



Analysis of fuel economy and GHG emission reduction measures from Heavy Duty Vehicles in other countries and of options for the EU

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Note: From 1 September 2015, we rebranded as Ricardo Energy & Environment, a trading name of Ricardo-AEA Ltd. The legal entity of Ricardo-AEA Ltd remains unchanged and all formal company information presented in this proposal, including previous years' financial accounts, are all in the name of Ricardo-AEA Ltd.

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Executive Summary

Ricardo Energy & Environment, and partners Transport and Environmental Policy Research and Ricardo UK, were commissioned by DG Climate Action to provide technical support to the European Commission on “Analysis of fuel economy and GHG emission reduction measures from Heavy Duty Vehicles in other countries and of options for the EU” (reference CLIMA.C.2/FRA/2013/0007). This final report provides a summary of the findings of the work completed during the course of this project.

Lorries, buses and coaches (together referred to as heavy duty vehicles - HDVs) produce about a quarter of the CO₂ emissions from road transport in the EU and some 5% of the EU's total greenhouse gas (GHG) emissions. The Commission has been carrying out a range of work in recent years as part of its overall strategy to reduce GHG emissions from HDVs, consistent with the EU's long-term goal of reducing GHG emissions in transport by at least 60% by 2050 compared to 1990 levels and its medium-term goal of achieving a 30% reduction in non-EU ETS sectors by 2030 compared to 1990 levels.

This work has included the development of the VECTO tool to simulate the efficiency of a given HDV, to enable full vehicle certification for HDVs, and also monitoring and reporting. The Commission's EU Strategy for low-emission mobility that was adopted on 20th July 2016 includes a commitment to make a legislative proposal on CO₂ standards for HDVs during the current Commission mandate.

This project prepares the ground for an Impact Assessment on HDV CO₂ standards by analysing international experiences in this field and proposing draft policy options, with following main objectives:

1. To provide a comprehensive review of the measures implemented to reduce GHG emissions and fuel consumption from HDVs in various international markets where these have been implemented, or where they are planned.
2. To provide a detailed analysis and comparison of the various measures in place/planned in the various markets considered, to understand their relevance and replicability for the EU market.
3. To document lessons learned and best practice from the design and implementation of these international measures which may be relevant to the EU context.
4. To use the analysis of relevance to the EU and best practice to develop a series of potential options for the EU to introduce measures aimed at reducing GHG emissions and fuel consumption from HDVs.
5. To produce a preliminary analysis of the feasibility, pros and cons and costs and benefits of the potential options developed for the EU.
6. To consult extensively with a range of expert stakeholders on the EU options considered, to help refine and optimise the list of HDV GHG emission reduction / efficiency options suitable for the EU market.

The first task for this project focused on identifying current and planned measures aimed at reducing CO₂ or improving fuel economy of HDVs in international markets. Ten markets were chosen; 5 'key' markets were studied in detail and 5 'secondary' markets were summarised more briefly (as outlined in Table ES1). The secondary markets often had only planned measures and thus a supporting stakeholder consultation was heavily relied upon for the latest information. The measures used in each market were characterised under a consistent set of headings:

- Introduction and broad market characteristics (key markets only).
- Background to measures.
- Measure design.
- Monitoring, reporting and verification (key markets only).
- Evaluation and next steps (key markets only).

Table ES1: International markets with current or planned HDV CO₂ or fuel efficiency measures studied in this report

Key international markets	Secondary international markets
California	Brazil
Canada	Chile
China	India
Japan	Mexico
United States	South Korea

In Task 2 of this project, a comparative analysis was used to score each measure’s suitability to the EU context and recorded the lessons learned in each market. The relevance of each measure was determined at a consistent, disaggregated level using criteria used in Task 1 and across the five primary headings below, with results of this analysis also summarised in Table ES2 for the key markets:

1. Transferability and replicability (technical; administrative and legal).
2. Effectiveness.
3. Efficiency.
4. Alignment and equity.
5. Explicit barriers.

Table ES2: Results overview of the comparative analysis from Task 2

	Transferability and replicability							Effectiveness in	Efficiency	Alignment and equity				
	Technical			Admin/legal						Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment
Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation								
USA	✓	✓✓	✓	-	✓	✓✓	✓	✓	✓	✓	✓✓	?	✓	✓
China	✓	-	✓	✗	-	-	-	-	-	?	✗	?	-	-
Japan	✓	-	✓	-	✓	-	-	-	-	✓	?	?	✓	✓
India	✗✗	✗	✗✗	-	✗	-	✓	-	-	-	?	?	?	?

The outputs of Task 2 were used to inform Task 3 – the development of options for the EU. This task used a prescribed methodology (outlined in the main report) to select two ‘base options’ composed of elements from the international measures. From this base, the study team created two policy options for the EU. One further option was then created using alternative policy instruments, not yet seen in international markets. Each option was described in detail and the advantages and disadvantages of the approach were explored, in addition to a high-level impact assessment. The policy options were characterised under a similar set of headings to Task 1:

1. Summary.
2. Timeline.
3. Design.
4. Advantages and disadvantages.
5. High-level impact assessment.

A stakeholder consultation exercise was then used to adjust and tailor the resulting options, where feedback from a wide range of industry representatives was considered. Finally, a combined favoured

illustrative policy option was constructed, taking into account feedback received from all stakeholders. The accompanying stakeholder consultation outcome provided a summary of the industry's key concerns and their relative support.

Overall, the following four options were presented for consideration by stakeholders:

- Business as usual (BAU).
- Policy option 1: Technology requirements and soft measures.
- Policy option 2: US-based measures.
- Policy option 3: Japanese-based measures.

Interviewed stakeholders were broadly supportive of introducing HDV CO₂ standards for the EU. All of them favoured the US-based policy option over the others, and thought that it would be the most effective approach to achieving CO₂ emissions reductions of the options presented, referring to its generous flexibility mechanisms (i.e. credit schemes) and technology-neutral approach. The principal concern with this option was the lack of intrinsic ability to handle alternatively fuelled vehicles; however, this was considered as possible to be addressed with a suitable credits system in the mid-term. Policy option 1 was the least supported due to its relatively lower GHG savings potential and compartmentalised improvement areas. However, most stakeholders identified that holistic elements of the measure (best practice dissemination, enhanced driver training and fleet performance benchmarking) would be complementary to any resulting regulation. Policy option 3, which was based on Japan's Top Runner method of setting standards, was considered by most stakeholders to have some intrinsic flaws (i.e. opportunities for gaming), which were difficult to mitigate, but some suggested that the method could be used to set the first HDV CO₂ limit values.

The major points of disagreement between the stakeholders included the timing of the regulations and the inclusion, or not, of separate engine testing. On the one hand, manufacturers sought for limit values to be considered only after a robust baseline had been developed from reliable data (i.e. the HDV certification data that will become available with the future monitoring and reporting system), arguing that this would reduce the risk of perverse incentives or negative effects on industry. Conversely, organisations such as NGOs were in favour of a two-phase approach, in order to facilitate the achievement of long-term EU CO₂ reduction objectives: first, the immediate introduction of a less stringent and less encompassing regulation, followed a few years later by a technology forcing and detailed regulation. For separate engine testing, manufacturers believed that this detached engine requirements from vehicle design, would lead to non-optimal powertrain design and a reduced flexibility of compliance. Opponents argued that engines standards maintain a link between standards for criteria pollutants and engine CO₂, and provide the regulatory clarity to encourage expensive but effective engine improvement research. A detailed comparison of the discussion has been provided in the main report.

Other findings from the consultation included the perceived importance of CO₂ performance standards for trailers from the majority of stakeholders. If introduced, all stakeholders were in favour of a simulated generic-tractor, specific-trailer approach and recognised that the marketplace was composed principally of SMEs and hence required minimally burdensome regulations. All interviewed stakeholders were supportive of the use of the VECTO simulation tool in any eventual measure, using metrics, drive cycles and disaggregation of HDVs already present in VECTO. All stakeholders were also supportive of a gCO₂/tonne-km metric but some also desired assessment over a volume-based metric; no consensus was reached on how this should be achieved.

For the final step in the analysis, a consolidated 'illustrative policy option' was developed, taking into account the median perspective of the stakeholders in order to form a combined option. The two major points of disparity – the regulatory timeline and separation of engine standards – remain as undecided.

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1 Introduction and overview

1.1 Introduction

Ricardo Energy & Environment was commissioned to provide technical support to the European Commission on the “analysis of fuel economy & GHG emission reduction measures from HDVs in other countries and of options for the EU” (hereafter, the ‘project’) under a framework contract (reference CLIMA.C.2/FRA/2013/0007). The project was commissioned by the European Commission’s DG Climate Action (hereafter ‘the Commission’).

1.2 Study context and objectives

Lorries, buses and coaches (together referred to as HDVs) produce about a quarter of the CO₂ emissions from road transport in the EU and some 5% of the EU’s total greenhouse gas (GHG) emissions. Whilst EU legislation is already in place to tackle CO₂ emissions/fuel efficiency from cars and vans (together referred to as light duty vehicles (LDVs)) and regulations are also in place to tackle local air pollutant emissions from heavy duty vehicle (HDV) engines, there is currently no legislation in place to directly tackle these significant CO₂ emissions from HDVs. Despite market-driven incremental improvements in HDV efficiency, a more rapid reduction in emissions/fuel consumption is therefore required in order to support the EU’s long-term goal of reducing GHG emissions in transport by at least 60% by 2050 compared to 1990 levels and its medium-term goal of achieving a 30% reduction in non-EU ETS sectors by 2030 compared to 1990 levels.

HDVs have a wide variety of applications, duty-cycles and configurations, making regulation a much more challenging task than that for LDVs. The difficulty in reliably ascertaining the CO₂ emissions from this diverse range of vehicles has meant that regulators have not had sufficient information on which to regulate. To fill this information gap, the Commission developed the VECTO tool to simulate the efficiency of a given heavy duty vehicle. A legislative proposal regarding HDV certification using the tool is currently being drafted, and expected to be adopted in the first half of 2017 (See Appendix A2 for a brief summary). This should be followed by a separate legislative proposal on HDV monitoring and reporting later in the same year. The Commission’s EU Strategy for low-emission mobility that was adopted on 20th July 2016 includes a commitment to make a legislative proposal on CO₂ standards for HDVs during the current Commission mandate.

Measures to tackle emissions from HDVs could take a wide range of forms, including: mandatory limits on average CO₂ emissions from newly-registered vehicles (as have been implemented for LDVs in the EU already); measures to support alternative fuel infrastructure; vehicle taxation-based measures; or road/infrastructure-pricing measures. Some international markets have already implemented HDV GHG emissions reduction or efficiency measures and have, so far, broadly focused on setting mandatory average CO₂ or fuel efficiency limits for newly-registered HDVs. The Commission is seeking to better understand the range of options available to it, so it can most effectively and efficiently approach HDV fuel economy and GHG emissions reduction measures.

This project prepares the ground for an Impact Assessment on HDV CO₂ standards by analysing international experiences in this field and proposing draft policy options.

Consequently, the main objectives of this study were as follows:

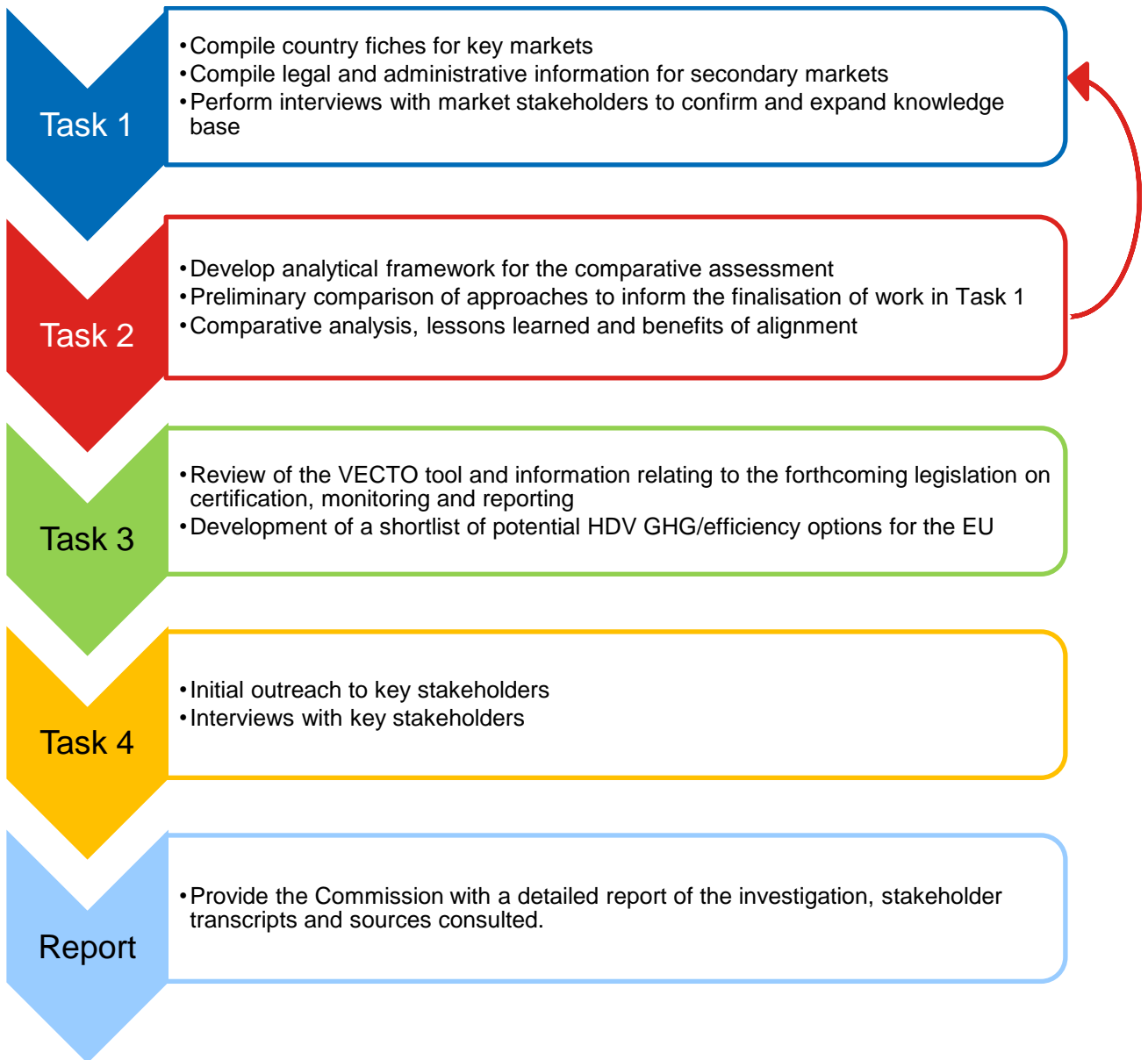
1. To provide a comprehensive review of the measures implemented to reduce GHG emissions and fuel consumption from HDVs in various international markets where these have been implemented, or where they are planned.
2. To provide a detailed analysis and comparison of the various measures in place/planned in the various markets considered, to understand their relevance and replicability for the EU market.
3. To document lessons learned and best practice from the design and implementation of these international measures which may be relevant to the EU context.

4. To use the analysis of relevance to the EU and best practice to develop a series of potential options for the EU to introduce measures aimed at reducing GHG emissions and fuel consumption from HDVs.
5. To produce a preliminary analysis of the feasibility, pros and cons and costs and benefits of the potential options developed for the EU.
6. To consult extensively with a range of expert stakeholders on the EU options considered, to help refine and optimise the list of HDV GHG emission reduction / efficiency options suitable for the EU market.

1.3 Breakdown of tasks

Figure 1.1 provides an overview of the five key tasks completed under this project. The following sections provide more details on the specific methodological approach.

Figure 1.1: Project task overview



2 Task 1: Literature review and interviews

Box 1: Key points for Task 1

Task outline:

1. Task 1.1: Detailed country case study fiches
2. Task 1.2: High-level review of other relevant markets
3. Task 1.3: Stakeholder interviews

Key outputs:

- Fiches of the measures implemented to reduce the GHG emissions/improve the fuel efficiency of HDVs in other countries around the world – informed by desk research and interviews
- Write-ups of the issues covered in the interviews for each country which would not otherwise be recorded in the fiches.

2.1 Overview and progress

The purpose of Task 1 is to gather and validate the information required to compare approaches taken by 10 markets around the world in the regulation of HDV efficiency¹. This part of the project commands the bulk of the data collection required, with a feedback loop from Task 2 (comparative analysis and lessons learned) to ensure it is suitably comprehensive.

As part of Subtask 1.1 (Section 2.2 below), detailed market case study fiches for the United States of America, California, Canada, China and Japan have been developed. These fiches are presented in the following subsection, with California and Canada merged under the US fiche for brevity.

A further five secondary markets have also been reviewed, though in less detail than the key markets. These are: Chile, Brazil, Mexico, India and South Korea. Summaries of available information on regulatory activity and plans from these countries are provided in Subtask 1.2 (Section 2.3).

Finally, Subtask 1.3 (see Section 3) provides an overview of the interviews held with regulatory authorities and experts to validate and extend the information contained within the fiches.

2.2 Subtask 1.1: Detailed market case study fiches

The detailed market case studies for the United States (with California and Canada), China and Japan are presented in this report section.

2.2.1 United States

2.2.1.1 Summary

2.2.1.1.1 *Introduction and broad market characteristics*

The United States has had CO₂ and fuel consumption regulations in place since 2014. The regulations are developed and managed by the Environmental Protection Agency (EPA; for CO₂) and the National Highway Traffic Safety Administration (NHTSA; for fuel consumption). The regulations cover all on-road vehicles with a gross vehicle weight rating over 8,500lbs (3,850 kg), which are broken down into 7 subcategories. Almost identical legislation is in place in Canada.

¹ Note: an improvement in HDV efficiency infers a reduction in HDV GHG emissions – the former has been used as the prevalent terminology in this report.

2.2.1.1.2 **Background to measures**

The drivers behind these measures involved a combination of energy security and environmental protection concerns. The regulations took 7 years from conception to implementation, beginning in 2007 and becoming effective for the 2014 model year (MY). The current regulations are known as Phase 1 and run until 2017, after which Phase 2 regulations will be implemented and run until 2027.

The regulations use a baseline derived from actual vehicle market data, taking representative vehicles for each subcategory for MY2010. From this baseline, improvements are expected through a range of technologies with varied adoption rates. Compliant MY2017 vehicles will be used as the baseline for Phase 2. However, Phase 2 also has an updated Greenhouse gas Emissions Model (GEM), described in Section 2.2.1.3.5, and therefore its stringency is not easily comparable to Phase 1 regulations.

A number of studies were carried out that informed the regulations, including assessment of the environmental and economic impacts and reviewing which technologies would best achieve the required results. Furthermore, extensive consultation was carried out with a wide range of stakeholders in the sector.

2.2.1.1.3 **Scope**

The current US regulations give standards for fuel consumption and CO₂ emissions for engines and whole vehicles. In Phase 2, further regulations are introduced specifically for trailers. The standards for CO₂ emissions and fuel consumption are given in gCO₂e/ton-mile and gal/1,000 ton-miles, respectively. The standards also cover nitrous oxide (N₂O) and methane (CH₄) emissions, as well as air-conditioning leakage and hydrofluorocarbon release.

Engines are certified using an engine dynamometer running two different drive cycles. The Federal Test Procedure (FTP) drive cycle is used to replicate urban driving conditions, while the Supplementary Emissions Test (SET) drive cycle reflects steady-state driving conditions common on highways. The standards for whole vehicle emissions and fuel consumption use the GEM simulation model, which has three different drive cycles and a further two idle cycles for vocational vehicles. The simulation currently uses default engine maps, but in Phase 2 manufacturers will provide engine maps to better simulate transient drive cycles. Pickups and vans (Class 2B/3) are tested on a chassis dynamometer instead, similar to the LDV programme.

Manufacturers must meet certain standards within each manufacturing year, although there are flexibility options to allow manufacturers sufficient lead-time to introduce technologies to their fleet. The flexibilities are provided through an averaging, banking and trading (ABT) scheme that also gives credits for early adoption and advanced technologies.

Through adopting separate engine and vehicle standards, the US agencies have sought to drive technology improvements in both engines and vehicles, while also leaving the market to decide the most cost effective technologies to meet the standards.

Overall, significant savings in fuel reduction (530 million gallons), CO₂ emissions (270 million metric tonnes of GHGs), fuel cost savings (\$50 billion²) and other social and environmental benefits (\$49 billion²) are expected in Phase 1 alone. Phase 2 is expected to see further savings significantly greater than Phase 1 in all respects.

2.2.1.1.4 **Monitoring, reporting, verification and enforcement**

Under the Clean Air Act, all vehicles must be certified at the point of sale. Testing is carried out by the manufacturer before sale, but also throughout the useful life of the vehicle (engines must continue to perform within tolerance, though no whole vehicle in-use standards are in place). Testing data is sent to the EPA and the NHTSA prior to manufacture, and this data is used to calculate model year emissions. Violations and penalties are issued on the basis of this information. There is a single reporting structure in which manufacturers report their sales for the year and their emissions given in the Certificates of Conformity. Given the flexibilities in place and the feasibility of compliance to the Phase 1 regulation, no penalties have yet been necessary.

² US dollars (2009).

2.2.1.1.5 *Evaluation and next steps*

The EPA is not formally obligated to produce an ex-post assessment of the regulations and instead chooses to undertake ex-post studies and alterations only where necessary due to issues highlighted by stakeholder feedback or significant non-compliance. To this aim, the EPA now develops gradual standards with multiple-technology pathways and introduced the first HDV fuel consumption measures (Phase 1) to be met with existing technologies, primarily in order to put in place the systems and processes to drive more substantial emission reductions in future regulatory iterations. The regulations were designed with multiple technology pathways due to experiences from recent regulations implementing exhaust gas recirculation in 2004, particulate matter traps in 2007 and selective catalytic reduction (SCR) in 2010 which had unforeseen impacts on the second hand vehicle market, principally due to durability concerns resulting from specific technology requirements.

The EPA does not currently have plans to significantly modify the HDV CO₂ regulation and will continue to monitor CO₂ emission projections to make any decisions on next steps. In 2017, the National Academy of Sciences is expected to release their next report on HDV efficiency looking at the Phase 2 regulations and out to the future, where information in this report may compel the EPA to further develop the regulations.

2.2.1.1.6 *Deviations for California*

California holds a unique regulatory position in the US, as the only state with an air quality regulator independent from the Federal Government. The California Air Resources Board (CARB) have led the way in emissions regulations, with a further 13 States adopting CARB regulations over the Federal equivalent. Historically, California have implemented more stringent emissions standards than the Federal Government.

Regarding HDV CO₂ and fuel consumption regulations, California has followed the federal US Phase 1 regulations in 2014. However, it is possible that California will decide to adapt slightly more stringent Phase 2 standards than the federal level. A decision is expected in 2017 on this.

