility criteria for eco-innovations did not extend to technologies that reduced off-cycle emissions, such as technologies that affect driver behaviour (see Section 5.6).

• The fact that LCVs are measured unladen on the test cycle.

From the perspective of non-industry stakeholders, other sources of inefficiency that were mentioned included the existence of super-credits and the phase-in, the focus on in-use emissions and the fact that the targets are set only every five years, all of which have been discussed in the context of weaknesses in this report (see Section 5.2.3). Others believed that the targets were too lenient generally, or that the absence of at least indicative targets beyond 2020 was a source of inefficiency. The lack of technological neutrality and the absence of an incentive to reduce energy consumption were also mentioned as inefficiencies. Another stakeholder argued that the focus on delivering short-term CO₂ reductions was a major source of inefficiency, while also arguing that the use of an absolute threshold of 50 gCO₂/km for the super-credits, rather than a relative threshold, and not allowing banking and borrowing were other sources of inefficiency.

In order to address some of these inefficiencies, it was suggested that the emissions as measured on the new test cycle should be complemented by some form of in-use testing to ensure that reductions on the test cycle are replicated in real-world conditions; this information could even be directly used in the Regulations based on the use of Portable Emissions Measurement System (as is being done for other pollutants) supported by a methodology that would account for different driving styles would be required. It was also suggested that super-credits could be replaced by a different type of incentive for ultra-low carbon vehicles that do not weaken the target, e.g. a flexible mandate. Under such a system, all carmakers would be required to supply some ultra-low carbon vehicles (potentially increasing the number and range of models being supplied). Manufacturers who perform well would be rewarded by raising their overall fleet average CO₂ target (i.e. making their target less stringent). Whereas manufacturers that choose not to supply ultra-low carbon vehicles would be expected to achieve greater improvements in the efficiency of conventional technologies – and would be required to achieve a more stringent target.

Another stakeholder identified a number of technical issues relating to the tests themselves, including the lack of common equipment and standards in relation to the way in which tests are carried out, that the parameter for rolling resistance was outdated and that IT tools that can be used to optimise vehicles for the test cycle are not banned. Another inefficiency that was raised was the potential adverse impact of the competition between type approval authorities. It was argued that this means that they can market themselves to meet the needs of the manufacturers, which may undermine the testing procedure. In order to address this, it was suggested that there needs to be some sort of oversight of the process, e.g. by the Commission, in order to ensure that type approval authorities cannot market themselves on the basis of their ability to optimise vehicles for the test cycles.

Finally, one stakeholder suggested that another source of inefficiency was related to the fact that there were no speed limits on German motorways. It was argued that this resulted in all cars from the medium sized cars upwards that are offered on the German market being over-specified in order to be competitive at speeds that are rarely ever driven in practice, even in Germany. If all cars were built to a lower specification in terms of their maximum speed, it was argued that there would immediately be greater efficiency with negative costs.
15.4 Stakeholder views in relation to coherence

The vast majority of stakeholders believed that the elements of both the car CO\textsubscript{2} Regulation and LCV CO\textsubscript{2} Regulation provided a consistent message to manufacturers (see Figure 15-15). The main comment in relation to the coherence of the elements of both Regulations were that they did not cover all CO\textsubscript{2} emissions associated with a car (e.g. they did not account for lifecycle fuel and embedded vehicle emissions, as discussed in Annex C). In this report, we have discussed this issue in the context of the weaknesses of the Regulations (see section 5.2.1). Other negative responses in relation to the LCV CO\textsubscript{2} Regulation were due to a concern that the CO\textsubscript{2} reduction targets for LCVs within the Regulation were not sufficiently strong to provide an incentive to manufacturers to reduce CO\textsubscript{2} emissions. The issue of multi-stage vehicles was raised, but no further detail on the associated issues was given.