In addition, California has adopted two separate programmes that go beyond the federal HDV regulations. Firstly, California have a Hybrid Truck and Bus Voucher Incentive Project (HVIP), which provides vouchers for the purchase of new hybrid lorries and buses. Secondly, California have made the EPA's SmartWay programme, discussed in Section 2.2.1.3.3, mandatory for certain lorries and trailers under the Tractor-Trailer regulation, adopted in 2010. This programme is voluntary on a national scale and requires the use of certain SmartWay-certified technologies to improve the aerodynamics and tyre rolling resistance of long-haul tractor-trailer vehicles. However, many of the measures set out in this regulation are incorporated into Phase 2 of the US regulations (applying from 2018) and will therefore essentially become obsolete.

2.2.1.1.7 *Deviations for Canada*

As tends to be common practice, Canada has followed US standards and adopted Phase 1. Similarly, it is expected that Canada will adopt the Phase 2 standard along the same timeline as the US.

Administration, monitoring and enforcement is handled by Environment Canada. Before the introduction of Phase 1, Environment Canada undertook a separate regulatory impact assessment which estimated a reduction of approximately 19.1 Mt CO₂e, 7.2 billion litres of fuel and economic benefits of \$5.3 billion³.

The Canadian Phase 1 standards contain very minor changes to the US equivalent. First, Canada allows for an optional certification for vehicles over 80,000 lbs which are not covered by the US regulations, due to the greater use of such vehicles in the Canadian fleet. Second, limit values in Canada are purely defined in terms of GHG emissions. Fuel consumption standards are not included in the Canadian legislation because this would have required significant amendments to the Motor Vehicle Fuel Consumption Standards Act (Canada Gazette, 2013). Canada does have fuel efficiency standards for light-duty vehicles (LDVs) but has not extended them to HDVs.

³ Canadian dollars (2011).

2.2.1.2 Introduction and broad market characteristics

2.2.1.2.1 Administrative framework

Two regulating bodies concern HDV legislation in the US: the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA). The EPA is responsible for noxious and CO₂ emissions legislation under the Clean Air Act (EPA, 1970) and has regulated HDV engines since 1974. The NHTSA is responsible for fuel economy under the Energy Policy and Conservation Act (EPA, 1975) and since 2010 has worked with the EPA to introduce the first GHG and fuel efficiency standards for HDVs in the US.

The legislation is echoed by Canada, which adopted the US Federal regulations for both LDVs and HDVs in light of the highly integrated nature of the engine and vehicle industry in North America⁴.

The only inhomogeneity of standards in North America arises from the Californian Air Resources Board (CARB), who have led the way in North American emissions legislation since the 1960s. It is the only state regulatory agency as California was the only state to have such a body before the Federal Clean Air Act was passed in 1974, giving authority to the EPA. The Clean Air Act includes a waiver process by which California can enact their own emissions standards for motor vehicles. The waiver must be authorised by the EPA before it can be enacted. The CARB standards are offered as an alternative to federal standards, and are currently adopted by 13 'CARB states'⁵ and the District of Columbia. Whilst Californian noxious emissions standards for light duty vehicles have historically been more stringent than federal requirements, HDV noxious and GHG emission standards have been predominately harmonised with federal emissions standards since 2004. A few subtle differences exist in the noxious emission standards, including marginally different testing regimes, not-to-exceed limits and urban bus standards; however, the same federal HDV fuel economy standards apply. In addition, California has over the years introduced a number of separate/complementary programmes intended to improve HDV fuel economy.

2.2.1.2.2 Fleet composition

2.2.1.2.2.1 Vehicle types, weights and sizes

The current US heavy-duty fleet is defined as vehicles ranging from 18-wheeler combination tractor-trailers to the largest pick-up trucks and vans. The classification of these vehicles is based on their Gross Vehicle Weight Rating (GVWR) as illustrated in Table 2.1.

Table 2.1: US vehicle weight classification⁶

Class	2b	3	4	5	6	7	8
GVWR (lbs)	8,501 – 10,000	10,001 – 14,000	14,001- 16,000	16,001- 19,500	19,501- 26,000	26,001- 33,000	> 33,001
GVWR (kg) ^a	3,856 – 4,536	4,536 – 6,350	6,351 – 7,257	7,258 – 8,845	8,846 – 11,793	11,794 – 14,969	> 14,969

Notes: ^a Conversion to kg is not from original source. Conversion factor used: 2.20462 lbs/kg. Figures are rounded to nearest whole number.

Vehicles within the US market are, for the CO₂ regulatory framework, separated into three categories within the regulations: combination tractor-trailers, vocational vehicles, and HD pick-up trucks and vans (EPA, 2016):

⁴ Most of the vehicles manufactured in Canada are exported to the US, and most of Canada's vehicles are imported from the US.

⁵ The CARB states are: California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington. Arizona reverted to federal standards in 2012.

⁶ Adapted from (EPA, Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule, 2011).

-
- Vocational vehicles span the extremes of the classifications, and are available in a variety of sizes, ranging from utility “bucket” lorries, to the largest dump trucks. Their annual mileage ranges from 15,000 to 150,000 miles (EPA, 2016), evidencing the breadth of duty cycles in this category. The regulations are implemented by setting fuel consumption targets in gallons/1000 ton-mile (gallons per unit of freight delivered) for vehicles or gallons/100bhp-hour for engines bench tested under the Heavy Duty Federal Test Procedure (FTP) test cycle.
 - Combination tractor-trailers are typically included within classes 7 and 8 of Table 2.1’s classification, and are fitted with either sleeper or day cabs. This subcategory of heavy-duty vehicle is the largest within the US heavy-duty sector, comprising 60% of the sector’s total CO₂ emissions and fuel consumption (EPA, 2016). These vehicles typically operate with one or more trailers with up to 50,000lbs (22,730kg) of payload, and operators tend to opt for vehicles with greater GVWR, thereby reducing fuel consumption per unit mass of payload. Frequently, these vehicles cover over 150,000 miles annually, and can operate for between 20 and 30 years (EPA, 2016).
 - Pickup trucks are the most profitable vehicles for US OEMs. Ford F series, GM Full-size Pickups and Dodge Ram recorded 30%, 29%, and 41% of the respective OEM’s 2014 sales in the US. Under GHG regulatory classifications these pickups are divided into Class 2a and Class 2b by their GVWR. Heavy duty pickups tend fall into Class 2b or Class 3 (ICCT, 2015). Unlike the other two Heavy duty vehicle categories, CO₂ limits (grams per mile) are set based on a work factor which takes into account the payload capacity, towing capacity and 4-wheel drive capability. Limits for gasoline and diesel pickups and vans are specified separately. Emissions are tested under a composite of US FTP and Highway Fuel Economy Test cycles with a 55% weighting towards the results from FTP cycle, which replicates US urban and crowded expressway conditions (EPA, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2, 2016).

2.2.1.2.2.2 *Typical journeys and duty cycles*

US HDVs have comparatively high utilisation rates, especially for the dominant tractor vehicles which frequently cover over 150,000 miles annually and can operate for between 20 and 30 years (EPA, 2016). Fuel costs are a key consideration for purchasers of these HDVs, as described for Class 8 combination tractors in Section 2.2.1.2.2.1, above.

Figure 2.1: Distribution of lorry fleet annual mileage of travel (R&D opportunities for heavy lorries: (US Department of Energy, 2009))

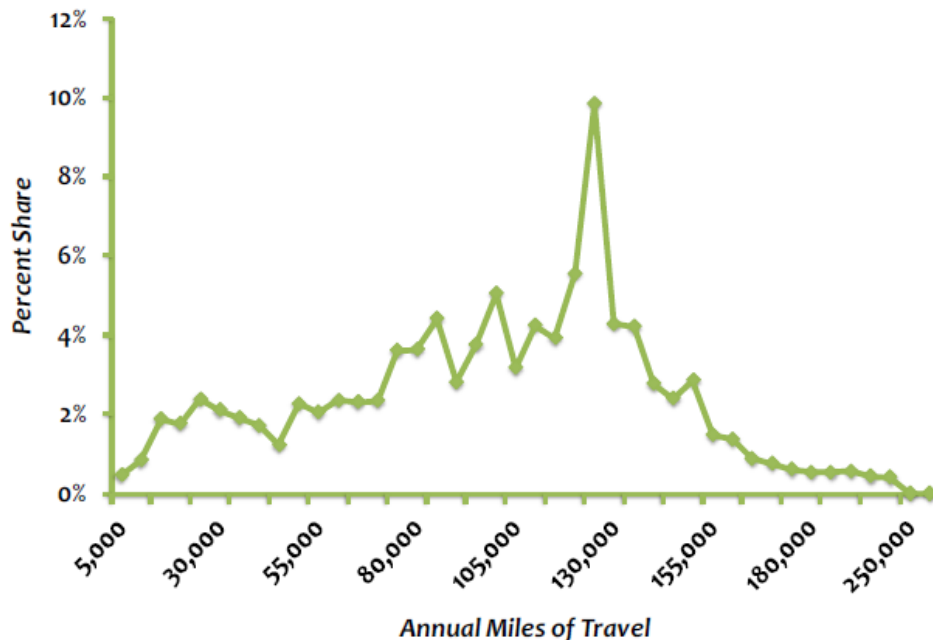


Table 2.2: California lorry categories; 2010 population, Average Vehicle Miles Travelled (VMT) and CO₂ equivalent emissions (California Hybrid, Efficient & Advanced Truck Research Centre, 2013)

Vehicle category	Vehicle stock	% of HDV stock	Average VMT	CO ₂ e (Mt/yr)	% CO ₂ e
Tractors – OTR	175,000	12%	85,000	12.9	38%
Tractors – Short haul / Regional	111,000	8%	55,000	6.3	18%
Class 3 – 8 Work - Urban	253,000	17%	25,000	3.6	11%
Class 3 – 8 Work – Rural/ Intracity	295,000	20%	35,000	6.1	18%
Class 3 – 8 Work – Work Site	77,000	5%	13,000	0.8	2%
Class 2b/3 vans/pickups	531,000	36%	21,000	4.2	12%
Unknown	15,000	1%	8,192	0.1	0%
Total	1,457,000	100%	34,255	34.0	100%

2.2.1.2.2.2.1 Deviations in California

As is expected, Californian HDV duty cycles are, in general, very similar to the rest of the US. Californian lorries were found to have a slightly lower annual mileage than that from the whole of the US, however. Table 2.2 shows an average of 85,000 miles per year for a Class 8 lorry. CARB's own figures suggest an average of 77,000 miles and 105,000 miles for Californian-registered tractor-trailer vehicles travelling in-state and inter-state, respectively. These figures fit within the distribution of all US HDV mileages, displayed in Figure 2.1, but are found at the lower end of the reported distribution. CARB suggest that this difference is principally due to the high population density in California compared to the rest of the US, requiring shorter journeys between distribution centres and population centres.

2.2.1.2.2.3 Overview of operating costs and typical ownership profiles

Although synonymous with Europe in terms of high utilisation and high maintenance costs, these factors have not translated into an increase in vehicle leasing as has been the case in Europe. American HDV operators typically choose to own their lorries. Rather than purchasing new vehicles, many owners opt to re-build engines where possible, and as a result there is a large re-sale market within the US. In fact, between 60 and 70% of the heavy duty fleet in the US is estimated to be second-hand vehicles (Spears, 2016). Therefore, in addition to concerns of fuel economy, a key consideration for purchasers is the re-sale value and adaptability of a vehicle.

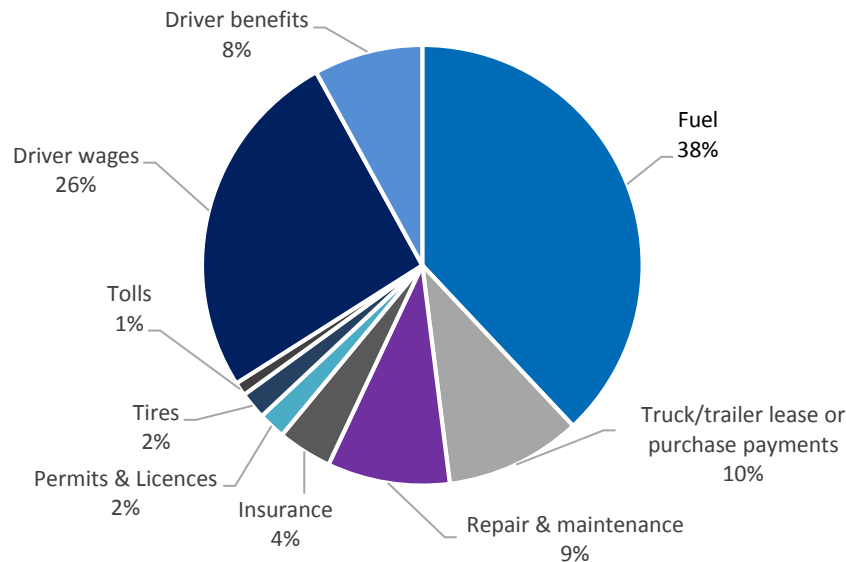
However, several features of the heavy-duty manufacturing industry complicate this picture. For example, the market is very fragmented, containing many manufacturers who design, manufacture, and service equipment for a wide range of users and uses, and unlike the light-duty vehicle industry these manufacturers most often build specific components rather than complete vehicles. Therefore, the complex supply chains and the heterogeneity of products means that designing efficient and effective regulations is challenging.

In the heavy duty sector, Class 8 lorries record the highest annual use at 150,000 to 200,000 miles per year with a Class 8 fleet turnover of approximately 3 years (NPC, 2012). Consequently, Class 8 lorries use the most amount of fuel in the US heavy duty sector; fuel efficiency legislation and technology development on Class 8 HDVs is expected to yield the greatest and most effective reductions in fuel use. As a result of the high mileage of these vehicles, fuel costs are a key consideration for purchasers. The lifetime fuel cost for an average passenger car is similar to the vehicle's original price, whereas costs of fuel for Class 8 vehicles are typically five times that of the original vehicle (US Department of Energy, 2009). Therefore, Class 8 heavy duty lorries have strong market incentives to implement new efficiency technologies, and since research and development activities typically have high return on investments for both transport operator and Federal Government, the market is characterised by rapid turnover of first-hand vehicles (US Department of Energy, 2009).

2.2.1.2.2.3.1 Deviations for California

There are no California specific total cost of ownership (TCO) surveys available; however, this is expected to be broadly similar to the general US TCO figures. One notable difference is that California has higher fuel taxes than other States, and therefore fuel costs are expected to be higher. However, as stated above, the lower annual driving distances may offset the increased fuel prices making it difficult to speculate on the impact of this on TCO for Californian lorries compared to US average lorries.

Figure 2.2: Breakdown of the average per-annum cost of a Class 8 lorry operation in 2013. The typical US Class 8 HDV costs \$67 per hour to run (ATRI, 2014).



2.2.1.2.2.4 Fuel efficiency technology uptake and effectiveness

The geography of the US necessitates that freight travels long distances by road: distances between urban regions are often large. As such, US tractor units spend much of their time at steady speeds on highways. The noxious emissions regulations for tractors recognise this through engine certification over the Supplementary Emissions Test (SET) cycle, a steady-state test which omits transient operations. Vocational vehicles such as refuse collection lorries and construction vehicles are tested over a transient cycle due to the start-stop nature of their duty cycle (FTP). The operational impact or effectiveness of new fuel saving technologies is based on the duty cycle of the vehicle as shown in the following tables.

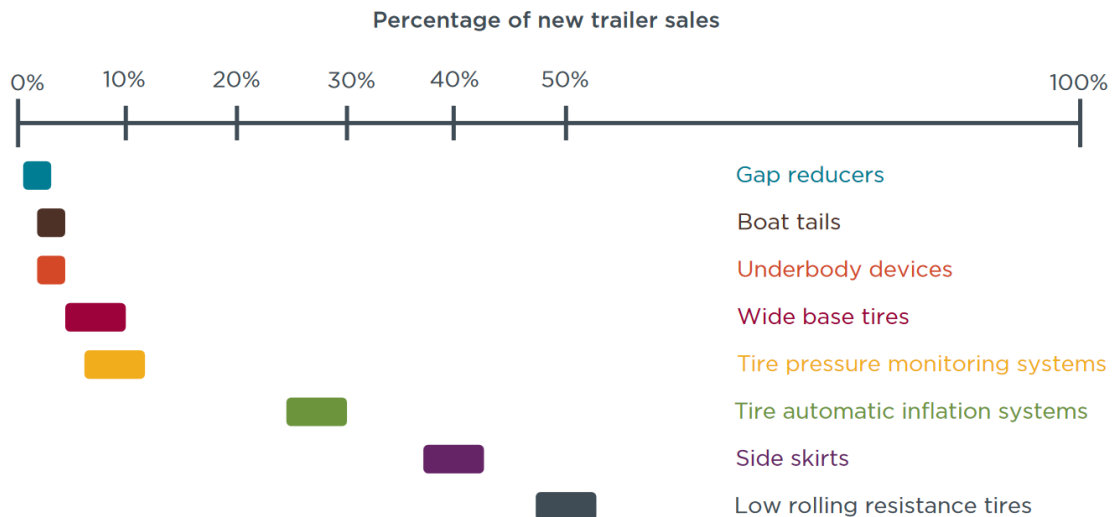
Different technologies are thus incentivised depending on the duty cycle of the vehicle. The technologies that the EPA envision to be incentivised under Phase 1 include engine friction reduction, after-treatment optimisation and turbo-compounding. Turbo-compounding is an example of a technology which gives very little benefit under transient operating conditions yet is very effective under steady-state conditions. By using two different test cycles (SET for combination tractors and Heavy Duty FTP for vocational vehicles), manufacturers are encouraged to include the technology in combination tractors but much less so in vocational vehicles with an inherently transient duty cycle. For Phase 1, in particular, the agencies are aiming to incentivise the implementation of technologies that are already commercially available to manufacturers, in an effort to avoid the early-implementation of technologies before their effectiveness over a vehicle's life-cycle is assessed.

The ICCT have reported on the uptake of aerodynamic technologies for trailers in North America based on survey data (ICCT, 2014). Overall, the report suggested that there has been significant maturity of the market, primarily with the adoption of low rolling resistance tyres, side skirts, and automatic inflation systems, shown in Figure 2.3. The study suggests a 50% adoption rate of low rolling resistance dual-sized tyres and an impressive uptake of trailer side skirts to nearly half of all new box trailers sold. The study also found that roughly one-quarter of all US trailers on the road have at least one aerodynamic technology. The success seen in this industry is attributed in part to the SmartWay programme and the California Tractor-Trailer GHG regulation which have driven technology development, cost reduction and increased adoption.

Table 2.3: Potential fuel economy improvements for different heavy duty applications, adapted from (NAS, 2010)

Technology Levers	Lorry categories and operational impact on fuel economy (% improvement)			
	Class 8 Line-Haul	Class 7, 8 Non-line haul	Bus	Class 4, 5, 6
Idling Technology	2-6%	-	-	-
Combustion Optimisation	4.5-12%	4.5-12%	4.5-12%	4.5-12%
Hybrids	6-9%	42-53%	27-42%	20-50%
Advanced Gasoline Engines	-	-	-	0-20.5%
Waste Heat Recovery	2.5-10%	-	-	-
After-treatment	3-6%	3-6%	3-6%	4-6%
Tyres	11%	1.5-2.5%	1.5-3.0%	2.4-3.0%
Aerodynamics	11.5-13.3%	1.4-1.6%	0-8%	6-9%
Weight/Chassis	1.25%	1%	4-6.25%	3.2-4.0%
Transmission and Driveline	7%	4%	3.5-5.0%	3.2-4.0%
APU and other secondary power	4-8%	-	-	-
Adaptive cruise control	1-10%	1-10%	-	1-10%
Predictive cruise control	1-3%	1-3%	-	1-10%
Telematics	1%	5-10%	5-10%	5-10%

Figure 2.3: Trailer technology adoption based on interview responses from ICCT study (ICCT, 2014)



2.2.1.2.2.4.1 Deviations for California

It is expected that technology uptake and effectiveness in California are very similar to the US more widely; no information on current differences between California and other US States is available. In terms of future technology uptake, CalHEAT has developed a range of California-specific scenarios for HDVs.

CalHEAT aims to coordinate accelerated research on clean HDV technologies to help California meet its pollution targets and is funded by the California Energy Commission. CalHEAT research, forecasts, roadmaps and recommendations determine future technology investment priorities, and thus are a useful indicator to understand the future direction of the Californian HDV fleet from a technology perspective. The 13 technology strategies deemed most feasible by CalHEAT research are shown in Figure 2.4, where solid circles represent the technologies in the CalHEAT roadmap that are expected to contribute to noticeable GHG reductions by 2020; half circles represent technologies expected to be implementable after 2020 with noticeable results; and, the empty circles indicate technologies not expected to offer significant results in the given lorry class.

Figure 2.4: Technology pathway effectiveness by vehicle category, (California Hybrid, Efficient & Advanced Truck Research Centre, 2013)

Pathway	Technology	Class 7-8 Urban	Class 8 OTR	C 3 – 8 Work Site	Class 3 – 8 Urban	Class 3 – 8 Rural	Class 2b – 3 Vans/ trucks
Electrification	Hybrid Electric	●	◐	●	●	●	●
	Electrified Auxiliaries	●	●	●	●	◐	●
	E-Trucks	●	○	◐	●	◐	◐
	Electric Power Take-off	○	○	●	○	○	○
	Plug-in Hybrids	●	○	●	●	●	●
	Electrified Corridor	●	○	○	◐	○	○
	AF Hybrid	●	◐	◐	●	●	◐
Engine and Driveline	Hydraulic Hybrid	◐	○	○	●	●	●
	Optimized AF Engine	●	●	●	●	●	●
	Waste Heat Recovery	●	●	○	●	◐	◐
	Engine Optimization	●	●	●	●	●	●
	Alternative Power Plants & Combustion Cycles	●	●	◐	◐	◐	◐
	Transmission and Driveline	●	●	●	●	●	●

2.2.1.3 Background to measures

2.2.1.3.1 Rationale

In a 2010 Presidential Memorandum, President Obama stated that through the development of a new generation of energy efficient medium- and heavy-duty vehicles, there was an opportunity to use innovative technologies to create high-quality domestic jobs and spur economic growth, enhance national energy security, and offer improved environmental protection (The White House, 2010). Further, the environmental argument for the introduction of standards was visible: standard inventory compilation activities of the anthropogenic emissions generated by the US indicate that transport sources emitted 29% of U.S. total GHG emissions in 2007, and had been the fastest-growing source of emissions since 1990. The heavy-duty transport sector accounted for 20% of all transport emissions (equivalent to 6% of total U.S. GHG emissions) in 2007 (EPA, 2009). The first US HDV CO₂ regulations were designed in this context. At this time, similar fuel-economy regulations for HDVs were in existence in Japan and these provided an indirect influence on the development of the US standards. The approach of the Japanese regulators was to use engine testing, and vehicle and drive cycle assumptions. For Phase 1, this provided a certification option which the agencies could consider the benefits and drawbacks of. However, due to the time-constraints for the development of Phase 1, the US standard developers favoured the use of their own data from test procedures and approaches to standards setting already in existence in the US. In Phase 2, the agencies were able to explore the standards in Japan in further detail, and as a result, some elements of the Japanese regulations are reflected in the Phase 2 rulemaking. For example, Japan had moved towards improved computer inputs

for engine testing, bearing similarities with the changes made to the GEM simulation model for Phase 2, as described further in subsection 2.2.1.4.7.4. In addition to this, the US Phase 2 regulation was influenced somewhat by engagement with the European Commission. For example, the agencies reviewed the VECTO model to understand potential methods for the integration of powertrain elements, such as shift strategies, into the Phase 2 GEM.