Of those stakeholders which had an opinion, the majority believed that the car and LCV CO\textsubscript{2} Regulations worked together to provide manufacturers with a consistent incentive to reduce CO\textsubscript{2} emissions (see Figure 15-16). Some negative comments reflected concerns about the relative stringency of the LCV CO\textsubscript{2} Regulation, i.e. the Regulations could not work well together, as the target in the LCV CO\textsubscript{2} Regulation was not sufficiently strong. There was a concern that the differences in stringency between the two Regulations could incentivise manufacturers to register high emitting cars as LCVs to take these out of the more stringent passenger car CO\textsubscript{2} Regulation. Another issue that was raised by a number of stakeholders was that consideration should be given to integrating at least the smaller, car-derived LCVs into the passenger car CO\textsubscript{2} Regulation, as they use similar technologies.
Just under half of the stakeholders believed that there were trade-offs between the economic, environmental and social impacts of the Regulations, and half of these thought that these were appropriate (see Figure 15-17). Some stakeholders suggested that there were no trade-offs, as the Regulations were beneficial for the environment, consumers and manufacturers. On the other hand, other stakeholders highlighted a number of trade-offs that were important, including that the Regulations need to ensure that:

- People were not excluded from accessing mobility, if the Regulations resulted in increased costs.
- Any increased costs did not slow down fleet renewal and thus the penetration of low CO₂ emitting vehicles and benefits for air quality.
The separate survey of non-EU international government organisations asked these stakeholders for their views on whether there is a case for greater levels of international harmonisation of vehicle CO\textsubscript{2}/fuel economy standards. All three responding countries (Mexico, South Korea and Switzerland) indicated that greater levels of international harmonisation would be beneficial. The Swiss representative indicated that the fact that the EU Regulations exempt vehicles type approved under national and EC Small Series Type Approval procedures has been problematic in Switzerland. In Switzerland, these types of vehicles are included within the scope of the national vehicle CO\textsubscript{2} regulations, and importers of such vehicles claim that they should be exempted, in line with the provisions in the EU regulations. The Swiss Government would welcome (a) the EU including these vehicles within the scope of the car and LCV CO\textsubscript{2} regulations, or (b) monitoring and reporting on them.

15.5 Stakeholder views in relation to “EU added value”

A clear majority of stakeholders agreed that it was appropriate to set CO\textsubscript{2} emission performance standards for passenger cars and LCVs at the EU level (see Figure 15-18), with only two dissenters (neither of whom substantiated their responses with further explanation). Several other stakeholders volunteered comments on the appropriateness of implementing legislation at the EU level, noting that voluntary standards had not worked and the difficulty that would be experienced in trying to harmonise LDV standards among Member States, as well as citing the benefits of the single market in terms of achieving higher sales volumes and minimising compliance costs.
Figure 15-18: Stakeholder responses to question: “In your opinion, was it appropriate to implement CO\textsubscript{2} emissions performance requirements for passenger cars or vans at the EU level?”

![Bar chart showing stakeholder responses to the question.]

Notes: \(N = 50\).
Source: Stakeholder survey conducted for this study, 2014

Stakeholders were asked how likely it would be that, in the absence of the EU Regulations, individual Member States would have attempted to reduce vehicle CO\textsubscript{2} emissions in alternative ways, specifically via national legislation or a voluntary agreement. The majority of respondents stated that it was somewhat or highly likely that national legislation would have been introduced in the absence of the EU Regulations for passenger cars and vans (see Figure 15-19). In general, responses from industry anticipated it was more likely that Member States would have taken action through national legislation compared to the responses from other stakeholders.

Figure 15-19: “In the absence of the EU Regulations, how likely is it that individual Member States would have attempted to reduce vehicle CO\textsubscript{2} emissions from passenger cars and vans by introducing national legislation?”

![Bar chart showing percentage of respondents.]

Notes: sample size = 55
Source: Stakeholder survey and interview responses – February to May 2014
The majority of respondents (39% - see Figure 15-20) stated that it would be highly or somewhat likely that Member States would have carried on with voluntary agreements for passenger cars. However, 33% of respondents stated that Member States would be either highly or somewhat unlikely to continue with voluntary agreements, suggesting a divide in opinions. In terms of introducing voluntary agreements for vans at the Member State level, opinion is again divided. 37% stated that it was highly or somewhat likely, versus 35% who stated it would be highly or somewhat unlikely for voluntary agreements to be introduced for vans. The effectiveness of the voluntary agreements with ACEA, JAMA and KAMA has been discussed in more detail in Section 5.3. Discussions with stakeholders revealed that they tended to hold the view that voluntary agreements are not very effective. Similarly to national legislation, the responses from industry appeared to anticipate the introduction of voluntary agreements was more likely compared to other stakeholders.

**Figure 15-20:** “In the absence of the EU Regulations, how likely is it that individual Member States would have attempted to reduce vehicle CO₂ emissions from passenger cars and vans through voluntary agreements?”

<table>
<thead>
<tr>
<th>Percentage of Respondents (%)</th>
<th>Cars (continuation of existing agreement)</th>
<th>Vans (new agreement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly likely</td>
<td>31%</td>
<td>18%</td>
</tr>
<tr>
<td>Somewhat likely</td>
<td>16%</td>
<td>18%</td>
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<tr>
<td>Neutral</td>
<td>15%</td>
<td>4%</td>
</tr>
<tr>
<td>Somewhat unlikely</td>
<td>5%</td>
<td>18%</td>
</tr>
<tr>
<td>Highly unlikely</td>
<td>4%</td>
<td>22%</td>
</tr>
<tr>
<td>No opinion / Don’t know</td>
<td>4%</td>
<td>22%</td>
</tr>
</tbody>
</table>

Notes: sample size = 55
Source: Stakeholder survey and interview responses – February to May 2014

In terms of effectiveness of the alternative measures in reducing CO₂ emissions from passenger cars and vans in comparison with the existing EU Regulations, the majority of respondents agreed that both national measures would be somewhat or significantly less effective (see Figure 15-21)
Evaluation of Regulations 443/2009 and 510/2011 on CO\textsubscript{2} emissions from light-duty vehicles

Figure 15-21: "In the absence of the Regulations, how effective would national policy measures have been in reducing passenger car and van CO\textsubscript{2} emissions?"

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure15-21}
\caption{Percentage of Respondents (\%)}
\end{figure}

Notes: sample size = 55  
Source: Stakeholder survey and interview responses – February to May 2014

Stakeholders also generally felt that voluntary agreements would have been less effective compared to the Regulations – see Figure 15-22. Regarding voluntary agreements, stakeholders pointed out that whilst things are going well, manufacturers are likely to be happy to demonstrate their achievements through reducing average CO\textsubscript{2} emissions from new vehicles. In periods where business is tough, voluntary agreements become neglected, and their effectiveness weakens.

Figure 15-22: "In the absence of the Regulations, how effective would voluntary agreements have been in reducing passenger car and van CO\textsubscript{2} emissions?"

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure15-22}
\caption{Percentage of Respondents (\%)}
\end{figure}

Notes: sample size = 55  
Source: Stakeholder survey and interview responses – February to May 2014
In terms of ranking the effectiveness, overall opinions from industry and non-industry stakeholders were fairly similar, with both groups rating the effectiveness as being lower on average compared to the Regulations.
16 Annex J: Terms of Reference – Technical Specifications

The evaluation shall respect the following constraints:

It shall examine the appropriateness, effectiveness, efficiency, social equity and competitive neutrality of all the basic elements of the Regulations. To this end it may take into account the outcomes and conclusions of other studies carried out to assess various relevant issues.

The contractor shall also assess the Regulation’s effectiveness with regard to other relevant pieces of legislation and taking into account foreseen trends in technology and market.

The reference period for the evaluation of the impact of the Regulations is 2009 – 2014. However the Contractor shall also consider the voluntary agreement (in force before the entry into force of the car Regulation) and perform a comparative assessment analysis and evaluation of the results and outcomes of both regimes.

The contractor shall assess in its evaluation the degree to which the Regulations are fit for purpose looking forward to the decade beyond 2020 in view of possible changes in technology, markets and other relevant aspects.

The geographical scope shall cover implementation in the EU but also take into account the relevant international context. The contractor will take into consideration the fact that the majority of automotive manufacturers and parts suppliers operate globally.