2.2.1.3.1.1 Deviations for California

CARB's focus prior and leading up to the US Phase 1 regulations centred on air pollution, and specifically ozone, such as in the HDV Regulations in 2004. The reasoning given for adopting the Phase 1 standards in 2014 was to reduce GHG emissions and to harmonise Californian and US federal regulations. This suggests that the regulations were pursued initially on a federal level, and California used this opportunity to also adopt similar measures. Since the passing of the California Global Warming Solutions Act of 2006 (AB 32), CO₂ emissions have featured prominently in CARB regulations. AB 32 aims to reduce California's GHG emissions to 1990 levels by 2020, regulating the major GHGs emitted into the atmosphere (including carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride). The scoping plan developed suggested that transport will achieve this through vehicle efficiency improvements, specifically through lorry efficiency, and through vehicle hybridisation of medium- and heavy-duty vehicles.

2.2.1.3.1.2 Deviations for Canada

The Government of Canada announced the development of new regulations in May 2010, on the same day as the Presidential Memorandum regarding fuel efficiency standards in the US. An environmental rationale is cited as the main purpose for introducing HDV emission regulations in Canada. Canada has committed to the recent Paris Agreement, Copenhagen Accord, the Cancun Agreements in reducing, by 2020, total GHG emissions by 17% from 2005 levels (Canada Gazette, 2013), and in alignment with those of the US. At the time of implementing the first standards other international agreements also included the Kyoto Protocol, however Canada has since formally withdrawn (Government of Canada, 2011). The relative contribution of HDVs to national GHG emissions is slightly higher than the US, representing 24-33% of the transport sector, and 7-8% of total GHG emissions in Canada (Environment Canada, 2010).

The socio-economic benefits of alignment with the US are also provided as rationale, especially in earlier regulations. As described in Section 2.2.1.2.2.1, the North American automotive industry is highly integrated and maintaining harmonisation ensures the Canadian market's competitiveness by preventing additional costs for manufacturers (Canada Gazette, 2003). Given that the majority of HDVs manufactured in Canada are exported to the US and therefore must meet US regulations, the introduction of multiple standards across the already fragmented supply chain would increase complexity and costs.

2.2.1.3.2 Overview of measure

The overall approach used by the US in their measure design was to consider the fuel consumption (or CO₂ emissions) reduction potential of a wide range of different technologies, or technical measures, when applied to heavy duty vehicles. Detailed consideration of the heavy duty baseline vehicles and the technologies already in use provided the starting point. Assumptions about uptake rates of different technologies led to the measure design discussed in the following section. Regulations are phased covering emissions of lorries sold up to 2017 (Phase 1) and for later years (Phase 2). Phase 2 both built on Phase 1 in terms of its methodology, updated the baseline vehicle performance from Phase 1 studies, and considered targets for an extended timeline.

2.2.1.3.2.1 Deviations for Canada

Canada's measures duplicate the US standards with a few subtle exceptions. Canada's regulations cover emissions of lorries sold up to 2017 (Phase 1) but as yet are not scheduled for later years (Phase 2). The Canada-specific provisions include:

- A Canada-specific averaging, banking and trading system to allow flexibility on compliance for fleet operators. The administrative burden was minimised by aligning reporting systems with the US EPA. Furthermore, in light of the shorter lead time available for Canadian companies to

comply, all MY2014 US EPA-certified vocational and tractor HDVs and engines were exempt from the requirements of the ABT system. This exemption was reduced to 50% of 2015 vehicles and engines, and 25% for 2016. This allowed US EPA-certified vehicles and engines that exceeded the required standards to be sold in Canada without requiring offsetting by vehicles and engines below the standards. There are also rules on the number of engines sold to prevent gaming strategies.

- Certification for vehicles between 80,000 and 140,000 lbs, as this weight category is more prominently used in Canada than in the US.

2.2.1.3.3 **Implementation timeline**

HDV fuel economy had been on the radar of the regulatory bodies for some time before the regulations were introduced, as demonstrated by the EPA's 'SmartWay Transport Partnership' launched in 2004.

2.2.1.3.3.1 *SmartWay Programme*

This programme aimed to voluntarily achieve fuel efficiency improvements and reduce the environmental impacts from freight transport without legislative requirements. Initially, the scheme was launched with the support of 15 charter members and the backing of the American Trucking Associations, and has since expanded to include more than 3,000 companies and affiliates who participate today (EPA, 2016). The SmartWay programme involves three aspects:

- The SmartWay Transport Partnership, which assists various stakeholders measure, benchmark and improve their logistics.
- The SmartWay Brand, which certifies various fuel-saving technologies and operational practices.
- SmartWay Global Collaboration, which aims to harmonise global carbon accounting methods in the freight sector.

The SmartWay brand is designed to encourage Partnership Members to upgrade their lorry fleets with various fuel saving technologies (see Table 2.4) and practices, and focuses on tractors and trailers. The key technologies covered include idling reducing technologies (IRTs) for lorries, school buses and locomotives, aerodynamic devices such as wind deflectors to reduce aerodynamic drag, and low rolling resistance (LRR) new and re-treaded tyre technologies for tractors and trailers.

Table 2.4: SmartWay approved technologies

Technology type	Specific technology	Vehicle type
IRTs	Auxiliary power units and generator sets	Lorries
	Battery air conditioning systems	Lorries
	Electrified parking spaces / truck stops	Lorries
	Fuel operated heaters, aka direct fired heaters	Lorries and school buses
	Thermal storage systems	Lorries
Aerodynamics	Skirt	Trailers
	Tail	Trailers
	Gap Reducer	Trailers
	Under Fairing	Trailers
	Splash Guard	Trailers
	Tyre	Drive, steer and trailer axles

Low Rolling Resistance Tyres	Re-tread: Mold Cure Tread	Drive, steer and trailer axles
	Re-tread: Pre Cure Tread	Drive, steer and trailer axles

Companies are encouraged to join the SmartWay programme through the EPA SmartWay website. Initially, the programme involves monitoring and accounting tools for reporting fuel efficiency. Once this reporting has been carried out, advice is provided on where improvements can be made. The SmartWay logo can be used by Partners to demonstrate their compliance to clients. Since 2004, the SmartWay programme is estimated to have saved its partners over 170 million barrels of oil, equivalent to around 73 million tonnes of CO₂ (EPA, 2016). In Phase 2, regulations will be put in place regarding fuel efficiency for tractor-trailers, which will effectively replace the technology part of the SmartWay programme by mandating fuel efficiency improvements.

2.2.1.3.3.2 SuperTruck Initiative

Further to this, the US Department of Energy launched its SuperTruck I initiative in 2009. This was a partnership between the Department of Energy and four industry teams to collaboratively fund projects to research, develop and demonstrate technologies to improve the fuel economy of the heavy-duty fleet. To date, three of the four teams have exceeded the goal of the initiative of 50% fuel efficiency improvement in comparison to the most efficient MY2009 vehicles, whilst the final team is on track to meet this target in late 2016 to early 2017 (EPA, 2016). In March 2016, the Department of Energy announced the second phase of this scheme, SuperTruck II, which will fund further projects with a budget of \$80m in total. This phase is more ambitious than the first, with the aim to fund projects that research, develop, and demonstrate technologies which further improve fuel economy by more than 100% relative to the most efficient MY2009 vehicles. This will require integrated systems and solutions, ensuring that the various technologies combine. To achieve these targets, the Department of Energy expects projects to utilise a wide variety of technologies, including further improvements to engine efficiency, drivetrain efficiency, aerodynamic drag, tyre rolling resistance, and vehicle weight (EPA, 2016).

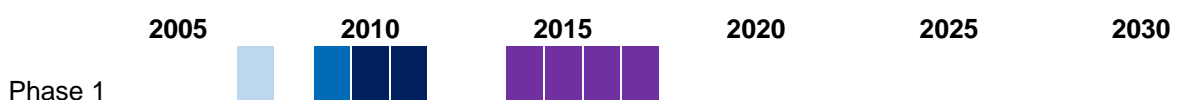
2.2.1.3.3.3 Regulatory implementation

The first substantial move in the US towards regulation was from the NHTSA who, in response to the Energy Independence and Security Act (Public Law 110-140, 2007), were required to conduct a study on the fuel efficiency of commercial medium- and heavy-duty vehicles, and were also mandated to conduct a rulemaking to implement a fuel efficiency improvement programme for these vehicles. The National Research Council (NRC) Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles was formed in response to this congressional mandate. They were tasked with submitting a report that assessed the availability, effectiveness and costs of current and potential technologies that would reduce fuel consumption for medium- and heavy-duty vehicles, and how these technologies could be used practically (NAS, 2010).

In parallel to this, the EPA issued an “Endangerment Finding” in 2009 which focused on US public health and welfare impacts caused by HDVs, as obligated under the Clean Air Act. The document found that elevated concentrations of greenhouse gases (GHGs) in the atmosphere may reasonably be anticipated to endanger public health and welfare of both current and future generations (EPA, 2009), and therefore the EPA is obliged to consider regulating emissions from the heavy-duty sector.

The context of the 2010 NAS study changed after the Presidential Memorandum in May 2010 to specify regulations over the 2014-2017 period (The White House, 2010). Resultantly, the EPA and NHTSA jointly published ‘Phase 1’ of the US measures in 2011 (EPA, 2011), making medium- and heavy-duty standards effective under US Federal law from 2014.

Figure 2.5: High-level implementation timeline





As a part of the comprehensive 2013 Climate Action Plan for the United States, the EPA and the NHTSA were directed to set the next round of standards to reduce GHG emissions and improve fuel efficiency for heavy-duty vehicles. In August 2016, these agencies published the final rulemaking for 'Phase 2' of the regulatory scheme, which will come into effect from 2018 to 2027 (EPA, 2016)⁷. Figure 2.5 gives a high level implementation timeline for the two phases.

2.2.1.3.3.4 Deviations for California

Since the passing of AB32 in 2006, CARB has been a strong proponent of expansion of CO₂ emissions regulations. This has resulted in the adoption of a number of new regulations designed to reduce GHG emissions and fuel consumption. Specifically, both the Tractor-Trailer regulation (essentially a mandatory application of SmartWay approved technologies, see Section 2.2.1.1.6) and the HVIP programme were seen as early action items identified in AB32, and these measures became a starting point for HDV CO₂ regulation in 2008. As CARB was focusing on the development and implementation of these measures, the US EPA took the lead on Phase 1 development. However, the development of Phase 2 was pursued in partnership with the EPA, with CARB having a significant involvement.

California has a Mobile Source Strategy, announced in 2015, that provides high level direction on a wide range of plans. These include the State Strategy for the Implementation Plan for Federal Ozone and PM_{2.5} Standards, the Scoping Plan Update, the California Sustainable Freight Action Plan, the Short-Lived Climate Pollutant Strategy, and the Sustainable Communities and Climate Protection Act. These goals are independent from the US and will be pursued independently if necessary (CARB, 2016).

The California Sustainable Freight Action Plan provides high level vision and broad direction for State agencies towards improving the freight transport system. Targets for 2030 and 2050 were presented, with the 2030 targets including system efficiency improvements of 25%, deployment of 100,000 freight vehicles and equipment capable of zero-emission operation and increased competitiveness and economic targets (California Department of Transportation, 2016).

2.2.1.3.3.5 Deviations for Canada

The Government of Canada announced the development of new regulations in May 2010, on the same day as the Presidential Memorandum regarding fuel efficiency standards in the US. This led to the publishing of Canada's final standards in March 2013, the 'Heavy-duty Vehicle and Engine Greenhouse Gas Emissions Regulations' (Canada Gazette, 2013), which introduced progressively more stringent GHG emissions standards for HDVs over the 2014-2018 period. This represents Phase 1 of the US programme, however Phase 2 is absent in the Canadian regulations: although a Notice of Intent was published in the Canada Gazette in October 2014 to "further reduce GHG emissions from post-2013 model year heavy-duty vehicles in alignment with the US", no announcement has yet been made confirming their implementation. All Canadian provincial environment ministries have expressed support for the regulations and continued alignment with the US, suggesting the adoption of US Phase 2 in the near future.

⁷ The Phase 2 rulemaking referenced here is a pre-published version and is currently under review. All information was correct at the time of writing. Although there may be subtle changes to the documentation within the final rulemaking, it is unlikely that there will be significant alterations after review.

2.2.1.3.4 **Baseline vehicle definition**

Initially, the agencies published a proposed rulemaking for Phase 1, consistent with the recommendations in the National Academy of Sciences (NAS) 2010 report to NHTSA (NAS, 2010). This paper is an analysis of current, near-to-production, and future technologies that can be incorporated into heavy duty vehicles in order to improve fuel consumption over the coming years, in terms of the potential GHG savings they can offer. In addition, US Congress specified that as a part of the programme, the NHTSA must adopt and implement appropriate test methods, measurement metrics, and compliance and enforcement protocols, and the NAS were tasked with providing recommendations on these criteria. The agencies undertook a detailed analysis of the US heavy duty vehicle industry, which is reported in Chapter 1 of the Phase 1 Regulatory Impact Analysis (EPA, 2011). From this, with additional information from OEMs covering which technologies are presently utilised in their fleets, they derived baseline engine and vehicle configurations for each regulatory subcategory by examining the existing fleet composition before assuming a number of vehicles as representative of a typical 2010 model year vehicle and engine.

Table 2.5: Baseline configurations for engines and vehicles for Phases 1 and 2 of the heavy-duty emissions programme (EPA, 2011), (EPA, 2016)

Regulatory Category	Baseline Configuration (MY2010)	Baseline configuration (MY2017)
Engines		
Heavy-Duty Spark Ignition Engine	<ul style="list-style-type: none"> Naturally aspirated, single overhead valve V8 engine 	<ul style="list-style-type: none"> MY2010 + 100% uptake of coupled cam phasing, engine friction reduction, SGDI
Heavy-Duty Compression Ignition Engine	<ul style="list-style-type: none"> Electronic control SCR/EGR/DPF exhaust aftertreatment system which achieves 2010MY emission standards 0.20g/bhp-hr of NO_x Turbocharged with variable geometry turbocharger 2200 bar injection pressure Single fixed overhead valve Belt driven accessories 	<ul style="list-style-type: none"> Uses engine that meets end of Phase 1 standards. Tractor engines were further adjusted by new SET weighting factors to reflect new information on real world conditions. Vocational engines were adjusted to reflect unexpected improvements in SCR+DPF systems. Engines were also separated into LHD, MHD and HHD.
Whole vehicle		
Combination Tractor	<ul style="list-style-type: none"> Aerodynamic Cd based on fleet composition and cab-type, roof height, and class of vehicle. Dual tyres with steer wheels, CRR = 7.8 (steer), 8.2 (drive) Body and chassis: steel components Idle reduction Vehicle Speed Limiter 	<ul style="list-style-type: none"> Aerodynamic Cd based on fleet composition and cab-type, roof height, and class of vehicle. Improved modelling for Phase 2. Dual tyres with steer wheels, CRR lower than Phase 1 and varied by subcategory Body and chassis: steel components Idle reduction Vehicle Speed Limiter
Vocational vehicle	<ul style="list-style-type: none"> Average tyre CRR of 9.0 	<ul style="list-style-type: none"> Average tyre CRR of 7.7

As reported in Chapter 1 (“Industry Characterisation”) of the Phase 2 RIA (EPA, 2016), the baseline vehicle definition for Phase 2 is assumed compliance with Phase 1 standards for MY2017 vehicles, evaluated under a revised GEM model. Due to improvements⁸ and changed evaluation methods in the GEM simulation model between the two phases, however, it is difficult to map Phase 1 compliance to vehicles evaluated under Phase 2 methods (evaluation over Phase 2 GEM would, in most cases, evaluate higher fuel consumption than Phase 1 GEM). In other words, direct comparison between Phase 1 and Phase 2 standards is inaccurate.

In addition to updating the baseline vehicles, Phase 2 both augmented the data with a more detailed analysis of the “vocational vehicles” (i.e. all vehicles that were neither HD pick-ups, vans nor tractor-trailer combinations) and incorporated a new category: trailer types. From this updated analysis, representative baseline vehicle characteristics for the three vehicle segments were derived. The Phase 2 baseline vehicles were calculated using the Phase 2 GEM simulation model, which combines the effects of technology packages which are cost-effective and technologically feasible (EPA, 2016).

In deriving the stringency of the Phase 2 standards it was necessary to review the technologies that formed the MY2010 baseline vehicles, comparing the expected pathways and market penetration of technologies to the actual technology utilisation found in the MY2016 fleet. It is expected that the technologies employed by the MY2016 fleet will be a fair approximation for the composition of each subcategory in MY2017, and as a result, these vehicles form the basis of the baseline vehicles for the Phase 2 rulemaking. Through stakeholder consultation activities with manufacturers, the estimates for market penetration of technologies can be assessed, and therefore, likely technology paths updated to reflect unexpected changes in the availability, use, and costs of emergent technologies over the forthcoming decade. For example, for gasoline engines, it was expected that market penetration for couple cam phasing, engine friction reduction, and stoichiometric gasoline direct injection technology would be 100% by MY2016. However, the consultation stage revealed that whilst the two former technologies have been widely utilised, there have been no examples of the introduction of stoichiometric gasoline direct injection. Therefore, it should be considered as a technology that may be plausibly available within Phase 2 of the regulations.

The Phase 2 baseline for combination tractors was adapted from theoretical MY2017 tractors that would meet the Phase 1 standards. Adaptions were required to reflect a new version of GEM that had additional capabilities including more refined modelling of transmissions and engines. The $C_d A_x$ aerodynamics figures were also adjusted to take into account a revised test procedure, a new standard reference trailer, and wind averaged drag. The new GEM also included road grade in the 55mph and 65mph highway cycles.

2.2.1.3.5 **Studies and Impact Assessments in support of the measure**

The first major study was undertaken by NHTSA in response to the Energy Independence and Security Act (EISA) of 2007, in which Congress required both the National Academy of Sciences (NAS) and NHTSA to conduct research informing development of a new regulatory system for improving the fuel efficiency of medium- and heavy-duty lorries. Two years were allotted from the beginning of the NAS study for both studies to be completed - NAS’ report was made public in March 2010, entitled “Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-duty Vehicles”; in October 2010 NHTSA published their own study, entitled: “Factors and Considerations for Establishing a Fuel Efficiency Regulatory Program for Commercial Medium- and Heavy-Duty Vehicles”. The context for NHTSA’s study was changed before its completion by a Presidential request in May 2010, which requested that both NHTSA and the EPA immediately begin work on a new joint rulemaking to establish fuel efficiency and greenhouse gas emission standards for medium- and heavy-duty lorries, with the aim of issuing a final rule by 30th July 2011 - over a year ahead of the schedule implied in EISA.

Ultimately, the recommendations from both reports were used by the EPA and NHTSA to support the economic and environmental justification for the Phase 1 regulations, as well as the key design elements of the HDV CO₂ emission reduction programme.

⁸ These changes include improved simulation of engines and transmissions, inclusion of road grade, and an additional aerodynamic drag coefficient.

The EPA and NHTSA use a collaborative approach in developing and revising the standards for both phases of the US measures. In order to establish the initial information on technologies, associated costs and estimated lead-times for Phase 1, there was a need for communication with many stakeholders, OEMs and experts. The EPA and NHTSA invited comments from stakeholders at each stage of the process in order to address concerns with the proposed measures (EPA, Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule, 2011). For example, comments were received by the EPA over the initial categorisation of the vehicles, changes to the GEM, the default technologies applied to each subcategory, and the costs and lead-times associated with each technology (EPA, 2011). This consultative process allowed the agencies to release realistic, cost-effective, and technologically-feasible standards that aligned with the industry's ambitions of reducing GHG emissions and fuel consumption through the required time-frame.

Under Phase 1, the NAS created three working groups to divide up the impact assessment tasks, and relied on specialised consultants to execute various portions of the study; TIAX developed detailed forecasts of fuel consumption reducing technologies (TIAX, LLC, 2009), focusing on a 10-year timeframe; the US Department of Energy's Argonne National Laboratory provided quantitative data as well as modelling and simulation analyses (Argonne National Laboratory, 2009); Cambridge Systematics, Inc., and Eastern Research Group, Inc., examined the possible consequences and unintended effects of regulations and assessed alternative approaches to improving heavy duty fuel efficiency. From this, the EPA and NHTSA released a Regulatory Impact Analysis, which described how the previous reports were used to calculate the standards, in an effort to ensure maximum possible transparency (EPA, 2011).

For Phase 2, two principal technical studies⁹ and a cost study were commissioned by NHTSA, performed and published by Southwest Research Institute (SwRI) in June 2015. These were opened to public consultation, and ERG published reports collating the comments received (ERG, 2015). In parallel, using these studies and a portfolio of evidence NHTSA published their proposal entitled: "Proposed Rulemaking for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty engines and Vehicles—Phase 2: Draft Regulatory Impact Analysis". The comments received were evaluated and in August 2016 NHTSA published their revised plan entitled: "Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty engines and Vehicles—Phase 2: Draft Regulatory Impact Analysis".

The costs of technologies were calculated on the basis of the direct and indirect costs a manufacturer would incur whilst developing a technology (EPA, 2011). Direct costs included the costs of materials and labour, whilst indirect costs are associated with producing the unit (such as research and development, or corporate operations). Many of the direct manufacturer costs can be sourced in the Phase 1 rule, which in turn, were sourced largely from a contracted study by ICF International (ICF International, 2010). These costs were updated by converting them into the more recent 2012\$, and the learning effects are continued in the manner discussed above. New costs are sourced from the study conducted by SwRI under contract to the NHTSA (Schubert, Chan, & Law, 2015). Additionally, the baselines are adapted by using the enhanced GEM simulation model.

2.2.1.3.5.1 Deviations for California

CARB did not carry out any supplementary studies specifically performed for the development of Phase 1 or 2. However, CARB did perform additional studies independently, which were used to inform the Phase 2 regulations. The studies predominantly consisted of technology assessments for HDVs on the current state of each technology and the likely state in the future. CARB suggested that these studies informed their opinion on the regulations and potentially impacted the EPA indirectly, also.

2.2.1.3.5.2 Deviations for Canada

Environment Canada were required to conduct a Regulatory Impact Analysis Statement (RIAS), which was published alongside the Regulation. The RIAS carries out a cost-benefit analysis of the Regulation,

⁹ Entitled Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Study – Report #1 and Report #2.

incorporating incremental impacts, vehicle lifetime timeframe, and costs and benefits estimated in monetary terms. The benefits include pre-tax fuel savings and avoided GHG damages, while the costs are technology and the related administrative burden, noise, accidents, congestion, and government administration.

The RIAS follows two scenarios: business-as-usual (BAU) and regulatory. The BAU scenario is used as a baseline and assumes that the regulations are not implemented - the methodology behind the baseline is described above in Section 2.2.1.3.4. This is contrasted with the regulatory scenario which assumes that certain GHG emission-reduction technologies will be chosen to comply with the new regulations. The RIAS used estimates of future vehicle sales, fuel prices and monetary values for GHG reductions to identify these technologies and their associated costs, and then to model future vehicle emissions, fuel consumption and distance travelled both with and in absence of the regulations. The BAU scenario assumed that technology choices for MY2014-2018 vehicles remain the same as those available for MY2010, which could result in an underestimation of natural technology changes that might occur in the absence of regulations. The regulatory scenario assumed that manufacturing costs will be passed onto vehicle purchasers who can recoup the costs during use with negligible impact on vehicle sales. In more detail, Environment Canada modelled HDV sales using their Energy-Economy-Environment Model (E3MC) with historical and forecasted provincial and national economic trends. Vehicle emissions were estimated using the US EPA’s Motor Vehicle Emissions Simulator (MOVES). Vehicle population data was input to the simulator, which used a default value for vehicle removal from the fleet per year. Kilometre accumulation rates were extrapolated to Canada as a whole based on inspection and maintenance programme data from Ontario and British Columbia, then added to the simulation using default MOVES growth rates. The social cost of carbon used in the cost-benefit analysis was based upon the work of the US Interagency Working Group on the Social Cost of Carbon and fuel price forecasts were adopted from the E3MC model. Finally, information regarding vehicle technologies which reduce GHG emissions were obtained from the US EPA’s Phase 1 Regulations (EPA, 2011)¹⁰. Table 2.6 displays the technologies which were considered in the RIAS as those most likely to be adopted within the timeframe in response to the regulations.

Table 2.6: Potential key technologies identified in the RIAS

HDV Category	Technologies assumed
Combination trucks	Engine improvements, increased use of low rolling resistance tyres, mass reduction, improved aerodynamics, increased use of auxiliary power units, reduced air conditioning leakage
Vocational vehicles	Engine improvements, increased use of low rolling resistance tyres
Heavy-duty pick-up trucks and vans	Engine improvements, more use of low rolling resistance tires, mass reduction, improved transmissions, reduced accessory loads

2.2.1.3.6 Stakeholders engaged

Stakeholders were consulted in many areas during the development of the regulations. For example, manufacturers provided information and data, whilst they also played a key role in reviewing the rulemaking, and offering suggestions for improvement to the agency. There is a record of all data submissions and comments submitted to the agency, available in the rulemaking.

¹⁰ Further details on the methodology used by the US in calculating the impact of vehicle technologies can be found in the US report.

2.2.1.3.6.1 Stakeholder demographic

The US ran multiple public consultations throughout the development of both phases of their legislation, and contracted much of the research work to private organisations. From consultation feedback notes and the evidence presented in the Phase 2 RIA, it is concluded that the stakeholders consulted include:

- Government bodies such as Congress, NHTSA, the EPA, CARB and Department of Transportation;
- NGOs such as National Research Council, American Council for an Energy Efficient Economy;
- Industry associations such as the Truck and Engine Manufacturers Association, American Trucking Association, The Association for the Work Truck Industry, National Automobile Dealers Association, Fire Apparatus Manufacturers Association, National Solid Wastes Management Association;
- Private companies such as Navistar, Daimler Trucks North America, BAE, Cummins, Spartan Motors, etc.

2.2.1.3.6.2 Data submission

Despite early apprehension to the development of the regulation, manufacturers later realised that engagement with the agencies would ensure the robustness and accuracy of information which formed the basis of the regulation (Spears, 2016). Therefore, engagement from manufacturers was good overall for the development of both Phase 1 and 2. The most significant areas where data was submitted to the agencies included:

- The development of the cycle-average engine mapping approach for the Phase 2 GEM. This approach was unique to these regulations. In response to concerns around submitting detailed engine data to the agencies expressed by manufacturers, in particular independent engine manufacturers, the agencies and the stakeholders collaborated to create engine maps with cycle-average performance over the test cycles within the GEM simulation model (Zhang, et al., 2016).
- OEMs also provided aerodynamic coast-down, tyre rolling resistance, shift-strategy, and gearbox data.
- Cost information from OEMs regarding the maintenance of the fleet and the warranties.
- OEMs also provided in-use vehicle data, including data from real-time engine monitoring, or parameters recorded during vehicle servicing.
- Additional baseline engine testing and modelling results were provided by NGOs.
- Software companies were forthcoming with assistance to help develop the GEM, although concerns over the requirement to publish all of the model code, including its source code, prevented these companies from offering ready-made software which the agencies could use.

2.2.1.3.6.3 Data validation and reviewing of the rulemaking

Stakeholders were also involved with validation efforts for the outputs of the GEM simulation models. For example, the agencies used laboratories to test engines for additional data, providing these results to the OEMs for review. These companies offered corrections to the tests and demonstrated areas where the results were not reflective of real-life engine cycles.

2.2.1.3.6.4 Deviations for Canada

Environment Canada consulted a wide range of stakeholders, including industry, provincial and territorial governments, other federal government departments and environmental non-governmental organizations. The commitment to take regulatory action was announced in May 2010. Then, in October 2010, a consultation document was released providing details on the main elements of the proposed regulation. A second, more detailed, consultation document was released in August 2011. Between August 2011 and publishing the proposed regulations in 2012, Environment Canada and Transport Canada co-hosted four consultation group meetings to facilitate stakeholder feedback. The stakeholder feedback provided during this period was taken into account, and the proposed Regulations were published in 2012, starting a formal 60-day comment period. During this period, interested parties were invited to submit their written views on the proposed regulations and Environment Canada also held meetings with a wide range of stakeholder groups to help inform possible written submissions. Environment Canada received 19 responses. The main issues discussed involved support for alignment

with the US EPA's standards, comments relating to low rolling resistance tires, fuel-neutrality, small volume companies, reporting, compliance flexibilities, vocational tractors and labelling. All of these comments were responded to by Environment Canada and duly considered in the final regulations.

Further to the Canadian Government's stakeholder consultation regarding the adoption of the measures, the underlying standards developed by the EPA and NHTSA had undergone multiple public consultations relating to each element throughout the development process.

2.2.1.3.7 Justification of the scope

The 2009 Endangerment Finding reviewed the impact that elevated greenhouse gases has on both public health and welfare, and found that it may be reasonably anticipated that they would have an effect (EPA, 2009). Therefore, the EPA is obliged to consider regulating emissions from the heavy-duty sector. Further studies since into the impacts of greenhouse gases and consolidated this finding, and therefore the EPA continues to justify its scope on those grounds (EPA, 2016).

2.2.1.3.8 Challenges, obstacles and solutions identified and avoided before implementation

2.2.1.3.8.1 Legal issues

The EPA and NHTSA have clear legal authority to develop and implement the regulations. In fact, when a court case was brought against the EPA in 2007 by 12 states and several cities of the US seeking to force the agency to regulate CO₂ and other GHGs as pollutants, the Supreme Court ruled that the EPA does have an obligation to consider regulating these gases if they are found to be a threat to human health and the environment, via an 'Endangerment Finding'. The NHTSA has parallel authority to set fuel economy standards. The legal element of developing the Phase 1 and 2 regulations was not deemed to have faced a greater barrier than in other wide-reaching US legislation.

In the case of California, a waiver from the EPA for any regulations adopted independently must be requested. This process took several years in the case of the Tractor-Trailer regulation (described below), however CARB considers this typical for all regulations and therefore not necessarily a specific challenge.

2.2.1.3.8.2 Practical / other issues

The requirement for both agencies to work together added complexity to the development of the rulemaking. For example, the agencies had to consider the Energy Independence and Security Act which rules that regulations proposed by NHTSA must provide sufficient lead-time (four years) for manufacturers to comply, whilst the EPA was not bound by this ruling. This is the reason why for both Phase 1 and 2, the first years of the regulation have compulsory EPA standards, but only voluntary NHTSA standards. OEMs, however, are encouraged to comply with both.

The most apprehensive stakeholders to the initial rulemaking were the owner-operators' association (OOIDA) and some trailer manufacturers. In the past, as discussed in greater depth in subsection 2.2.1.4.1, regulations had been introduced that had, in effect, required the immediate introduction of technologies into the marketplace which may not have been ready for commercial use. This was the case for the introduction of exhaust gas recirculation and particulate-matter traps, where the earliest examples were later known for their durability problems. Members of OOIDA are typically reliant on the second-hand market, often purchasing vehicles without warranties, and therefore were exposed disproportionately to these reliability issues and as a result this demographic is typically apprehensive of regulatory action on heavy-duty vehicles. For example, OOIDA recently wrote to the incoming Presidential administration and Congress requesting that they overturn the Phase 2 rulemaking. However, there is strong support for the regulations from the industry and manufacturers themselves and so, at present, the influence of this letter is uncertain.

For Phase 2, the introduction of trailer standards from trailer manufacturers saw a practical issue also. The trailer market in the US is characterised by a few major manufacturers, with at least a hundred smaller manufacturers. These smaller manufacturers expressed concerns with having the resources to comply with the regulations, and therefore offered some resistance to the rulemaking.

In addition, time constraints created further problems for the agencies. For Phase 1, the regulations were developed at an unprecedented pace. The development of Phase 1 began in 2009, with the

rulemaking being proposed in 2011, and finalised in 2012. Therefore, for Phase 1, the agencies did not have sufficient time to consider all the elements they would have liked. For example, differentiation by powertrain and the application of standards to trailers were left out of Phase 1 since the time and resources required to include these elements was not available. Therefore, these elements are only included in Phase 2 of the rulemaking. In fact, Phase 1 focused entirely on existing, commercially available technologies and the standards are designed to allow OEMs to comply without the requirement for further development of GHG-saving technologies. Additionally, since the agencies lacked the time to develop new test cycles for the regulations they were reliant on pre-existing tests for a number of elements, including characterisation of baseline rolling resistance and aerodynamic coefficients. Therefore, Phase 1 may be considered more similar to a data collection exercise.

For Phase 2, time pressures still existed. The agencies felt compelled to finalise the rulemaking before the conclusion of President Obama's administration, since the development of the second phase is listed in President Obama's Climate Action Plan. Therefore, at the time of publication of the standards, data was still arriving from OEMs which may have influenced the rules themselves. For example, late-arriving data suggested that it may have been more efficient for the vocational vehicle group to be reduced to between six and eight regulatory subcategories (rather than the nine proposed). The agencies will continue to explore this, and if a change is required, they will propose an amendment to the rule in the future.

2.2.1.3.8.2.1 Deviations for California

Whilst the measures as a whole were implemented without structural issues, the requirements for low rolling resistance tyres under the Tractor-Trailer programme (described below) were found to be "challenging" to implement. This was principally due to a lack of clarity in the qualification criteria for 'low rolling resistance' and the labelling of tyres, but also presented a further challenge of regulating in-use tyres. During an interview with the project team, CARB suggested that with hindsight a clearer certification programme for low rolling resistance tyres would have made the implementation of the Tractor-Trailer regulation simpler.

2.2.1.3.8.3 How was fairness between manufacturers ensured?

For Phase 1, it was decided that small manufacturers of heavy-duty engines, combination tractors, and chassis manufacturers for vocational vehicles would be exempted from the standards. The criteria for what defines a small manufacturer is those that meet the 'small business' criteria set by the Small Business Administration. For heavy-duty lorry manufacturers this threshold is 1,500 employees, whilst for engine manufacturers it is reduced to 1,000. The reason for this exemption in Phase 1 was due to the appreciation that small businesses may not have the resources required to meet the standards. Phase 1 was viewed by the agencies as more of a data collection exercise, in order to inform the standards of Phase 2, in which small businesses would be included. Small businesses could opt into the standards in order to generate credits for use in Phase 2 as a result of this intention.

For Phase 2, since small business are included under the scope of the regulations, the Regulatory Flexibility Act requires the EPA to prepare a flexibility analysis, and to certify that the rulemaking will not have a significant economic impact on a substantial number of small businesses. In addition, the rulemaking is reviewed by a Small Business Advocacy Review Panel, as required by the Small Business Regulatory Enforcement Fairness Act (SBREFA), who make recommendations and provide advice on how small businesses may potentially be affected by the rulemaking. As a result of this stage, the agencies provide increased flexibilities for small businesses including:

- Trailers - Adopting simpler requirements for non-box trailers
- Alternative fuel converters - omitting recertification of a converted vehicle when the engine is converted and certified, reduced N₂O testing, and delayed required compliance by a further year.
- Vocational chassis – less stringent standards for certain vehicle categories, and greater opportunity to generate credits under the Phase 1 programme.

- Glider vehicle¹¹ assemblers – exempting existing small businesses, but limiting the level of annual production in these businesses.

2.2.1.3.9 **Reasons for the division of administrative responsibilities described above**

The EPA and the NHTSA were legally obligated to consider introducing regulations for CO₂ and fuel economy as described above in subsection 2.2.1.2.1. Both are responsible for the monitoring, enforcement, and certification of their own division of standards. The only area where responsibility is not divided like this is for the development, maintenance and upgrade of the GEM simulation model. Due to the in-house capabilities of the EPA, it was decided that this agency would be responsible for its development, whilst NHTSA would act in a similar manner to a stakeholder, reviewing the process and the source code, and suggesting improvements that can be made.

2.2.1.4 Measure design

2.2.1.4.1 **Description of the measures and overview of methodology for limit setting**

The technology paths that the agencies considered available for each regulatory sub-category were examined to determine which standards would be cost-effective, technologically feasible and afforded appropriate lead-time, starting from the baseline vehicles. The EPA and NHTSA felt that driver training and other more holistic improvements were beyond the scope of the regulations, although the effects of improved driving on the effectiveness of technologies is considered. Instead, the EPA will continue to promote fuel-efficient driving through its SmartWay programme.

The implementation of NO_x and particulate matter (PM) standards to US HDVs in prior legislations had inadvertently led to the introduction of under-developed and under-tested technology into the market, drawing criticism. Some OEMs were required to implement technologies two years ahead of schedule due to consent decrees (punishments for prior non-compliance), resulting in additional costs to these manufacturers due to increased customer warranty claims for the failing technologies and also the reduction of the environmental effectiveness of the regulation. In an effort to avoid this scenario the heavy-duty fuel economy and CO₂ standards ensure there is sufficient lead-time for manufacturers and do not require 100% market penetration of specific technologies. Phase 1 is focused on incentivising the introduction of 'off-the-shelf' technologies and as a result the standards for Phase 1 may be achieved using technologies already available to manufacturers through a variety of different technology paths. By contrast, Phase 2 is more technologically-focused, and will require additional research and development. For this, the agencies have provided extended lead-time to manufacturers (up to 10 years), anticipating that this gives manufacturers sufficient time to plan their compliance pathways.

For engines, the baseline fuel consumption and CO₂ performance were developed from manufacturer-reported CO₂ values used in the certification of non-GHG pollutants for MY2010 vehicles (EPA, 2011). Standards were derived for gasoline-burning spark-ignition engines, which comprises a single regulatory category, and for diesel compression-ignition engines, which comprises four regulatory subcategories dependent upon the weight of the vehicle and the test cycle over which CO₂ performance is measured.

In a similar fashion to engines, technologies which had the potential to reduce fuel consumption and CO₂ emission rates over the whole vehicle were considered, including aerodynamics, rolling resistance, weight reduction, idle control technologies, and vehicle speed limiters. The agencies used inputs based on the technology package calculated through a cost-analysis similar to that used for engines, and technology application and penetration rates which were inputs into GEM. For each subcategory, GEM input parameters were weighted according to the vehicle design (for cab type and roof height), and the GVWR was varied to be consistent with the groups defined by the regulations. Output values from the GEM for 2014 and 2017 represent the standards for these model years.

The methodology took a bottom-up approach in establishing the combined fuel consumption savings for each technology. By considering the effects of each individual technology improvement on the whole-vehicle and/or engine, namely using the report submitted to the NHTSA by the NAS in 2010, the

¹¹ 'Glider' vehicles are new trucks or tractors that then receive rebuilt or remanufactured powertrain components.

benefits of each technology could be estimated. Fuel savings were estimated using a combination of extensive stakeholder engagement with OEMs and computer simulation modelling. To address the issue that some technologies are not mutually exclusive, and the savings produced by two technologies may not always equal the multiple of the two savings (in percentage terms), simulation models were utilised in order to establish the effectiveness of likely technology paths.

Note that vehicles must satisfy standards for CO₂ and fuel consumption for both their engine and the whole vehicle.

2.2.1.4.1.1 *Deviations for California*

The measures in California align with the rest of the US and as such the testing procedures are duplicated. The main difference at this time is the requirement for Californian-registered lorries to take part in the SmartWay programme under the Tractor-Trailer regulation, rather than as a voluntary scheme elsewhere in the US. Whilst California see harmonisation with the US as the preferable approach, CARB plan their emission reduction requirements independently and would consider divergence from federal regulations if necessary in the future.

In a recent review of the US Phase 2 regulations, CARB have recommended a number of changes. These include accelerating the phase-in timeline by 3 years (2024 instead of 2027), an increase in standards for tractor engines (7% improvement instead of 4%), inclusion and greater reliance on advanced technologies, a review of PM and NO_x controls, and addressing emissions from improperly designed hybrid systems (CARB, 2015). This highlights CARB's involvement in Phase 2 regulations. California may add California-only elements to Phase 2 if the US EPA does not address these recommendations, although this is yet to be confirmed. See Section 2.2.1.6.1.1 for further detail.

2.2.1.4.2 **Scope**

2.2.1.4.2.1 *Vehicle categories covered and their segmentation*

The standards are split into three broad, discrete categories due to the complexity of the HDV industry, for which different rules apply:

- Combination tractors
- Vocational vehicles
- HD pick-up trucks and vans.

The standards are applicable to all on-road vehicles with a gross-vehicle weight rating of ≥8,500lbs (3,855.5 kg). Further details regarding the three broad categories are:

- **Combination tractors:**
 - Standards are adopted based on three attributes, namely weight class, cab type and roof height, with a total of 9 sub-categories, as follows:
 - Day cab class 712: low, mid and high roof
 - Day cab class 813: low, mid and high roof
 - Sleeper cab class 8: low, mid and high roof
 - Additional standards apply to the engines incorporated into the combination tractors, with categorisation as follows:
 - Medium-heavy-duty diesel engines (MHDDE)¹⁴
 - Heavy-heavy-duty diesel engine (HHDDE)¹⁵
 - Note that trailers are not included in Phase 1 of the programme.
- **Vocational vehicles:**

¹² Class 7 vehicles defined as HDVs with a Gross Vehicle Weight Rating (GVWR) between 26,001 and 33,000lbs.

¹³ Class 8 vehicles defined as HDVs with a GVWR greater than 33,000lbs.

¹⁴ MHDDE defined as engines for use in HDV classes 6-7 (i.e. 19,501 to 33,000 lbs GVWR).

¹⁵ HHDDE defined as engines for use in HDV classes 8 (i.e. > 33,000 lbs GVWR).

- Standards are adopted based on vehicle class, split into the following classes:
 - Light Heavy Class 2b-5 (i.e. GVWR 8,501 to 19,500 lbs)
 - Medium Heavy Class 6-7 (i.e. GVWR 19,501 to 33,000 lbs)
 - Heavy Heavy Class 8 (i.e. GVWR > 33,000 lbs)
- Additional standards apply to the engines incorporated into the vocational vehicles, with categorisation as follows:
 - Light-heavy-duty diesel engines (LHDDE)¹⁶
 - Medium-heavy-duty diesel engines (MHDDE)
 - Heavy-heavy-duty diesel engine (HHDDE)
 - Gasoline engines
- **Heavy duty pickup trucks and vans** (GVWR >8,500lbs (3,856kg)): These vehicles must meet CO₂ and fuel economy standards in an approach similar to that taken for light-duty vehicles, but with different standards for gasoline and diesel vehicles. The EPA has established CO₂ standards in the form of a set of target standard curves, based on a “work factor” that combines a vehicle’s payload, towing capabilities, and whether or not it has 4-wheel drive. NHTSA has set corporate average standards for fuel consumption that are equivalent to the EPA’s standards.

The Regulatory Impact Analysis proposed for Phase 2 treats vocational vehicles in greater detail than in Phase 1. Section 1.3 (Industry Characterisation: Vocational vehicles) illustrates how broad the “vocational vehicles” segment is, and how it is endeavouring to have considered all non tractor-trailer HDVs and all non-HD pickups or vans. Seven different vocations are identified for which there are specialist manufacturers. These are referred to as “custom chassis” in the rule making, and include:

- Coach (intercity) bus
- Motor home
- School / transit bus
- Refuse collection lorry
- Cement mixer
- Emergency vehicle

In addition, there are a wide range standard chassis “vocational vehicles”, which include standard box-lorries, but also include terminal tractors, street sweepers, concrete pumpers, asphalt blasters, aircraft de-icers, sewer cleaners, mobile medical clinics, bookmobiles, and mobile command centres.

In Phase 2, the scope of the regulations expands to include fuel consumption standards for trailers, with the onus falling on trailer manufacturers to ensure compliance. These are separated into ten subcategories, depending on the size of the trailer, the type of trailer (refrigerated or dry), and the degree to which a trailer is capable of utilising aerodynamic technologies (termed “full-aero”, “partial-aero”, or “non-aero”¹⁷).

2.2.1.4.2.2 Emissions covered

The US measures cover not only CO₂ but also include other greenhouse gases. There are engine standards for both combination tractors and vocational vehicles covering nitrous oxide (N₂O) and methane (CH₄) emissions. The standard that is required to be met from MY2015 is 0.10g/bhp-hr for both N₂O and CH₄. The EPA also adopted standards for air-conditioning leakage and hydrofluorocarbon release, encouraging manufacturers to utilise leak-tight air-conditioning systems, or use systems with alternative refrigerants with a low Global Warming Potential.

¹⁶ LHDDE defined as engines for use in HDV classes 2b-5 (i.e. 8,501 to 19,500 lbs GVWR).

¹⁷ The definition of a “partial-aero” box van is a dry or refrigerated van that has work-performing equipment either on the underside or on the rear of the trailer that would limit a manufacturer’s ability to install aerodynamic technologies. The standards for these subcategories is based on the adoption of tyre technologies, and a single aerodynamic device. A “non-aero” van is defined as having work-performing equipment on both the underside and the rear of the trailer. Standards for this subcategory are based solely on tyre technologies.

2.2.1.4.2.3 Metrics used

For vehicles, the metric used to regulate greenhouse gas emissions (principally CO₂) is gCO₂eq/ton-mile (set by EPA), whilst the metric used to regulate fuel consumption is gal/1,000 ton-miles (set by NHTSA)¹⁸. The European equivalent metrics would be gCO₂eq/tkm, and litres/1,000 tkm. Note that a US ton is equivalent to 1.01605 metric tonnes.

For engines, the metric used to regulate greenhouse gas emissions, is gCO₂eq/bhp-hr whilst the metric used to regulate fuel consumption is gal/100 bhp-hr. The European equivalents would be gCO₂eq/kWh and litres/100 kWh.

2.2.1.4.2.3.1 Deviations for Canada

Environment Canada only uses the metrics of gCO₂eq/ton-mile for vehicle emissions and gCO₂eq/bhp-hr for engine emissions, in alignment with the US EPA. Fuel consumption standards were omitted.

2.2.1.4.2.4 Limit values

As noted earlier vehicles must satisfy standards for CO₂ and fuel consumption for both their engine and the whole vehicle. Limit values must be valid over the useful life of the engine, minus a small degradation factor.

Since the three broad vehicle categories identified above are likely to require a different set of technology solutions (a reflection of the differing challenges facing each segment to combat emissions) the broad categories were further divided into a number of subcategories. The drive cycles and payload specified for the testing against limit values are described in the following sub-sections.