Tasks

Task 1

Task 1 concerns data collection. The main relevant data, material and sources of expertise are the following:

- Reports compiled for the Commission on various issues related to the Regulations, and related topics. Reports for the period 2006-2013 are set out at: http://ec.europa.eu/clima/policies/transport/vehicles/cars/studies_en.htm
- Relevant Commission, JRC and EEA databases and websites:
- Other car and light commercial vehicle databases (e.g. JATO, ACEA, ICCT)
- Stakeholders in industry, consumer, lease companies, small business and driver organisations, civil society and academia from EU and other countries.
- Other institutions working in the area of LDV CO₂ emissions. The contractor should make use of relevant data sources not only in the EU but also in USA, Japan, Korea, China and Australia.
- Commission and Member State officials involved in the implementation of Regulations.

The tenderer will describe in the bid the methodology to be followed to gather the relevant data for the evaluation. The tenderer will explain the reasoning for the choices made, the key stakeholders to be contacted, the data series that are available or to which access will be possible.
Task 2

Task 2 is to provide evidence-based answers to the following questions by using the proposed methodology and through employing expert judgement. The tenderer will describe in the bid how the interviews will be prepared, the questionnaire developed and reviews and analyses completed to respond to the questions set out in this Task.

Relevance:
(1) To what extent do the objectives of the Regulations still respond to the needs?
The contractor should consider the current and projected (up to year 2030) technical, environmental and economic challenges.

Effectiveness
(2) How do the effects of the Regulations correspond to the objectives?
(3) To what degree have the Regulations contributed to achieving their targets and what are their weaknesses?
(4) To what extent have the Regulations been more successful in achieving their objectives compared to the voluntary agreement on car CO₂ emissions?

Efficiency
(5) Are the costs resulting from the implementation of the Regulations proportional to the results that have been achieved?
(6) What are the major sources of inefficiencies? What steps could be taken to improve the efficiency of the Regulations? Are there missing tools and/or actions to implement the Regulations more efficiently?
The contractor should consider aspects relating to administrative burden and competitiveness of the European automotive industry (vehicle manufacturers and component suppliers).

Coherence
(7) How coherent are the Regulations’ modalities with their objectives?
(8) How well do the Regulations fit with other EU policy objectives?

EU Added Value
(9) What is the EU added value of the Regulations? To what extent could the changes brought by the Regulations have been achieved by national or individuals’ measures only?
(10) Are there other technological, economic or administrative issues that are not covered by the existing Regulations and that could be introduced in view of their potential added value?
The contractor should provide clear evidenced answers to these 10 questions in the final report. Task 2 will be accomplished through:

• Interviews with relevant Commission, European Parliament, industry, civil society and
• Member States’ officials who are working with/responsible for the Regulations;
• Consultations including questionnaires and interviews with key stakeholders from the EU and as appropriate from other countries with similar legislation (e.g. US, Canada, China, Korea, Australia, Brazil);
• Review of existing literature on the issue (EU and worldwide);
• Analysis of opinions, reports and data series and feedback from the European Parliament, industry, NGOs, lease companies, small business, consumer and driver organisations.
• Analysis based on the data gathered under Task 1

**Input by the Contracting Authority**

A steering committee, chaired by DG CLIMA, will be set up for the management of this evaluation contract and to consider the deliverables set out in point 3.5. In addition, DG CLIMA will update the contractor on on-going developments on the related legislative framework.
17 Annex K: References and Sources