2.2.1.4.2.4.1 Tractor-trailers

2.2.1.4.2.4.1.1 Engine standards

The limit values for tractor-trailer combinations are displayed in Table 2.7. The two available options of compliance under Phase 1 are a result of aligning the standards with mandated OBD improvements in 2013 and 2016 to allow manufacturers to avoid large number of model releases. This is just one example of a number of flexibility measures which act to minimise market disruption whilst achieving the greatest GHG savings, further described in Section 2.2.1.4.10. It is noted that by 2017 the two options under Phase 1 converge to the same values.

Table 2.7: Combination tractor CO₂ and fuel economy standards (SET cycle)

Model Year (MY)	CO ₂ Limit (g/bhp-hr)		Fuel Consumption Limit ¹ (gallons/100 bhp-hr)	
	MHDDE	HHDE	MHDDE	HHDE
Phase 1: Option 1				
2014 - 2016	502	475	4.93	4.67
2017	487	460	4.78	4.52
Phase 1: Option 2				
2013 - 2015	512	485	5.03	4.76
2016 - 2017	487	460	4.78	4.52
Phase 2: Limits				
2018 - 2020	481	455	4.73	4.47
2021 - 2023	473	447	4.65	4.39
2024 - 2026	461	436	4.53	4.28

¹⁸ 'eq' stands for 'equivalent'.

Model Year (MY)	CO ₂ Limit (g/bhp-hr)		Fuel Consumption Limit ¹ (gallons/100 bhp-hr)	
	MHDDE	HHDE	MHDDE	HHDE
2027 and Later	457	432	4.49	4.24

The US is currently the only key international market to maintain separate engine CO₂ standards. Separate engine standards were maintained by the US regulators between Phase 1 and Phase 2.

2.2.1.4.2.4.1.2 Whole vehicle standards

Whole vehicle standards are differentiated into nine subcategories for Phase 1, based on weight class, cab type and roof height, as demonstrated in Table 2.8. In Phase 2, a Class 8 heavy-haul regulatory subcategory is added to capture the largest vehicles in excess of 120,000lbs (54,430kg) GCWR (Gross Combined Weight Rating).

It is important to note that direct comparability between the two phases is inadvisable in an absolute sense, since there have been revisions to the test procedures and GEM model. In particular, revisions being made to the highway 55mph and 65mph cruise cycles have the effect of making the cycles more challenging (and more representative of real-life driving conditions), and so Phase 2 is more stringent¹⁹. As such, whilst the Phase 1 standards appear more stringent than the initial Phase 2 standards, this is not the case.

Since the MY2017 limit values form the basis of the Phase 2 baseline, it is necessary to test the projected MY2017 vehicle from Phase 1 using the Phase 2 GEM. This establishes limit values which are directly comparable to the remainder of the regulatory time-period (2021-2027). These values are used as the standards from 2018-2020 (EPA, 2016).

Table 2.8: Combination tractor CO₂ and fuel economy standards (calculated using the Greenhouse Gas Emissions Model)

	EPA CO ₂ Emissions Limit (g/ton-mile)			NHTSA Fuel Consumption Limit (gallons/1,000 ton-mile) ¹		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Phase 1: MY2014 – 2016						
Class 7 (day cab)	107	119	124	10.5	11.7	12.2
Class 8 (day cab)	81	88	92	8.0	8.7	9.0
Class 8 (sleeper cab)	68	76	75	6.7	7.4	7.3
Phase 1: MY2017						
Class 7 (day cab)	104	115	120	10.2	11.3	11.8
Class 8 (day cab)	80	86	89	7.8	8.4	8.7
Class 8 (sleeper cab)	66	73	72	6.5	7.2	7.1
Phase 2: MY2018-2020						
Class 7 (day cab)	119	127	130	11.7	12.5	12.7
Class 8 (day cab)	91	97	98	9.0	9.5	9.6
Class 8 (sleeper cab)	84	90	88	8.2	8.9	8.6

¹⁹ The relative weighting of the three cycles is unaltered, at 19% ARB + 17% 55mph cruise + 64% 65mph cruise for day cab tractor trailers. A specific example of changes that occur between Phase 1 and Phase 2 is that GEM inputs for tractor-trailers for Phase 1 specify electrical accessory power is 350 W, and mechanical accessory power is 1,000W. For Phase 2 these are increased to 1,200W and 2,300W, respectively. This is an increase of 2,150W, or 260% of the original value, is a constant drain on the engine, and affects CO₂ emissions and fuel consumption.

	EPA CO ₂ Emissions Limit (g/ton-mile)			NHTSA Fuel Consumption Limit (gallons/1,000 ton-mile) ¹		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Phase 2: MY2021-2023						
Class 7 (day cab)	105.5	113.2	113.5	10.36	11.12	11.15
Class 8 (day cab)	80.5	85.4	85.6	7.91	8.39	8.41
Class 8 (sleeper cab)	72.3	78	75.7	7.10	7.66	7.44
Class 8 (heavy-haul)	52.4			5.15		
Phase 2: MY2024-2026						
Class 7 (day cab)	99.8	107.1	106.6	9.80	10.52	10.47
Class 8 (day cab)	76.2	80.9	80.4	7.48	7.95	7.90
Class 8 (sleeper cab)	68	73.5	70.7	6.68	7.22	6.94
Class 8 (heavy-haul)	50.2			4.93		

2.2.1.4.2.4.1.3 Trailer standards

Trailer standards are differentiated into ten subcategories based on the length, shape, type of trailer (refrigerated or dry), or whether the trailer is defined as “full-aero”, “partial-aero”, or “non-aero”¹⁷. Improvements for trailers are expected to be gained through three primary streams; aerodynamic improvements, reduced rolling resistance tyres, and light-weighting. Fuel consumption and CO₂ savings are estimated within the GEM model as a trailer being pulled by a standard tractor, the design of which matches the physical characteristics and patterns of the trailer. The CO₂ standards will become effective in MY2018, whereas fuel consumption standards will become effective in MY2021. Prior to this, the standards are voluntary.

Table 2.9 gives the limits for non-box and non-aero box trailers, based upon rolling resistance. Table 2.10 gives the limits for full-aero and partial-aero box vans. To reflect the limited improvements that a partial-aero box van can offer, the limits are not tightened beyond 2021 for these vans. It was felt that since aerodynamic improvements in these vehicles are hampered by the necessity of work-performing equipment on these models, it would not be feasible for trailer manufacturers to meet the targets required for full-aero trailers. For non-aero and non-box trailers, no fuel consumption standards have been suggested. Instead, design standards that require manufacturers to adopt tyre technologies are required. The standards also require the trailers to meet or exceed tyre rolling resistance measures.

Table 2.9: Design-based standards for non-box trailers, and non-aero box vans (Phase 2)

MY	Tyre technology	Non-box trailers	Non-aero trailers
2018 - 2020	Tyre Rolling Resistance (kg/ton)	6.0	5.1
	Tyre Pressure System	TPMS or ATIS	TPMS or ATIS
2021 - 2027	Tyre Rolling Resistance (kg/ton)	5.1	4.7
	Tyre Pressure System	TPMS or ATIS	TPMS or ATIS

Note: TPMS – tyre pressure monitoring systems, ATIS – automatic tyre inflation systems.

Table 2.10: Trailer CO₂ and fuel consumption standards for full-aero and partial-aero box vans (Phase 2)

MY	CO ₂ Limit (CO ₂ /t.mile)				Fuel Consumption Limit (gallons/ 1,000 t.mile)			
	Dry		Refrigerated		Dry		Refrigerated	
	Long	Short	Long	Short	Long	Short	Long	Short
Partial-aero box trailers								
2018 - 2020	81.3	125.4	83.0	129.1	7.99	12.31	8.15	12.68
2021 - 2027	80.6	123.7	82.3	127.5	7.92	12.15	8.08	12.52
Full-aero box trailers								
2018 - 2020	81.3	125.4	83.0	129.1	7.99	12.31	8.15	12.68
2021 – 2023	78.9	123.7	80.6	127.5	7.75	12.15	7.92	12.52
2024 - 2026	77.2	120.9	78.9	124.7	7.58	11.88	7.75	12.25
2027	75.7	119.4	77.4	123.2	7.44	11.72	7.60	12.10

2.2.1.4.2.4.2 Vocational vehicles**2.2.1.4.2.4.2.1 Engine standards**

Vocational vehicle engine standards are displayed in Table 2.11.

Table 2.11: Vocational CO₂ and fuel economy standards (heavy duty FTP cycle)

MY	CO ₂ Limit (g/bhp-hr)			Fuel Consumption Limit ¹ (gallons/100 bhp-hr)		
	LHDDE	MHDDE	HHDE	LHDDE	MHDDE	HHDE
Phase 1						
2014 - 2016	600	600	567	5.89	5.89	5.57
2017	576	576	555	5.66	5.66	5.45
Phase 2: Proposed Limits						
2021 - 2023	563	545	513	5.53	5.35	5.04
2024 - 2026	555	538	506	5.45	5.28	4.97
2027+	552	535	503	5.42	5.26	4.94

2.2.1.4.2.4.2.2 Whole vehicle standards

The whole-vehicle fuel consumption and CO₂ standards for vocational vehicles are listed in Table 2.12. Since the definition of a vocational vehicle is so diverse the standards are further split into three regulatory subcategories: light-heavy class (corresponding to Class 2b to 5), medium-heavy (Class 6 to 7), and heavy-heavy (Class 8), consistent with the disaggregation of engine standards to light-heavy, medium-heavy, and heavy-heavy duty engines (see Table 2.11).

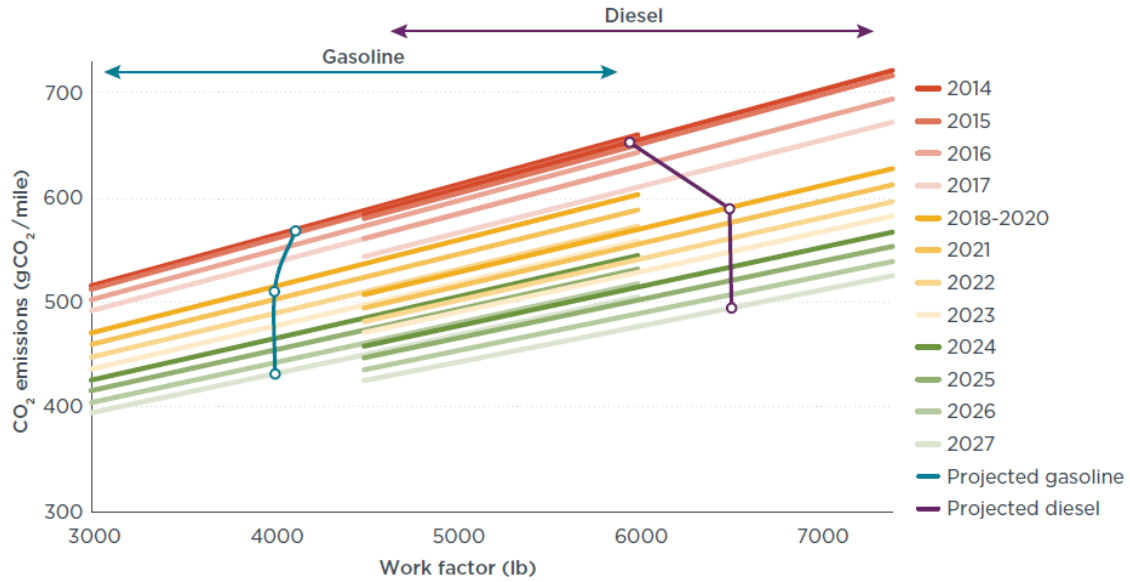
Table 2.12: Vocational whole-vehicle CO₂ and fuel consumption standards

MY	Duty cycle	EPA CO ₂ Emissions Limit (g/ton-mile)			Fuel Consumption Limit ¹ (gallons/ 1,000 t.mile)		
		Class 5	Class 6-7	Class 8	Class 5	Class 6-7	Class 8
Phase 1							
2014 – 2016	N/A	388	234	226	38.1	23.0	22.2
2017	N/A	373	225	222	36.7	22.1	21.8
Phase 2: Limits							
2018-2020	Urban	482	332	338	47.3	32.6	33.2
	Multi-purpose	420	294	287	41.2	28.9	12.2
	Regional	334	249	220	32.8	24.5	21.6
2021 – 2023	Urban	424	296	309	41.7	29.1	30.3
	Multi-purpose	373	265	261	36.6	26.0	25.6
	Regional	311	234	205	30.6	23.0	20.1
2024-2026	Urban	385	271	283	37.8	26.6	27.8
	Multi-purpose	344	246	242	33.8	24.2	23.8
	Regional	296	221	194	29.1	21.7	19.1
2027+	Urban	367	258	269	36.1	25.3	26.4
	Multi-purpose	330	235	230	32.4	23.1	22.6
	Regional	291	218	189	28.6	21.4	18.6

2.2.1.4.2.4.3 Heavy duty pickups and vans

Emissions for heavy duty pickup trucks and vans are based on a series of standard emission curves developed based on a ‘work factor’. An example is shown in Figure 2.6, below.

Figure 2.6: Heavy-duty pickup and van work factor-based CO₂ regulatory targets. Projected average CO₂ for gasoline and diesel pickups and vans is also shown (ICCT, 2015)

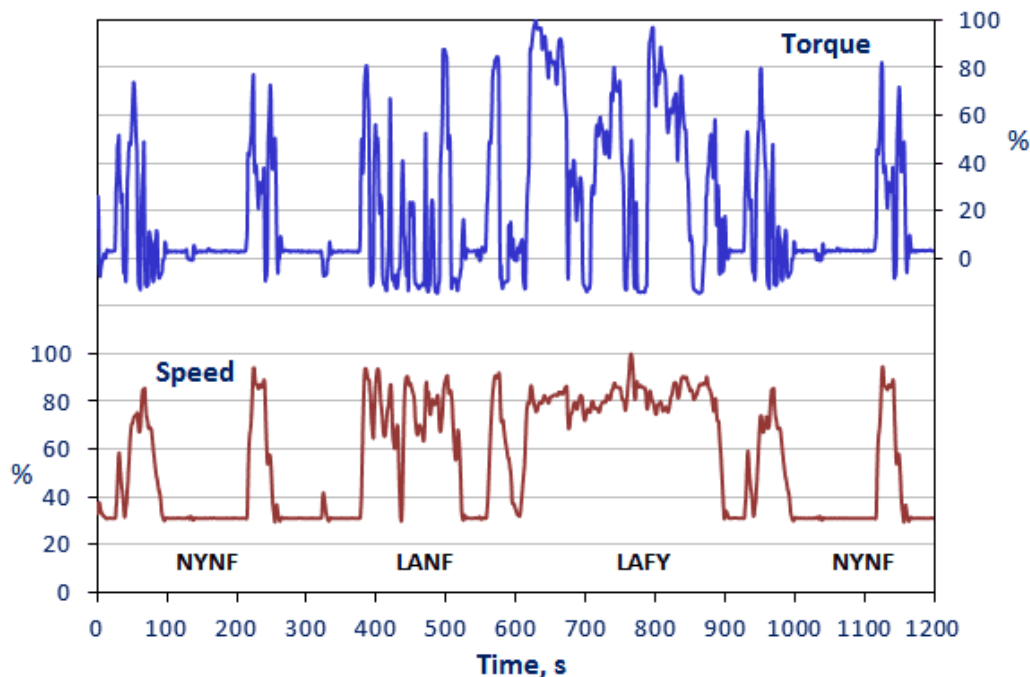


2.2.1.4.3 Drive cycles and payloads

The Federal Test Procedure (FTP) transient test is based on the EPA Urban Dynamometer Driving Schedule, which was developed for chassis dynamometer testing of heavy-duty vehicles. This was modified to take into account a variety of urban driving conditions that heavy-duty vehicles may have to face in American cities. It consists of four phases;

- New York Non Freeway – light urban traffic with frequent stop/starts
- Los Angeles Non Freeway – crowded urban traffic with few stops
- Los Angeles Freeway – expressway traffic
- Repetition of the New York Non Freeway phase.

The time-speed profile of the FTP cycle is shown in Figure 2.7.

Figure 2.7: Time-speed and time-torque profiles for the Federal Test Procedure (transportpolicy.net, 2016)

The average vehicle speed is around 30km/h, travelling a distance of 10.3km and lasting 1200s. This cycle is typically run both as a cold- and hot-start test, with the final result calculated as a weighted average (1/7:6/7 for cold:hot). Due to the modification of this test to include urban-like driving conditions, this test is most representative for vocational vehicles whose typical drive cycle is most closely aligned. The EPA and NHTSA therefore use the FTP cycle to verify CO₂ and fuel consumption limits for vocational vehicles.

The Supplementary Emissions Test (SET) is a steady-state dynamometer cycle. There are several versions of the test: two ramped mode cycles and one discrete mode cycle. The discrete mode cycle is equivalent to the European Static Cycle (ESC). Since 2007, however, heavy-duty engines are tested on the ramped mode cycle. The test consists of 13 steady-state conditions at a range of speeds, held for differing periods of time. Transition between these states is linear and takes 20 seconds. The constant speeds associated with this test cycle make it suitable for assessing the fuel consumption of heavy-duty combination tractors spending considerable time at highway speeds. As previously mentioned, revisions are being made for Phase 2 to the highway 55mph and 65mph SET cruise cycles and these have the effect of making the cycles more challenging (and more representative of real-life driving conditions), and so Phase 2 limits are comparatively more stringent. Retrospective changes to Phase 1 in light of these revisions are not taking place as this would lead to significant changes to the stringency of the regulations. The 2017 baseline is tested under Phase 2 standards and GEM software to establish appropriate values to be applied from 2018-2020 (EPA, 2016).

For whole-vehicle fuel consumption, the GEM simulation model is used. There are several drive cycles simulated within this model. For tractor-trailer vehicles, three cycles are used: the transient mode is defined by CARB in their Highway Heavy-Duty Diesel Transient cycle and the two constant cruise speed cycles of 65mph and 55mph, but with varying road grade. For vocational vehicles, two additional idle cycles are modelled, one simulating parking idling operation, and the other idling in traffic conditions. Each regulatory subcategory is assigned a set of drive cycle weightings. For example, combination tractor-trailers will have greater weighting on the cruise speed cycles, whereas urban vocational vehicles will have greater weighting on the transient and idling modes (EPA, 2016).

In Phase 2, manufacturers must provide cycle average engine maps. This is because of the recognition of the limitation of steady state engine maps for transient simulations. Payload is predefined within the simulation model, as demonstrated by Table 2.13.

Table 2.13: Predefined payloads modelled within the GEM

Category	Class / Type	Payload (tons)
Trailers	Long Box	19
	Short Box	10
Tractors	Class 7 – Combination Tractor	12.5
	Class 8 – Combination Tractor	19
	Class 8 - Heavy-Haul Combination Tractor	43
Vocational	Class 2b-5 - Light Heavy-Duty	2.85
	Class 6-7 – Medium Heavy-Duty	5.6
	Class 8 – Heavy Heavy-Duty	7.5

The weighting of urban, rural, and highway driving for each regulatory subcategory is calculated on the basis of both measured and simulation data. The distribution of vehicle miles travelled at different speeds was assessed using the EPA MOVES simulation model, and validated with data analysis by the Federal Administration, measured in 1999. In addition, the University of California and CARB have evaluated engine control module data from 270 lorries which travelled over one million miles to develop a heavy-duty diesel lorry activity report in 2006 (EPA, 2011).

2.2.1.4.4 Deadlines for compliance

There are a number of deadlines which manufacturers must meet as a part of the scheme. For the standard option in Phase 1 manufacturers must comply with limits from 2014-2016, and in 2017. In order to allow manufacturers sufficient lead-time to introduce technologies into their fleet a flexibility is included in the form of a second option, where the limits must be met from 2013-2015, and from 2016 onwards.

In Phase 2, the standards will be introduced in three year increments from 2018 to 2027.

2.2.1.4.5 Regulated entities

The regulated entities are generally the manufacturers of the engine or vehicles: these are the organisations who need to apply to the EPA and NHTSA for a Certificate of Conformity, which enables their vehicle to be sold. In Canada, manufacturers need to apply to Environment Canada to receive a national emissions mark. However, Environment Canada also accept an EPA or NHTSA Certificate of Conformity, or CARB equivalent.

For the seven “custom chassis” listed in Section 2.2.1.4.2.1 the agencies have consulted with industrial stakeholders and default GEM parameters have been developed. For these vehicles, their engines would be certified by the engine OEM, and the whole vehicle, built on a chassis by a body builder, would need to be certified by the body builder.

2.2.1.4.6 HDVs present in the market that are not covered by the measure

As demonstrated in Section 2.2.1.4.2.1 (Vehicle categories covered), Phase 1 and Phase 2 are very comprehensive. The regulations cover all vehicles either in terms of modelled vehicle emissions and their engine emissions for the vocational and tractor-trailer segments, or whole vehicle chassis dynamometer testing for HD pickups and vans.

Consequently, all on-road HDVs present in the US market are covered by these measures. Competition HDVs which are built exclusively for racing are excluded from the regulations.

2.2.1.4.7 **Testing and certification requirements**

Separate testing and certification procedures are defined for combination tractors and vocational vehicles (both engine and whole vehicle tests). For heavy duty pickups and vans, only whole vehicle testing is required.

2.2.1.4.7.1 *Engine certification – combination tractors and vocational vehicles*

Whereas the EPA's noxious emission standards for engines require manufacturers to demonstrate compliance over three tests to cover most operating conditions, they have chosen to regulate based on "a single test procedure, either the Heavy Duty FTP or SET, depending on the primary expected use of the engine" for fuel economy legislation (EPA, 2010). This is so that engine manufacturers "will design engines for the best GHG and fuel consumption performance" relative to their real-world usage. The EPA reason that as combination tractors spend considerable time at highway speeds the SET procedure is most appropriate, and that the transient nature of the FTP cycle is most appropriate for vocational vehicles. Engine manufacturers are therefore subject to tests under the SET or FTP cycles using standard testing procedures:

- The Supplementary Emission Test (SET) cycle is an engine dynamometer-based test cycle including a variety of steady-state modes defined by engine speed and torque, under each of which the engine must be tested for a minimum amount of time. It is similar to the European Stationary Cycle (ESC).
- The Heavy Duty Federal Test Procedure (FTP) cycle is an engine dynamometer-based test cycle including various transient loads to mimic the variety of HDV lorry and bus driving patterns in American cities. It covers both freeway operation and light/crowded urban traffic operation, with an average speed of approximately 30km/h. It is shown in Figure 2.7.

2.2.1.4.7.2 *Vehicle certification – combination tractors and vocational vehicles*

Chassis manufacturers are subject to certification using the EPA's GEM and therefore do not require chassis dynamometer testing. Similar to the VECTO model, various physical characteristics of each vehicle are measured and then used as inputs to the GEM model. These measured characteristics can then be applied in the model by the user, allowing them to vary technologies such as aerodynamic features, weight reduction measures, tyre rolling resistance, idle-reducing technologies and vehicle speed adjustment measures, depending on whether the vehicle is a combination tractor or vocational vehicle. Other equipment and trailers are defined by a series of standardised assumptions that apply to all vehicles.