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## 18 Annex L: Glossary of Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACEA</td>
<td>European Automobile Manufacturers Association</td>
</tr>
<tr>
<td>Biofuels</td>
<td>A range of liquid and gaseous fuels that can be used in transport, which are produced from biomass. These can be blended with conventional fossil fuels or potentially used instead of such fuels</td>
</tr>
<tr>
<td>BEV</td>
<td>Battery Electric Vehicle. Also referred to as a pure electric vehicle (EV). A vehicle powered solely by electricity stored in on-board batteries, which are charged from the electricity grid</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide, one of the principal greenhouse gases</td>
</tr>
<tr>
<td>CoC</td>
<td>Certificate of Conformity</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EEA</td>
<td>European Environment Agency</td>
</tr>
<tr>
<td>EV</td>
<td>Electric vehicle</td>
</tr>
<tr>
<td>ELV</td>
<td>End-of-life vehicles</td>
</tr>
<tr>
<td>FCEV</td>
<td>Fuel cell electric vehicle. A vehicle powered by a fuel cell, which uses hydrogen as an energy carrier</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gases. Pollutant emissions from transport and other sources, which contribute to the greenhouse gas effect and climate change</td>
</tr>
<tr>
<td>GWP</td>
<td>Global warming potential</td>
</tr>
<tr>
<td>HEV</td>
<td>Hybrid electric vehicle. A vehicle powered by both a conventional engine and an electric battery, which is charged when the engine is used</td>
</tr>
<tr>
<td>IA</td>
<td>Impact Assessment</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal combustion engine, as used in conventional vehicles powered by petrol, diesel and natural gas</td>
</tr>
<tr>
<td>LCA</td>
<td>Life cycle assessment</td>
</tr>
<tr>
<td>LCV</td>
<td>Light Commercial Vehicle, also known as vans</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas. The liquefied form of propane which can be used as a transport fuel.</td>
</tr>
<tr>
<td>M1 vehicles</td>
<td>Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver’s seat</td>
</tr>
<tr>
<td>M2 vehicles</td>
<td>Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver’s seat, and having a maximum mass not exceeding 5 tonnes</td>
</tr>
<tr>
<td>M3 vehicles</td>
<td>Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver’s seat, and having a maximum mass exceeding 5 tonnes.</td>
</tr>
<tr>
<td>M category</td>
<td>Passenger vehicles, including categories M1, M2 and M3</td>
</tr>
<tr>
<td>N1 vehicles</td>
<td>Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>N2 vehicles</td>
<td>Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 3.5 tonnes but not exceeding 12 tonnes</td>
</tr>
<tr>
<td>N3 vehicles</td>
<td>Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 12 tonnes</td>
</tr>
<tr>
<td>N category</td>
<td>Goods vehicles, including categories N1, N2 and N3</td>
</tr>
<tr>
<td>NEDC</td>
<td>New European Driving Cycle</td>
</tr>
<tr>
<td>NOx</td>
<td>Oxides of nitrogen. These emissions are one of the principal pollutants generated from the burning of fossil and biofuels in transport vehicles.</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer. Refers to car manufacturers in this document</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in hybrid electric vehicle, also known as extended range electric vehicle (ER-EV). Vehicles that are powered by both a conventional engine and an electric battery, which can be charged from the electricity grid. The battery is larger than that in an HEV, but smaller than that in a BEV</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter. Inhaling particulate matter has been linked to asthma, lung cancer, cardiovascular problems, birth defects and premature death. Subscripts indicate the particle diameter, for example PM$_{2.5}$ denotes fine particles with diameter of 2.5 micrometres or less. Smaller particles are thought to be more damaging to health as they can penetrate further into the gas exchange regions of the lungs.</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>Sulphur dioxide</td>
</tr>
<tr>
<td>SOx</td>
<td>Oxides of sulphur (including sulphur dioxide)</td>
</tr>
<tr>
<td>TAD</td>
<td>Type-Approval Document</td>
</tr>
<tr>
<td>TTW emissions</td>
<td>Tank to wheel emissions, also referred to as direct or tailpipe emissions. The emissions generated from the use of the fuel in the vehicle, i.e. in its combustion stage</td>
</tr>
<tr>
<td>WLTP</td>
<td>Worldwide Harmonised Test Protocol</td>
</tr>
<tr>
<td>WTT emissions</td>
<td>Well to tank emissions, also referred to as fuel cycle emissions. The total emissions generated in the various stages of the lifecycle of the fuel prior to combustion, i.e. from extraction, production and distribution.</td>
</tr>
<tr>
<td>WTW emissions</td>
<td>Well to wheel emissions</td>
</tr>
</tbody>
</table>