GEM and VECTO are internally consistent, giving similar relative patterns for each vehicle and duty cycle, and having similar sensitivities to variations in key parameters. Some of the parameters can be brought into alignment through simple unit conversions, such as the tyre rolling resistances. However, notable discrepancies can be found in the driver model and gearshift strategies as a result of conceptual differences and therefore these factors do not effectively align.

The latest version of GEM includes five test cycles which are applied with different weightings to various combination tractor categories, or vocational vehicle categories. These cycles include the transient California Air Resources Board Highway Heavy-Duty Diesel Transient (HHDDT) cycle, two cruise cycles set at 55mph and 65mph and, for vocational vehicles only, two additional idle cycles, one simulating parking idling operation and the other idling in traffic conditions. Testing and certification using the GEM model is described more expansively in Section 2.2.1.4.7.4.

2.2.1.4.7.3 *Vehicle certification – heavy duty pickup trucks*

For heavy-duty pickup trucks and vans, vehicle fuel efficiency and GHG emission standards will be tested on a chassis dynamometer. This closely mirrors the light-duty vehicle program. A combined cycle based on the light-duty FTP (55% weighting) and the Highway Fuel Economy Test Cycle (HFET; 45% weighting) will be used to measure emissions using the dynamometer.

2.2.1.4.7.4 *Testing and certification requirements – the GEM model*

The Greenhouse gas Emissions Model is a simulation model that was designed to make assessing and enforcing compliance cost-effective for both the manufacturer and the enforcement agencies. Vehicle

simulation was favoured over other test methods such as chassis dynamometer since the HDV market is not vertically integrated. Additionally, it was recognised that HDVs have much greater scope for custom-configuration, and so testing of all variants would be impractical both in terms of agency resources and the lack of chassis dynamometer test centres in the US.

GEM was designed by the EPA and is a free desktop application. An initial version of the model was released for public comment in 2010 as a part of the proposed rules. The model was validated against testing data from commonly used vehicle models from the industry. The model requires a number of inputs including the coefficient of aerodynamic drag, rolling resistance of both steer and drive tyres, vehicle speed limiters, automatic engine shutdown and weight reduction. GEM is used to predict whole vehicle fuel consumption and therefore encourages uptake of efficiency technologies and vehicle design optimisation to mitigate emissions.

The agencies were aware that the technologies modelled by GEM were by no means exhaustive since some technologies were felt to be too complex to model for compliance purposes, whilst others require standardisation such as the calculation of the GHG and fuel consumption benefits due to aerodynamic improvements. Therefore, to account for this, some standardised reductions in fuel consumption were determined for technologies that were not modelled by GEM. A number of elements were predefined within the model. For tractors, this included the lorry frontal area, payload weight, gearbox efficiency, final drive ratio, and an engine fuel map.

Development of the model

The model itself was developed by the EPA. The NHTSA played a key role in reviewing the code, in a similar manner to stakeholders, but were not involved with the creation of the code and executables.

For Phase 1, GEM was developed by initially reviewing existing commercially-available simulation programs. However, since the government would require a fully-transparent tool, offering all code, including source code, for public comment, these companies were unwilling to offer their product for direct use. Instead, whilst software companies would be useful, the agencies were required to develop the software themselves. It was initially designed using MATLAB software, due to the existing knowledge of the agency staff. Many of the governing equations within the model, however, are based on those from other existing software.

For Phase 2, the agency had developed an in-house software development capability. Realising that this model needed to be upgraded, the agencies developed a model suitable for application for the second phase of the heavy-duty emissions control programme. The enhanced GEM differs from the first phase in a number of ways. Firstly, in Phase 1, the model assumed a default engine and transmission maps which were applied to each simulation. In Phase 2, manufacturers are expected to provide detailed engine maps. This is part of an upgrade to the engine controller within the model, which includes engine fuel cut-off during braking and decelerating and the option to apply cruise cycles. Also, manufacturers have the option to use engine and transmission data obtained from a powertrain testing to replace the engine and transmission files. Additionally, manufacturers can opt to include data for axle losses and/or transmission power losses, a feature unavailable in Phase 1. Finally, the model exhibits an enhanced driver model with a distance-compensating driver (i.e. the driver will drive a prescribed distance regardless of the increased drive time association with vehicle underperformance). Therefore, emissions are calculated more on a distance-based measure rather than time-based, ensuring a more realistic output to the model. The agencies are continuing to expand their own software development capabilities and are currently exploring the creation of a dynamic link library which can be embedded into manufacturer IT systems.

In the case of the development of improved methods of testing, or technological innovation that isn't recognised by GEM, the model would then be further developed as required. Since corrections or changes to GEM directly impact certification requirements, the agencies must open the code for a period of public comment, before proposing and finalising changes. Therefore, no changes to the software happen quickly. In this sense, the GEM software code is treated in an equivalent manner to the regulations themselves. For Phase 1, the agencies were required to release a version of GEM on more than one occasion.

High level costs associated with the GEM model

The development of the GEM model required 3-4 full time equivalent employees to commit around 50% of their time for two years, in the case of Phase 1, and for three years, in the case of Phase 2. The major costs to develop the model were related to the validation efforts which informed the model input data, however. Roughly half of the annual budget for the development of the regulations was consumed by this extensive validation exercise, equating to around \$1-1.5m per year of development. The agencies both performed and asked contractors to generate chassis dynamometer, rolling resistance, and engine test data. Further unreported costs were borne by the industry and OEMs themselves in validating the model. These manufacturers would assist the agencies by providing large quantities of data for free, at significant costs which are not accounted for above.

2.2.1.4.7.5 In-use testing

Under Phase 2, manufacturers must collect and report post-production performance data using a chassis dynamometer, though this is for information only and no in-use standard is applied. Regulators are interested in using this data to ensure improvements output from GEM simulations are synonymous with real-world improvements to maintain the integrity of GEM. HDVs must remain in their certified configuration for the duration of their operating life, which the US authorities believe will maintain their GHG performance.

In-use testing of engines is performed using an engine dynamometer for both Phase 1 and 2. The useful-life certification standards are reduced by a 3% reduction factor over production certification standards.

2.2.1.4.8 Secondary systems covered

The US regulations also apply to air conditioning refrigerant leakage, as described in Section 2.2.1.4.2.2. These cap the percentage refrigerant leakage at:

- 1.5% of system capacity per annum for Class 7 and 8 tractor vehicles with a total system capacity exceeding 733 grams.
- 11.0 grams per annum for vehicles with a total system capacity of less than or equal to 733 grams.

The ICCT estimate that the average percentage leakage for a MY2010 HDV is roughly 2.7% of system capacity (ICCT, 2011), thus manufacturers have needed to re-design the systems and cab seals to meet this requirement.

2.2.1.4.9 Main efficiency technologies targeted/incentivised by the measures

The US agencies have, by adopting separate engine and vehicle standards, sought to drive technology improvements in both engine and vehicle technologies.

Further, because the measures are outcome based, having CO₂ emissions and fuel efficiency targets that are independent of the technology that delivers them, the technologies targeted are those which the market place decides are the most cost effective and practical for the different vehicle categories. Various analyses, e.g. including several by ICCT, have concluded that one technology does not dominate all HDV categories.

HD pickups and vans are found to undertake an above average amount of urban stop-start driving, a below average amount of high-speed driving and are the smallest of the HDVs, hence strong hybridisation, light-weighting, low rolling resistance tyres and improvements in engine efficiency are anticipated to be the technologies chosen to deliver the reductions in CO₂ emissions and fuel consumption required.

Tractor-trailer combinations undertake long haul delivery operations and a below average amount of urban stop-start driving, an above average amount of high-speed driving and are the heaviest of the HDVs, hence improvements in aerodynamics, waste heat recovery systems, low rolling resistance tyres and improvements in engine efficiency are the technologies anticipated to deliver the reductions.

For vocational vehicles the technologies incentivised by the measures include all those identified for the other two vehicle segments, dependent on their vocation. School buses, transit buses and urban delivery lorries undertake much urban stop-start driving and travel only modest distances in a day at

relatively low speeds, thus the technologies appropriate for HD pickups and vans apply. Coaches, inter-city buses and rigid box-lorries undertake regional delivery driving and typically travel long distances in a day at relatively high speeds, hence the technologies appropriate for tractor-trailer combinations apply. Under Phase 1, where vocational vehicle standards were split across three segments by GVW, only tyre and engine improvements were incentivised. In Phase 2, the number of segments was increased for vocational vehicles to take into account GVW, fuel type and usage profile, resulting in the promotion of other technologies suited to the particular vehicle's duty cycle.

2.2.1.4.10 **Flexibilities on compliance**

For each heavy-duty vehicle and engine category the EPA and NHTSA designed provisions to allow manufacturers a degree of flexibility in complying with the standards, as alluded to above. They believe that by introducing flexibility it has allowed the agencies to make the overall standards more stringent and will become effective sooner than in a more rigid programme (EPA, 2011). The provisions provided by the NHTSA and EPA are essentially identical in structure and function. There are four primary types of flexibility; averaging, banking and trading (ABT) provisions; early credits; advanced technology credits; and innovative technology credit provisions. These types of flexibility are aimed at incentivising the development and take-up of technologies faster than the market would otherwise, by offering tradeable credits which can be used to offset future underachievement with respect to meeting the phased regulations.

ABT programmes encourage vehicle manufacturers to reduce CO₂ emissions and fuel consumption levels beyond what is required in the standards, by providing them with tradeable credits if they achieve this. The manufacturer can then use these credits to offset higher emissions or fuel consumption levels in the same averaging set of vehicles. Averaging sets are restricted to vehicles or engines within the same regulatory subcategory based only on weight class. For example, earning a credit for the manufacture of a Class 7 vocational vehicle may not be used to offset underachievement in CO₂ of fuel consumption reductions for a Class 8 combination tractor, but may be used for offsetting a Class 7 combination tractor. FTP-heavy duty and SET test cycle provisions are included in the same averaging set. Additionally, credits gained from engine developments and improvements may not be used to offset underachievement of emissions savings for whole-vehicle standards, and vice versa. Credits may be "banked" for future use (carried up to a maximum of five years), or can be "traded" with another manufacturer, providing a financial incentive to exceed the standard requirements where possible. Manufacturers are also able to enter credit deficits for up to three consecutive years.

Early credits and advanced technology credits are incentivised by providing credits which are worth more within the ABT scheme. These credits receive a multiplier of 1.5x, and represent an effective means of bringing technology sooner to the heavy-duty sector than would otherwise be the case. Advanced technology credits may be traded in any averaging set within the ABT scheme, whilst for early credits, this is not the case. For other technologies not covered by the early and advanced technology credits scheme, the agencies encourage development through innovative technology credits. These technologies are defined as those that are shown to produce emissions and fuel consumption reductions, but their operation is not currently recognised by the current test procedures, and are not already in widespread use throughout the heavy-duty sector. There is no credit multiplier for these technologies.

A further temporal flexibility on compliance is described in Section 2.2.1.4.2.4.1.1, whereby the introduction of OBD requirements in close proximity to the fuel consumption target years led the regulators to introduce two 'options' of when to meet slightly differing targets.

All 2014 vehicles which are covered by a US EPA certificate are also exempt from the Canadian requirements of the CO₂ emissions credit system. This reduces to 50% exemption for 2015, and 25% for 2016.

2.2.1.4.11 **Estimated costs and benefits of measure**

2.2.1.4.11.1 *Costs and benefits of Phase 1*

EPA and NHTSA estimate total benefits from Phase 1 of about 270 million metric tonnes of avoided GHGs, and approximately 530 million barrels of oil saved over the lifetime of the vehicles from 2014 to

2018. Overall, EPA and NHTSA estimate that the programme will cost the industry around \$8 billion²⁰, whilst saving vehicle owners around \$50 billion in fuel costs over the lifetime of the vehicles manufactured over the Phase 1 period. In addition, the estimated benefits from CO₂ reductions and other social factors such as improved road safety, reduced time spent refuelling, and traffic congestion, are \$49 billion over the lifetimes of the vehicles. Over this Phase 1, the regulations require a 9-23% reduction in CO₂ emissions for combination tractors, and a 5-9% reduction for vocational vehicles. Some of these reductions can be mitigated through engine efficiency and technology improvements, which also require a 5-6% improvement over the course of Phase 1.

Using technologies commercially available today, payback periods will typically be between one and two years (dependent on annual mileage).

In total, the combined standards will reduce GHG emissions from the U.S. heavy-duty fleet by approximately 76 million metric tonnes of CO₂-equivalent annually by 2030.

2.2.1.4.11.1.1 Deviations for Canada

Environment Canada estimate the total benefits of a reduction in approximately 19.1 Mt of CO_{2e} in GHG emissions over the lifetime operation of the new vehicles sold between 2014 and 2018. Furthermore, the regulations will reduce fuel consumption by 7.2 billion litres over the lifetime of the 2014-2018 fleet. The cost of the Regulation is estimated at \$0.8 billion²¹, largely as a result of additional vehicle technology costs. This is compared to benefits estimated at \$5.3 billion, resulting from \$0.5 billion in GHG reductions and \$4.8 billion in fuel savings. Overall, the net benefit is estimated to be \$4.5 billion, with a payback period of less than one year.

2.2.1.4.11.2 Costs and benefits of Phase 2

The EPA and NHTSA estimate that the total benefits from Phase 2 of about 1100 million metric tonnes of avoided GHGs (in CO₂ equivalent), and approximately a fuel reduction of 82 billion gallons over the lifetime of regulated vehicles.

Overall, they estimate that the programme will cost the industry \$29 billion²² to the industry, whilst saving owners around \$169 billion in fuel costs. In addition, the social benefits arising from this regulation, including the estimated monetary benefits of reduced CO₂ reduction, improved road safety, and traffic congestion, total to \$88 billion over the lifetime of vehicles covered by this regulation (ICCT, 2016).

Overall, payback periods are estimated to be somewhat longer than for Phase 1. In this case, it is expected that payback periods will be around two years for combination tractors and four years for vocational vehicles (EPA, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2, 2016). In all, however, the total benefit-to-cost ratio for Phase 2 exceeds that for Phase 1. Table 2.14 summarises the basic details for the first and second phases of the regulation.

Table 2.14: Summary of the basic details of the heavy-duty emissions regulations (adapted from (ICCT, 2016))

Parameter	HDV Type	Phase 1 2014-2018	Phase 2 ^b 2018-2027
Per vehicle			
CO ₂ reduction (%)	Combination tractors	9-23%	12-27%
	Trailers	-	3-9%
	Vocational vehicles	5-9%	10-24%
	Engines	5-6%	0-5%

²⁰ US dollars (2009).

²¹ Canadian dollars (2011).

²² US dollars (2013).

Parameter	HDV Type	Phase 1 2014-2018	Phase 2 ^b 2018-2027
Vehicle technology cost (2009\$ Phase 1; 2013\$ Phase 2)	Combination tractors	\$6,215	\$12,300
	Trailers	-	\$1,100
	Vocational vehicles	\$378	\$2,700
Annual payback period	Combination tractors	1	2
	Vocational vehicles	1	4
	Trailers	-	2
Lifetime fuel savings (3% discount rate) (2009\$ Phase 1; 2013\$ Phase 2)	Combination tractors	\$79,089	<i>Not stated</i>
	Vocational vehicles	\$5,872	<i>Not stated</i>
Nationwide			
Energy and climate impact	GHG savings over regulated vehicle lifetimes (Mt CO ₂ eq)	273	1,098
	Fuel reduction over regulated vehicle lifetime (billion gallons)	22	82
	Fuel savings	\$50bn	\$169bn
Monetary impact (3% discount rate) (2009\$ Phase 1; 2013\$ Phase 2)	Social benefits ^a	\$7bn	\$88bn
	Total costs	\$8bn	\$29bn
	Benefit-to-cost ratio	7:1	9:1

Notes:

^a Social benefits include the value of health and monetized CO₂ benefit.

^b Phase 2 figures based upon Table 2 within (EPA, 2016).

2.2.1.4.11.2.1 Deviations for Canada

Canada is yet to estimate the costs and benefits of introducing Phase 2 legislation but has announced its intention to follow the US legislation.

2.2.1.4.12 Further regulatory programmes in California

The same federal HDV fuel economy standards currently apply in California, although it is possible that California will set slightly more stringent standards under Phase 2. In the past, California has set up a small number of further programmes on HDV fuel economy which were either introduced before the federal standards or complement these.

2.2.1.4.12.1 Idling requirements

In 2004, CARB adopted the Airborne Toxic Control Measure, limiting the idling of diesel-fuelled vehicles over 10,000lbs to 5 minutes. This measure required new engines to be equipped with a non-programmable engine shutdown system that automatically turns off the engine after five minutes of idling, or optionally meet a stringent NO_x emission standard (30g/h) at idle. These requirements became effective in 2008.

2.2.1.4.12.2 The Hybrid Truck and Bus Voucher Incentive Project (HVIP)

In 2008, CARB approved the Hybrid Truck and Bus Voucher Incentive Project (HVIP). This provided vouchers on a first come, first serve basis for the purchase of new eligible hybrid lorries or buses. The eligible technologies include battery-electric, fuel cell, hybrid, electric power take-off, and ultra-low-NO_x natural gas engines. The project aimed to achieve 0.5 Mt CO₂e benefit by 2020, in line with the AB 32

scoping plan. The plan assumed that, starting in 2015, all new lorries sold will use hybrid technology, with the greatest benefits being seen in vocational HDVs with significant urban operations.

2.2.1.4.12.3 Tractor-Trailer regulations

In 2008 CARB also adopted the Tractor-Trailer GHG regulations 'to reduce greenhouse gas emissions from heavy-duty vehicles' (California Air Resources Board, 2008), through mandatory adoption of the EPA's SmartWay-approved aerodynamic technologies. The regulation applies to owners of tractors pulling 53-foot or longer box-type trailers, drivers of 53-foot or longer box-type trailers, motor carriers and California-based brokers that dispatch 53-foot or longer box-type trailers, and California-based shippers that haul freight in 53-foot or longer box-type trailers. Part of the EPA's SmartWay Transport Partnership Program involves approving technologies such as aerodynamic equipment and low-rolling resistance tyres, and certifying tractors and trailers which incorporate these technologies. The regulation requires the use of these certified tractors and trailers in California, and the retrofitting of vehicles with SmartWay technologies. The expected fuel efficiency improvement from this regulation is between 7% and 10%, resulting in cumulative GHG reductions of approximately 8 Mt CO₂e in California and approximately 52 Mt CO₂e nationwide between 2010 and 2020, as well as NO_x reductions (California Air Resources Board, 2008). The regulations took effect in 2010 for the same model year, with low rolling resistance tyres required on tractors of older model years from 2013.

2.2.1.5 Monitoring, reporting, verification and enforcement

As previously discussed, the EPA has been responsible for noxious and CO₂ emissions legislation under the Clean Air Act and has regulated HDV engines since 1974. The NHTSA is responsible for fuel economy under the Energy Policy and Conservation Act and since 2010 has worked with the EPA to introduce the first GHG and fuel efficiency standards for HDVs in the US.

2.2.1.5.1 Monitoring and verification

Under Section 203 of the Clean Air Act, sales of vehicles are prohibited unless the vehicle is covered by a certificate of conformity. The EPA issues certificates based on the testing procedures described in subsection 2.2.1.4.7.4 above, with testing either performed directly by the EPA, or by the manufacturer itself (with validation testing performed by the EPA). The standards are required not only at the pre-sale certification stage, but throughout the useful life of the vehicle for engines. The EPA measures CO₂, CO and unburned hydrocarbons, before using these measurements to calculate the fuel consumed over the test period through mass balance equations (EPA, 2011). The measured CO₂ is also used for compliance with the NHTSA regulations.

Manufacturers must fill in engine family and vehicle certification templates jointly to EPA and NHTSA, based on their measured/modelled performance depending on the requirement of the regulation for the particular vehicle type. They must also submit Compliance reports and Engine Compliance Averaging, Banking & Trading Reports, using a series of Excel templates available online. Enforcement audits and production line testing are carried out randomly by the EPA and NHTSA to verify compliance.

The EPA and NHTSA perform validation testing prior to production. The results of the validation testing are used to create a finalised reporting that confirms the manufacturers' final model year GHG emissions. Penalties are issued on the basis of this calculation. The EPA and NHTSA have the authority to issue notices of violations and the penalties associated with them.

Each HDV engine is also subject to an in-use standard. The standards take into account degradation in the function of emission control technologies, and hence become somewhat slacker as vehicle age increases. The in-use limit is governed by a deteriorated emission level (which is dependent upon engine type amongst other factors). Manufacturers run an in-use testing programme and must submit quarterly engine test data which has been completed during that quarter. In addition, the EPA may conduct, or request, an emissions test on production engines/equipment in a selective enforcement audit.

Around 50% of the EPA's heavy-duty laboratory resource is consumed by compliance testing, monitoring, and validation efforts. This is expected to increase. Subsequent to the Volkswagen scandal, there is greater emphasis within the industry on in-use testing, such as through the introduction of portable emissions measurement systems (PEMS). Under Phase 1, the EPA sent engineers to test

facilities across the US to perform tyre and basic engine testing. For Phase 2, transmission efficiency, axle efficiency and idle reduction strategies will need to be assessed, so costs of monitoring are likely to further increase.

2.2.1.5.1.1 *Deviations for Canada*

Manufacturers and importers are responsible for producing and maintaining evidence to Environment Canada that demonstrates conformity to the regulations. Environment Canada monitor GHG emissions performance for compliance with the regulations. Environment Canada require engines or vehicles to have the national emissions mark, or a US equivalent (EPA certificate, CARB certificate), or other documentation proving that it meets the Canadian emissions standards. The Canadian national emissions mark is authorised and monitored by Environment Canada, who also carry out inspections of test vehicles and engines, and tests on new and in-use engines and vehicles. Monitoring is also coordinated with the US EPA through information sharing, given the integrated nature of the market.

2.2.1.5.2 **Reporting**

EPA and NHTSA have established a single reporting structure where manufacturers record and report the number of engines/vehicles sold in a year, together with their emissions as given in their Certificates of Conformity. This mechanism is in place and being used.

For Phase 2 the agencies propose to simplify end of the year reporting and also retain much of the certification and compliance structure developed in Phase 1. It is proposed that a single reporting structure to satisfy both agencies is maintained, requiring limited data at the beginning of the model year for certification, and determining compliance based on end of year reports.

Different reporting details apply to manufacturers participating in the averaging, banking, and trading (ABT) provisions. They are required to provide two reports a year (90 day and 270 day reports) after the end of the model year (EPA, 2015). As final production values are needed to determine compliance status, the manufacturers give production estimates for the model year. After the production year ends, compliance credits and deficits are calculated.

2.2.1.5.3 **Enforcement and penalties**

The EPA is able to provide for HD non-conformance penalties under Section 206(g) of Clean Air Act. At the time of writing the EPA did not believe the penalties would be necessary, given the flexibility mechanisms and that the standards are “readily feasible.”

Section 207 of the Clean Air Act grants the EPA the broad authority to require manufacturers to remedy its vehicles if a substantial number are found to be non-compliant. The maximum penalty which the EPA is permitted to issue is \$37,500 per non-complying vehicle. The exact figure is influenced by the severity of the violation, the economic impact of the violation, and the violator’s history of compliance. For consistency, the NHTSA also issue maximum civil penalties of \$37,500 per violating engine or vehicle²³.

For heavy duty pickup trucks and vans, again the flexibility system allows some freedom in achieving compliance and manufacturers would be allowed a negative balance of credits for a maximum of three years before facing a penalty. Consequently, it is not anticipated that it will be necessary to introduce penalties.

²³ There has been some disagreement to the NHTSA’s interpretation of 49 U.S.C. 32902(k)(2) to allow the agency to issue civil penalties for violation. The ruling states that the NHTSA must adapt and implement appropriate, cost-effective, and technologically feasible compliance and enforcement protocols for the fuel efficiency programmes. The lack of guidance as to how “protocol” should be interpreted affords the NHTSA substantial breadth of discretion, which it has interpreted to allow the authority to determine, assess, and exercise civil penalties for violation. There is some opposition to this interpretation, as detailed further in the final Phase 1 rulemaking (EPA, Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule, 2011).

The EPA is yet to find a single instance of non-compliance. In fact, OEMs were so conservative that they placed themselves in more stringent aerodynamic bins than they could have, and hence qualified for reduced credits as a result.

These penalties are applied to both Phase 1 and 2 of the heavy-duty emissions programme. Further to this, trailers are covered by the Phase 2 of the regulations.

2.2.1.5.3.1 Deviations for California

CARB stated during our stakeholder interview that they only started enforcing the Tractor-Trailer regulation in 2016. Overall, there has been very good compliance. Typically, CARB enforce these regulations as part of performing a suite of compliance checks, rather than enforcing each measure individually. Checks are carried out at random or specifically on fleets which have been flagged for potential non-compliance.

2.2.1.5.3.2 Deviations for Canada

Environment Canada enforcement officers can apply the Compliance and Enforcement Policy, which is part of CEPA 1999. This policy sets out a range of possible responses to violations including warnings, directions, environmental protection compliance orders, ticketing, ministerial orders, injunctions, prosecution, and environmental protection alternative measures. The officer bases the action on three factors: the nature of the alleged violation, the effectiveness in achieving the desired result with the alleged violator, and consistency with similar situations.

2.2.1.6 Evaluation and next steps

The implementation of Phase 1 of the standards demonstrated willingness from manufacturers to comply with the standards. In some cases, the manufacturers voluntarily chose to comply earlier than they would otherwise be mandated to do (EPA, 2016). It is uncertain whether this was driven by the incentive of credits for early compliance or by market factors. Manufacturer plans for compliance indicate an intention to utilise the flexibilities offered in Phase 1 (EPA, 2016). The market appears accepting of new technologies and there has been no evidence of a “pre-buy” effect, where manufacturers stock up on new vehicles prior to the introduction of the regulations. In fact, domestic sales of heavy-duty vehicles are higher in recent years than they were before the introduction of Phase 1 (EPA, 2016). There have been no examples of significant non-compliance throughout the duration of Phase 1 to date.

As a part of the development of Phase 2, the EPA tested many Phase 1 compliant vehicles in order to assess whether the GEM was representative of the increased amount of in-use testing data. This data is used to validate GEM and to establish the baseline values. Ultimately, the vehicles tested in GEM meet the standards, and therefore, it was concluded that the baseline for Phase 2 would be the compliant vehicle from Phase 1 for MY2017. Road grade was added to the GEM, whilst weighting factors for transient and static operation were modified as a result of this evaluation. Also, as a part of Phase 2, OEMs are required to report chassis dynamometer test results to the EPA (over the cycles within GEM). These are not used as a compliance mechanism, but are more to investigate whether the improvements made in real-life are accurately reflected in GEM. If there are disparities between these results, the EPA will investigate the reasons.

2.2.1.6.1.1 Deviations for California

No formal evaluation process has been undertaken by the Californian authorities on Phase 1 or the Tractor-Trailer regulation. In general, CARB evaluate the practicality of regulations based on feedback from stakeholders - by working with relevant parties required to interact with each particular component of the regulation (i.e. the enforcement division, the implementation team, etc.), CARB gains an understanding of the situation ‘on the ground’ and uses this to decide on the need for amendments or further regulation. This applies also to feedback from industry, where highlighted issues are investigated by CARB and may result in legislative changes. An example can be taken from the implementation of the noxious HDV emission standards where it was realised that some SCR technologies were contributing to high NO_x emissions at low engine loads, hence CARB prioritised studies into verifying this and revised the regulation. At present, no issues or difficulties in applying the fuel efficiency measures have been raised.

Overall, CARB assess both whether the measure is performing as intended when it was designed and whether non-compliance is an issue; if neither of these indicate problems then the measure is not a candidate for evaluation. The exception to this is if Congress requests a review of the implementation.

CARB are likely to modify the federal Phase 2 standards for their own adoption, with changes being made in 2017. A workshop was conducted in February 2017 to provide further information on the proposed CARB-specific elements for Phase 2. The publically available slide deck suggested the following topics for discussion under the heading 'Areas Where California Phase 2 May differ From Federal Phase 2' (CARB, 2017):

- Credits (see the source for proposed credit rates)
 - Additional credits for use of low-GWP refrigerants (federal Phase 2 requirements do not include any requirement or credit incentive for the use of low-GWP refrigerants)
 - Additional requirements for plug-in hybrid electric vehicles to qualify for advanced technology credit multiplier
 - Other credit provision changes under consideration
- Proposed modifications to California Tractor-Trailer Greenhouse Gas Regulation
- California enforcement
 - Adopting tampering and selective enforcement audit provisions of Phase 2
 - 'Sun-setting' provisions of Tractor-Trailer GHG Rule that impact model year 2018 and newer trailers
- Vehicle and Trailer labelling
 - Considering additional information to be included in vehicle and trailer labels to aid enforcement
- Consumer labels for heavy-duty pick-ups and vans
 - Require 'light-duty style' consumer labels for heavy duty pick-ups and vans (provides fuel efficient and environmental performance scores)
- Vocational custom chassis
 - Exclude transit buses and refuse trucks from custom chassis provisions
- Hybrids
 - Hybrids must demonstrate no NO_x increases to qualify for Advanced Technology Credit multiplier
- Alternate emission standards for speciality heavy-duty vehicles
- Engine and vehicles certification requirements
 - Require each vehicle manufacturer to include engine family for each certified vehicle in end of year report
 - Require vehicle manufacturers to provide additional air conditioning system information to support A/C leakage standards
 - Establish zero emission vehicle certification procedures
- Natural gas engines
 - Continue to include ethane in the hydrocarbon emission standards for natural gas compression-ignition engines

These headings were topics for discussion by the meeting participants and it is not known whether the changes will enter into force. A second public workshop will be held in 'Spring 2017' and a public consultation period on CARB's Phase 2 staff report is planned to begin in September 2017. The final consideration of CARB's Phase 2 proposal is scheduled for October 2017.

2.2.1.6.2 **Performance**

The EPA is not obligated to perform retrospective studies on regulation unless requested by Congress. Congress recently demanded a study into the benefits and costs of the Phase 1 regulations as part of

a review into six efficiency regulations, where it was well-received thanks to the multiple analyses, uncertainty ranges, flexibilities, technology packages, and discount rates used in its development.

There are also internal initiatives within the compliance division to publish a compliance report whilst certification data is released halfway through each model year, although this does not illustrate which technologies have been utilised.

Since it encompasses small businesses, the Phase 2 rulemaking is subject to the Small Business Regulatory Enforcement Fairness Act (SBREFA). This involved a formal panel of SME representatives which reviewed all the elements of the rulemaking, and generated a report to recommend flexibilities for smaller businesses. There is also a follow-up report required 10 years after the rulemaking was published to assess the effect on SMEs. In 2026, therefore, the EPA will be obligated to assess the impact Phase 2 has had on SME's in terms of costs.

2.2.1.6.2.1 Methodology improvements

The OEMs suggested improvements of aerodynamic testing to the EPA for Phase 2. Test procedure improvements were therefore made to eliminate systematic biases and uncertainties.

The agencies continue to search for improvements in test methodologies with the intention of introducing these changes in the future. For example, the agencies are currently considering improvements in the methods of tyre testing. Additionally, there is concern over the repeatability of engine mapping tests. GEM shows a variability on the order of around 1.5%, whilst laboratory testing shows variability can be on the order of 3%. Currently there is a programme being conducted by the SwRI looking into this variability. Finally, the EPA has found that stoichiometric analyses of common fuel samples at different laboratories yields different results. Therefore, tests in this area could also be improved.

2.2.1.6.2.2 Ex-post assessment of costs

For Phase 1, there have been no complaints from the industry that the costs estimated in the rulemaking have been underestimated. Since Phase 2 was only proposed in August 2016, the OEMs are unlikely to have made full assessments of the compliance plans they will undertake to meet the regulations, and as such it is too early to comment.

2.2.1.6.3 Lessons learned

The lessons that the agencies have learned from the development and implementation of this and previous regulations for the heavy-duty industry are:

- Use gradual standards – for the implementation of NO_x and PM standards, some OEMs were required to implement technologies two years ahead of schedule, due to punishments for previous non-compliance. This meant the introduction of under-developed and under-tested technologies into the market. These technologies were later found to be unreliable, and as a result, the costs to OEMs for settling warranty claims were much larger than anticipated.
- Use multiple technology pathways – in the same example as above, since the regulations effectively required a single technology path, the manufacturers were unable to explore more appropriate technologies. This meant that market penetration rose to 100% extremely rapidly, and it was this type of implementation that was the source of problems for customers and manufacturers.
- Include flexibilities – the introduction of flexibility options, such as the ABT scheme, help to smooth out problems with compliance, giving manufacturers the ability to carry credit deficits for up to three years, and therefore, provide sufficient time to ensure the effectiveness and reliability of introduced technologies.

2.2.1.6.3.1 Deviations for California

In terms of lessons learned, CARB indicated that it is possible to benefit from 'easy' greenhouse gas emission reductions by driving people to existing cleaner technologies. During an interview with the project team, CARB stated that given the trade-off between introducing measures in a reasonable timeframe and perfecting the details, CARB's philosophy is to act soon and to set up regulatory systems and processes with less stringent targets. CARB's experience suggests that development of less

meticulous measures should be performed as soon as is practicable, while further refining the regulations for increasingly tailored future efforts.

2.2.1.6.4 **Future standards**

For now, there are no plans to develop regulations beyond 2027. It is believed that, in terms of absolute CO₂ regulations, overall annual emissions will reduce until 2033. After this, growth in the fleet size will cause increases in emissions, which the EPA will track. The next NAS report is due in 2017, which will be concerned with the future of HDV efficiency.

The EPA have noted their intention to include further in-use compliance testing where possible in any future regulations, though no discussions have yet taken place regarding how to implement such a programme and it is not a regulatory priority. The EPA suggested that the determination of an in-use pass/fail threshold is challenging as the GEM simulation yields relative improvements from a nominal and fixed baseline vehicle, payload and duty cycle, whilst an in-use test determines absolute performance via measurements (Spears, 2016).

2.2.1.6.4.1 *Deviations for California*

Whilst CARB's preference is to maintain alignment with the federal HDV fuel economy measures, the principal driver of future plans is determined by California's progress towards their emission reduction targets. If the impacts of the EPA measures would cause California's emissions to deviate from the trajectory set by CARB in their AB32 Scoping Plan / State Implementation Plan air quality goals, then CARB will diverge from federal standards and impose more stringent measures.

CARB are funding a small number of research programmes aimed at improving fuel efficiency for specific vehicle types, such as vocational vehicles. These programmes are still in their early stages, however, and no indication of future direction can yet be gained from them.

CARB also have active regulatory programmes for developing measures in 'advanced technology transit' and last-mile delivery improvement. The programmes represent two well-positioned areas for zero-emission technologies – California's eventual goal – which may also see the added benefit of increased vehicle lifecycles. These measures are currently planned for implementation in 2017, though this may be pushed back: CARB have noted the particular challenge in developing standards which are as far-reaching and long-term in their outlook. The measures will seek to foster zero-emission mobility for the future, rather than imposing solutions in the short term.

2.2.2 China

2.2.2.1 Summary

2.2.2.1.1 **Introduction**

China have had regulations in place for heavy duty fuel consumption since 2008. These first standards are the responsibility of the Ministry of Transport (MOT) and regulate fuel consumption from in-use vehicles. In 2012, the Ministry of Industry and Information Technology (MIIT) implemented a second standard which requires manufacturers to obtain a certificate of conformity for all new type approvals before production can take place. In 2014, this became a requirement for all vehicles sold. Later in 2014, the second stage of these regulations was introduced for all new type approvals (2016 for all vehicles sold). The third stage of the regulations, expected to be introduced for all new type approvals in 2019 (2021 for all vehicles sold), has recently been announced and is currently open to public comment.

2.2.2.1.2 **Background to measures**

The measures were pursued following environmental and economic rationale. China has expressed its interest in controlling emissions from its rapidly growing HDV sector, whilst it is also interested in its energy security, road safety, and improving technological capability within the sector.

A modified version of the World Harmonised Vehicle Cycle (WHVC) test procedure was developed by the China Automotive Technology and Research Center (CATARC) in order to take into account typical

accelerations, decelerations, and weighting between urban, rural, and motorway driving of the Chinese heavy duty sector. Due to the lack of data concerning the fuel efficiency and composition of the fleet, efforts were focussed on accumulating fuel consumption data in order to inform the development of the standards. Vehicles were tested by CATARC and the results used to inform regulatory subcategories and limit values. Stage I was a deliberately lenient regulation, as it was seen as a data collection exercise by MIIT. Further data collection through testing by CATARC and data submission required from manufacturers informed the development of Stage II and III, which as a result are much more difficult to satisfy.

2.2.2.1.3 **Scope**

Stage I regulations cover rigid lorries, articulated lorries and coaches, whilst for Stage II the scope expanded to include construction HDVs and urban buses. The proposed scope remains the same for Stage III. Function-specific HDVs, such as salt spreading vehicles, are exempt.

2.2.2.1.4 **Monitoring, reporting, verification, and enforcement**

China regulates new type approvals, conducts conformity of production testing and runs inspection and maintenance programmes as a part of its heavy duty emissions regulation programme. The former two compliance mechanisms are the responsibility of the Ministry of Environmental Protection (MEP). The institution implementing the programmes is the Vehicle Emission Control Center (VECC) under the MEP.

China's emissions regulatory programme primarily focuses on enforcing requirements at the pre-market stage, by requiring manufacturers to obtain emission type approvals and to satisfy conformity of production. The MOT standards are responsible for regulating in-use vehicle emissions, although the limit values are known to be staggered and attainable, so enforcement efforts are reduced.

2.2.2.1.5 **Evaluation and next steps**

Evaluation studies were carried out after Stage I to assess the correlation between measured and simulated test methods. Improvements were made to the testing of tyre rolling resistance as a result. In future, the regulators will seek to introduce the standards mainly on a whole-vehicle basis, rather than to certify base models on the C-WHVC test cycle.

2.2.2.2 **Introduction and broad market characteristics**

2.2.2.2.1 **Administrative framework**

In 2008, the Ministry of Industry and Information Technology (MIIT) first announced its plan to develop fuel consumption standards for commercial heavy duty vehicles (HDVs). Now in its second phase, the regulations were introduced in an effort to curb emissions from a sector that saw its fleet size quadruple between 2000 and 2010 (ICCT, 2010). The MIIT is responsible for the development and implementation of the regulations, whilst the Ministry of Environmental Protection and Environmental Protection Bureaus (EPBs) are responsible for regulating emissions from pollutants. The reason for the division of responsibility is due to differing legislative strands: MIIT is tasked by Congress to regulate fuel consumption, whilst the MEP and EPBs are directed under the Clean Air Act to regulate air pollutants. In addition, the MOT also has regulations which monitor fuel consumption. Due to their heritage, MIIT is responsible for HDV fuel economy regulations prior to production and MOT is responsible for regulation after purchase.

China currently regulates new type approvals for HDVs, conducts conformity of production testing and runs inspection and maintenance programmes as a part of its heavy-duty emissions regulation programme. The former two compliance mechanisms are the responsibility of the MEP, which develops and issues national standards. Inspection and maintenance programmes are conducted on a more local level by municipal EPBs. This can lead to variations in the stringency of the inspections and maintenance between different regions.

In an analogous manner to the California Air Resources Board in the US, cities and regions are allowed to implement vehicle emissions standards before nationwide legislation has been introduced²⁴.

²⁴ An example of this is the enhanced limits imposed within Beijing before the Olympics were held in 2008.

However, this has most typically been enacted for municipal and public vehicles only. Historically, Beijing has led China's vehicle emission regulations, followed by Shanghai and Guangzhou.

The Air Pollution Prevention and Control Law bans the operation of vehicles whose emissions exceed local standards, with the potential of fines for drivers under a somewhat complex devolutionary system. A nationwide emission labelling programme has required all EPBs to adhere to a uniform, colour-coded sticker scheme since October 2009, enabling increased understanding of individual vehicle emissions and local requirements for consumers.

China is engaged in developing a system for improved enforcement of its compliance programme, and has expressed interest in emulating the federal and state relationships used in the US. In fact, in 2013 the US began to assist China to reduce its emissions, with one of the five Climate Change Working Group initiatives titled "Heavy Duty and Other Vehicles" (The White House, 2013) in preparation for the Paris Conference in 2015. As a part of this working group, China has committed to introducing low-sulphur fuels and to combat PM_{2.5} emissions by promoting HDV 'clean action plans'.

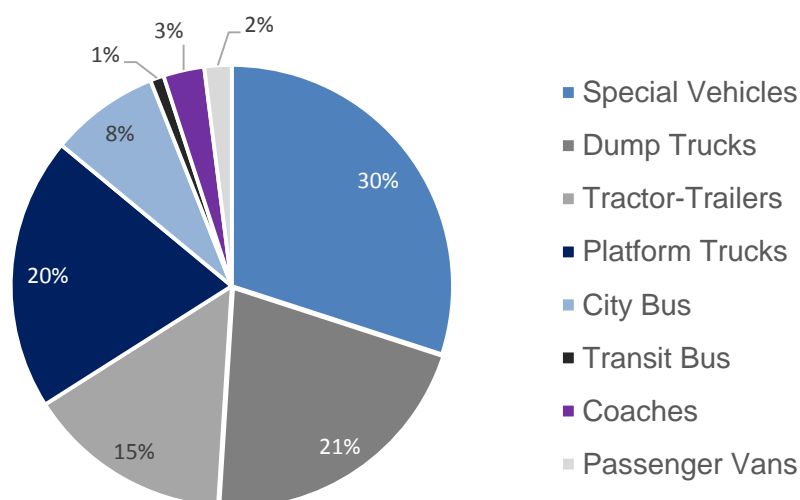
2.2.2.2.2 Fleet composition

Since joining the World Trade Organisation in 2001, the automotive sector in China has been rapidly growing. Between 2000 and 2010, China's fleet of cars and HDVs more than quadrupled to over 60 million units (ICCT, 2010). Annual production of automobiles in China is the largest in the world, surpassing the production in the US in 2009 (The Economist, 2009). Typical of inventories of rapidly-industrialising nations such as Brazil and India, heavy-duty vehicles represent the largest sector by fuel consumption, equating to 65% of total oil demand despite consisting only 10% of the total fleet (ICCT, 2015).

At the time that the regulations were drafted in 2011 the composition of the fleet and its associated fuel consumption was poorly documented. Since this time understanding has greatly improved, largely due to the requirement of the standards for new vehicle type approvals to submit their measured fuel consumption data (using the standardised test cycles described in 2.2.2.4.4) to CATARC.

As shown in Figure 2.8, the majority of in-use heavy duty vehicles in China consist of special, dump, trailer and platform lorries making up 86% of the fleet composition, while public transport vehicles amount for the remaining 14% (ICCT, 2015). Most HDVs are comparatively small: in 2014 over 3.18 million lorries were sold, of which 31% weighed over 6 tonnes and 52% between 1.8 and 6 tonnes (EUSME and China-Britain Business Council, 2015). The fleet is also comparatively old: over 90% of in-use HGVs conform to China III emissions legislation or lower (Reja, 2016).

Figure 2.8: Estimated breakdown of the total in-use heavy duty fleet in China (ICCT, 2015)



2.2.2.2.1 Typical Journeys and Duty Cycles

The average annual mileage of a Chinese commercial lorry is 52,000 miles (Huo, 2011), however duty cycles are heavily dependent on application and weight class. Articulated vehicles of over 25 tonnes typically spend 90% of their time on motorways and no time in urban areas, while rigid lorries of the same gross vehicle weight (GVW) typically spend 10% of time in urban areas, 30% in rural areas and 60% on motorways. In contrast, dump trucks operate almost 100% of the time in rural areas. As a general rule of thumb, as the weight of a rigid lorry increases so does the time spent on motorways (Zheng, et al., 2011). This is broadly similar to the EU.

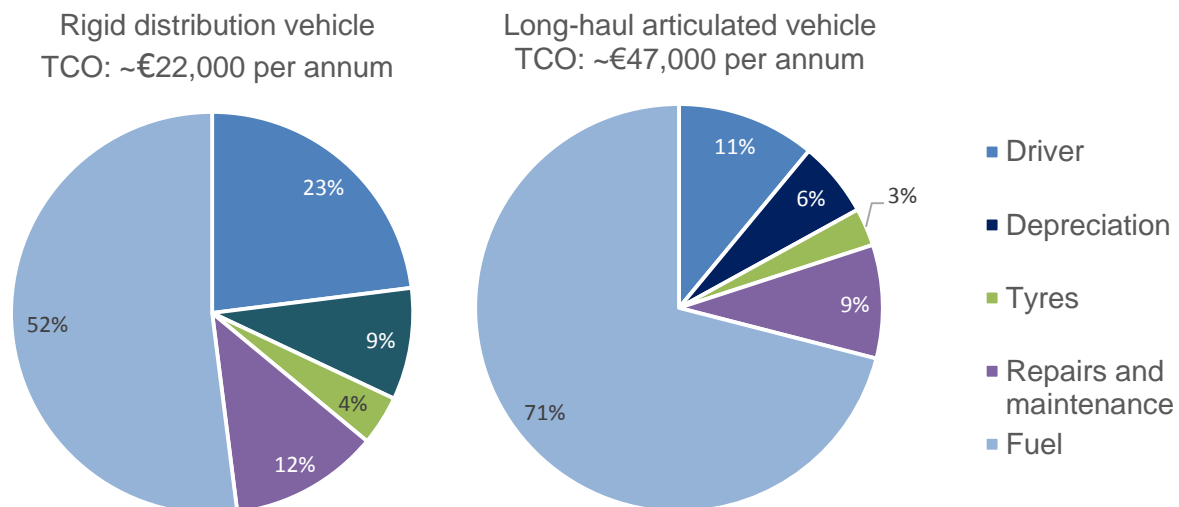
Table 2.15: Approximate proportion of vehicle mileage split by vehicle type and GVW (Zheng, et al., 2011)

Vehicle type	GVW (tonnes)	Urban	Rural	Motorway
Articulated lorry	9 - 25	0%	40%	60%
	≥25	0%	10%	90%
Dump truck	≥3.5	0%	100%	0%
Rigid lorry	3.5 - 5.5	40%	40%	20%
	5.5 - 12.5	10%	60%	30%
	12.5 – 24.5	10%	40%	50%
	≥24.5	10%	30%	60%

2.2.2.2.2 Overview of operating costs and typical ownership profiles

In China the total cost of ownership is lower than within the EU, in terms of both initial and operating costs. The average sale price for a lorry in China is €30,000 compared to €80,000-€100,000 in Europe, although the vehicles are more basic as there is a time-lag of some years behind European vehicle standards (KPMG, 2011). In addition, operating costs over the life of the vehicle are €30,000 and €23,000 cheaper in China than Germany for rigid distribution vehicles and long haul tractors, respectively. This is partially due to higher fuel prices and driver wages in the EU, but also as Chinese lorries better maintain their value (A.T. Kearney and VDA Team, 2014).

Figure 2.9: Average cost of ownership for Chinese heavy duty vehicles (A.T. Kearney and VDA Team, 2014)



China's ownership of HGVs is highly fragmented, with many small haulage companies owning only a few vehicles each – for example, in 2009, the 152,000 lorries operating within the Guangdong province

(the third largest by population) were owned by 90,000 different freight transportation companies (Reja, 2016). Leasing and financing plans are uncommon due to lack of awareness and culture so 90% of companies buy the vehicles outright. The Chinese government did not allow non-state owned companies to offer vehicle financing until 2004 (KPMG, 2011).

2.2.2.2.3 Fuel efficiency technology uptake and effectiveness

The MOT have estimated that fuel efficiency of Chinese lorries is 30% lower than other OECD countries, partly as a result of advanced fuel saving technologies and practices not being adopted. MOT suggested that the market lacked information on the performance, cost and availability of fuel efficient technologies, which prevented uptake, as well as a lack of investment capital or credit lines for small companies (The World Bank, 2016). Furthermore, there is little public data available on the uptake of fuel efficiency technologies in the Chinese fleet.

The most relevant technologies to the Chinese fleet were investigated by the Chinese Green Freight Initiative (CGFI), set up by Clean Air Asia and the World Bank after the success of the US SmartWay programme and earlier HDV studies in Guangzhou and Guangdong. CGFI investigated a broad range of air quality and GHG improvement mechanisms, with a large percentage of the effort attributed to reviewing energy efficiency technologies (Clean Air Asia, 2011). Greater emphasis was placed on reducing rolling resistance than aerodynamic drag due to the slower speeds travelled by Chinese lorries (an average of 43mph compared to 65mph in the US). Initially 6 technologies were trialled on 145 lorries with the three most successful tested on an additional 1,200 lorries. The three best performing technologies - low rolling resistance tyres, gap fairing and driving behaviour & operation monitoring systems - were able to achieve fuel savings of 3.9%, 2.9% and 2.6% respectively. In addition, lightweight aluminium trailers saved a further 5.9% fuel (Reja, 2016). Whilst there is no public domain information for the uptake of these technologies across the fleet, the demonstration did have a significant effect on the participant fleets. All enterprises involved in the CGFI demonstration noted their intention to retrofit their fleet with low rolling-resistance tyres; roof fairings have subsequently been installed in almost all new lorries in Guangdong; and, further training has been received by 3,200 lorry drivers and over 200 government officials and project managers.

2.2.2.3 Background to measures

2.2.2.3.1 Rationale

The primary basis for developing standards to regulate emissions from the heavy-duty sector was in an effort to reduce the energy consumption from its rapid expansion. For example, in 2006, in order to promote energy conservation work for heavy-duty vehicles, the National Development and Reform Committee (NDRC) submitted "Fuel Consumption Limit Standards for Soon-to-Appeal Large Commercial Vehicles" to the Opinion Paper on Automotive Industry Restructuring (Development and Reform Work) (NDRC, 2006). Additionally, in 2008, attention towards fuel consumption standards for heavy commercial vehicles was explicitly requested by the State Council, the chief administrative authority of China which includes the heads of each governmental department and agency. Other factors that drove the development of the standards include the need to improve technology and competitiveness, energy security, parallel reductions in air quality pollutants and safety (Jin, 2016).

As mandated by Chinese National Congress, MIIT first announced plans to develop standards for commercial heavy duty vehicles in 2008.

2.2.2.3.2 Implementation timeline

At the time of the MIIT's announcement in 2008, robust measurements of HDV fuel consumption were not readily available. CATARC was thus commissioned to develop test procedures for the measurement of fuel consumption from heavy-duty vehicles. A modified version of the WHVC test procedure was produced, named the C-WHVC, which had modified characteristics to better align with Chinese HDV operating conditions.

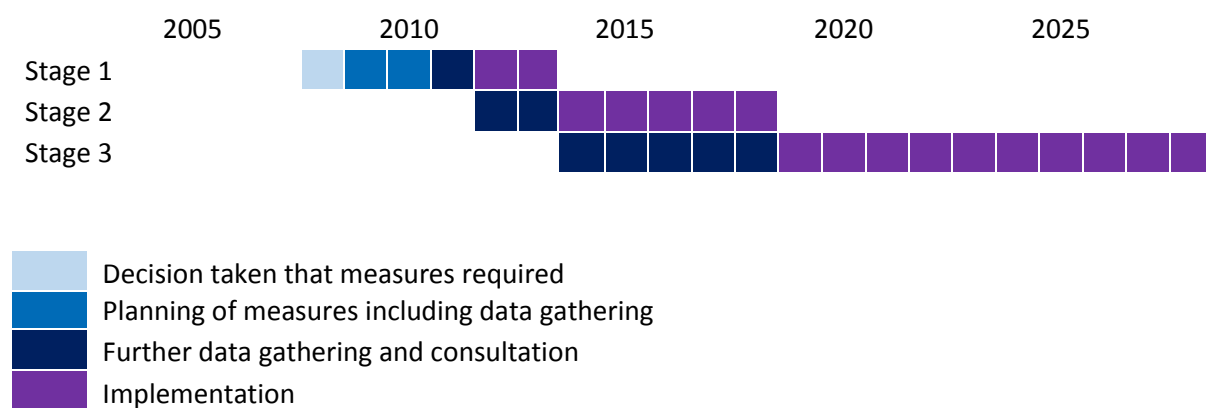
Using the C-WHVC, CATARC and two other laboratories conducted a study of measuring fuel consumption from the newest vehicles in the existing fleet. Between 2010 and 2011, over 300 HDVs were tested, from a broad range of vehicle types and gross vehicle weight ratings (GVWR) (Zheng, et al., 2011). These values were then used to set the stringency of the initial standards for three vehicle

types; tractors, straight lorries and coaches. The standards were effective for new type approvals from July 2012, and for all vehicles from July 2014. Due to highly uncertain nature of the heavy-duty fleet at the stage of implementation, the standards for the first stage were made fairly easy to satisfy.

In an effort to better understand the fleet characteristics and estimate fuel consumption to a greater level of certainty, all new type approvals since February 2012 have been required to submit fuel consumption estimates measured through the C-WHVC. Additionally, MIIT has been collecting more data through further testing and simulation on the latest models within the fleet. This allowed for the development and adoption of more stringent standards for the heavy-duty sector. Stage II of the standards were stipulated in 2012, with a final rule published in February 2014. These standards became effective in July 2014 for new type approvals and July 2016 for all vehicles.

In April 2016, the third stage of the measures was released for public comment. It is anticipated that this will come into effect in July 2019 for new type approvals and in July 2021 for all heavy duty vehicles sold within China. In preparing these standards, CATARC gathered data from 3,760 models across five vehicle segments, demonstrating the improved knowledge of the fleet's fuel consumption gained from the set-up of the standardised test cycle and the requirement for submission of measured fuel consumption data. This estimated timeline is given in Figure 2.10.

Figure 2.10: Timeline for the implementation of the Chinese HDV fuel consumption measures



2.2.2.3.3 Stakeholder engagement

Stakeholders were typically engaged during the development of the standards via committees. The National Industrial Standardisation of Vehicle Technology Committee was set up by MIIT's regulations department. This committee contained a working group known as the Energy Efficiency Technology of Vehicles Working Group which consisted of a large number of universities, manufacturers and research institutions, but no government organisations. This group was largely responsible for the development of the standards, and for the development of the simulation model (Jin, 2016).

Prior to the announcement of the standards, there was a period for public comment, allowing stakeholders to express concerns with the regulations. Feedback is gathered and standards are adjusted over a period of a year. The information gained from this consultation is reported back to the public, national, and international organisations (Jin, 2016). In the case of the Stage I regulations, no changes were made as a result of this public consultation.

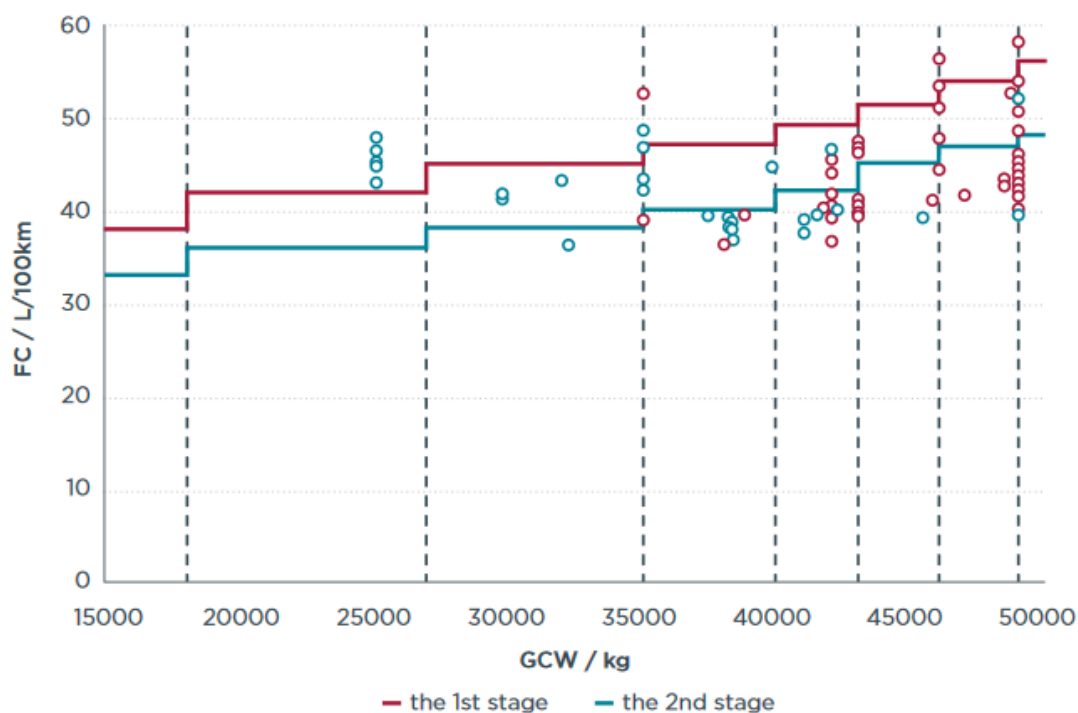
2.2.2.3.4 Data used to develop the baseline

As described in Section 2.2.2.3.2, the data used to develop the standards was derived from tests and simulations of fuel consumption of the latest vehicles in the fleet at the time of drafting. Standards in China are not time-independent, in that they do not use technology penetration forecasts to simulate baseline vehicles. Instead, the feasibility of a standard is assessed by the capability of the current fleet to satisfy the standards. As shown in Figure 2.11, the standards are loosely based on measured data. Red entries represent measurements made that informed the development of Stage I. The final standard is slack compared to most of the data points, indicating the relative ease of compliance. By

contrast, Stage II illustrates an improved regulator knowledge of fuel consumption by vehicle type and GVWR, and a more significant challenge for manufacturers. In fact, across all vehicle types, only around half of tested vehicles that were used to define the Stage II standards would have complied (ICCT, 2014).

This, therefore, requires the standards to be regularly updated in order to continue to encourage the heavy-duty manufacturers to produce vehicles incorporating greener technologies. Since the test cycles themselves were developed to be independent of driver behaviour, there is no consideration within the rulemaking for the possible benefits of driver training or logistics optimisation. These approaches are implemented in separate measures. To satisfy the regulation, manufacturers are reliant on technological improvements.

Figure 2.11: Chassis dynamometer results for a tractor-trailer developed by CATARC. Taken from (ICCT, 2015), adapted from (Zheng T. , 2013).



2.2.2.3.5 *Studies and Impact Assessments in support of the measure*

Studies to support the measure, such as cost-benefit analyses, feasibility studies, impact assessments, and evaluations were all carried out. However, these are only distributed between members of the relevant committees, and are not publically available.

2.2.2.3.6 *Justification of the scope*

The extent of the scope for Stage I, II and III was largely justified by the availability of data to base the standards upon. For Stage I, data relating to fuel consumption was limited. Therefore, it was decided that the standard would be restricted to only rigid and articulated lorries, and coaches, where the data was the most readily available. During the development of Stage I, CATARC gathered much more data to inform the regulatory development process on all six of the HDV subcategories defined within China. Additional evaluations on the reliability of measured and simulation data, and the close correlation between these two assessment methods, gave the regulators sufficient confidence to expand the scope to include construction dump trucks and urban buses. However, continued technical difficulties in assessing function HDVs (such as salt spreaders) have justified the exclusion of this subcategory from all stages of the MIIT standards to date.

2.2.2.3.7 **Challenges, obstacles and solutions identified and avoided before implementation**

There were several issues faced during the development of the standards. In particular, these included;

- Conflicts of interest in the stakeholder working group described in subsection 2.2.2.3.3.
- Differences in technical capability, equipment availability, and staff competency in different regions has caused problems in the assessment and monitoring stage of implementation.
- The degree of law enforcement also varies, causing a competitive disadvantage for some manufacturers.
- Coordination between several departments within central government, for example, MIIT, MOT, and EPBs.

There were no legal issues faced during the development of the standards.

2.2.2.3.8 **Reasons for the division of administrative responsibilities described above**

MIIT is tasked by Congress to regulate fuel consumption, whilst the MEP and EPB are directed under the Clean Air Act to regulate air pollutants. The legal basis for MOT's development and enforcement of its own fuel consumption limits is unclear.

2.2.2.4 Measure design

2.2.2.4.1 **Overview of measures**

Within China there are two sets of standards which regulate fuel economy of HDVs in parallel. These standards were issued by different bodies within the Chinese Administration, namely the MIIT and MOT. The MIIT standards, first issued in 2012, require that a vehicle is evaluated over a chassis dynamometer test procedure based on the C-WHVC. This standard is now in its second stage, with a third stage recently released for public comment. This third stage is likely to be introduced in 2019 for new type approvals, and 2021 for all new vehicles. The MOT standard was issued in 2008, and is known as the 'Limits and Measurement Methods of Fuel Consumption for Commercial Tractors'.

2.2.2.4.2 **Scope**

2.2.2.4.2.1 *Stage I*

The Stage I MIIT standards are applied to commercial heavy-duty vehicles. A heavy-duty vehicle is defined as a vehicle with >3,500kg GVWR. The standards are divided into a number of subcategories, both by vehicle type, fuel type and GVWR. They limit fuel economy in litres per 100km for HDVs applicable from July 2012 for type approvals, and 2014 for all new vehicles. The limits are listed in Table 2.16. As can be seen from the table, gasoline standards are directly related to diesel standards, but are slightly slacker. Gasoline standards in Stage I are 30% greater. This figure is a result of testing that shows that fuel consumption is 30% greater in gasoline engines.

The standards relate to the results of the standardised C-WHVC test cycle. This was modified from the WHVC cycle as it was thought that the original test procedure was unsuited to the Chinese fleet characteristics. For example, China's heavy-duty vehicles tend to have lower engine power-to-weight ratios when compared to other major markets such as the US, Japan and the EU, for which the WHVC was based. It was therefore deemed appropriate to adjust the accelerations and decelerations within the WHVC to better fit the Chinese fleet. In addition, the weighting between urban, rural, and motorway driving cycles, as well as other vehicle characteristics and driver behaviours were modified to align with the requirements of Chinese driving conditions (ICCT, 2015). The C-WHVC varies for vehicle types as a result of this modification. China's use of the cycle is further explained in Section 2.2.2.4.4.

The scope of Stage I is limited. Only rigid and articulated lorries, and coaches are covered by the Stage I standards. The reason for this is because of the technical difficulties CATARC had in assessing different vehicle types. As described earlier, the data available during the development of Stage I was minimal, and so MIIT intentionally targeted Stage I at improving data availability.

2.2.2.4.2.2 *Stage II*

Limits for the second stage of China's heavy-duty fuel consumption standards became applicable from July 2014 for type approvals, and from July 2016 for all vehicles. As with Stage I, they regulate fuel

economy in litres per 100km for HDVs applicable. Test procedures are also the same for Stage I and II, thereby allowing consistency and comparability of standards. The limits are listed in Table 2.16.

The second stage follows a similar design to the first in that it is a time-independent standard, based on measured fuel consumption data from recent models within the HDV fleet. In this stage, however, as discussed in section 2.2.2.3.2, MIIT had a much better view of the composition of the fleet, as well as the fuel consumptions for a given vehicle type, GVWR and fuel type. Therefore, they had greater confidence in applying stricter regulations that would present a more significant challenge to China's HDV manufacturers.

Stage II extended the scope of vehicles covered to include urban buses and tipper/dump trucks (or construction HDVs) and also tightened limits for tractors, lorries, coaches and buses. Comparing the first and second stages, the second stage represents a 10.5-14.0% fuel consumption reduction over Stage I, as illustrated in Figure 2.12. Total oil demand savings are estimated to be 5-6 million tonnes annually from this stage.

With regards to fuel consumption standards to gasoline engines, the mark-up with comparison to diesel standards is reduced to 20% compared to 30% in Stage I. As before, this figure is derived from extensive testing.

2.2.2.4.2.3 Stage III

Stage III inherits largely the same design and scope as Stage II. The test cycles used to verify and enforce standards are the same as in Stage II, namely a chassis dynamometer test running on the C-WHVC cycle for base models, and simulations for variants. Similarly to Stage II, the standards set fuel consumption limits as a step-wise function, using GVWR to further segment each vehicle type. They represent a further tightening of the standards by 12.5% to 15.9% (ICCT, 2016) with respect to Stage II (21.7% to 27.2% compared to Stage I). These standards will be implemented together with some other measures, such as optimising logistics and driver training.

Stage III is currently awaiting public comments before it can be finalised. It is expected that this standard will come into effect in 2019 for type approvals and 2021 for new vehicle types.

Figure 2.12: Comparison of the stringency of the Stage I Industry Standard and Stage II National Standard for new commercial heavy-duty vehicles (taken from (ICCT, 2014))

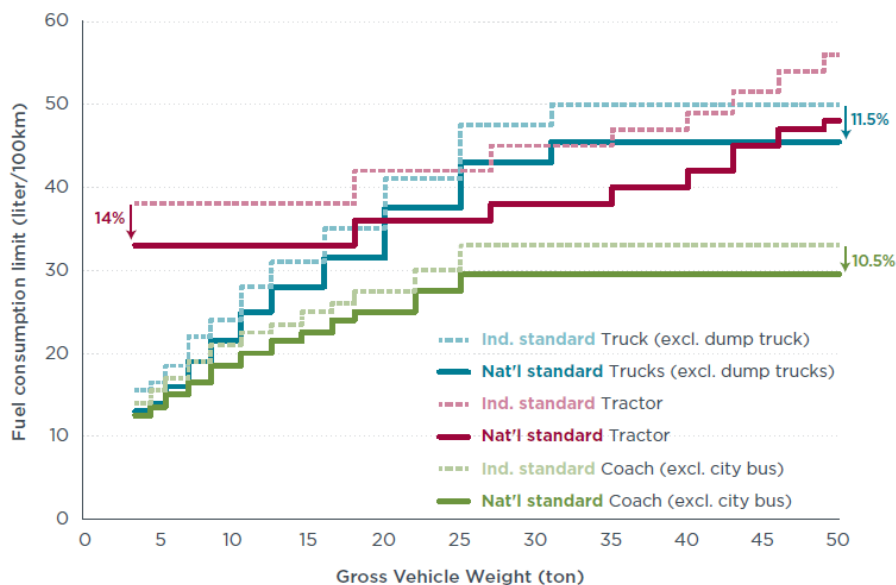


Table 2.16: Chinese HDV fuel consumption limits for Stages I and II (Industrial Standard QC/T 924-2011 and National Standard GB 30510-2014 respectively).

Gross Vehicle Weight (GVW) Band (kg)	Stage I - Fuel Consumption (diesel) (l/100km)	Stage II - Fuel Consumption (diesel) (l/100km)	Stage III – Fuel Consumption (l/100km)
Rigid lorry			
3,500 < GVW ≤ 4,500	15.5 ^a	13.0 ^b	11.5 ^b
4,500 < GVW ≤ 5,500	16.5 ^a	14.0 ^b	12.2 ^b
5,500 < GVW ≤ 7,000	18.5	16.0	13.8
7,000 < GVW ≤ 8,500	22.0 ^a	19.0 ^b	16.3 ^b
8,500 < GVW ≤ 10,500	24.0 ^a	21.5 ^b	18.3 ^b
10,500 < GVW ≤ 12,500	28.0 ^a	25.0 ^b	21.3 ^b
12,500 < GVW ≤ 16,000	31.0	28.0	24.0
16,000 < GVW ≤ 20,000	35.0	31.5	27.0
20,000 < GVW ≤ 25,000	41.0	37.5	32.5
25,000 < GVW ≤ 31,000	47.5	43.0	37.5
31,000 < GVW	50.0	45.5	38.5
Articulated lorry (includes weight of trailer – Gross Combination Weight)			
18,000 ≤ GCW	-	33.0	28.0
18,000 < GCW ≤ 27,000	42.0	36.0	30.5
27,000 < GCW ≤ 35,000	45.0	38.0	32.0
35,000 < GCW ≤ 40,000	47.0	40.0	34.0
40,000 < GCW ≤ 43,000	49.0	42.0	35.5
43,000 < GCW ≤ 46,000	51.5	45.0	38.0
46,000 < GCW ≤ 49,000	54.0	47.0	40.0
49,000 < GCW	56.0	48.0	40.5
Heavy duty passenger vehicles (excluding urban buses)			
3,500 < GVW ≤ 4,500	14.0 ^a	-	-
4,500 < GVW ≤ 5,500	15.5 ^a	-	-
5,500 < GVW ≤ 7,000	17.0	-	-
7,000 < GVW ≤ 8,500	19.0	-	-
8,500 < GVW ≤ 10,500	21.0	-	-
10,500 < GVW ≤ 12,500	22.5	-	-
12,500 < GVW ≤ 14,500	23.5	-	-
14,500 < GVW ≤ 16,500	25.0	-	-
16,500 < GVW ≤ 18,000	26.0	-	-
18,000 < GVW ≤ 22,000	27.5	-	-
22,000 < GVW ≤ 25,000	30.0	-	-
25,000 < GVW	33.0	-	-
Coaches			
3,500 < GVW ≤ 4,500	-	12.5 ^b	10.6 ^b
4,500 < GVW ≤ 5,500	-	13.5 ^b	11.5 ^b

Gross Vehicle Weight (GVW) Band (kg)	Stage I - Fuel Consumption (diesel) (l/100km)	Stage II - Fuel Consumption (diesel) (l/100km)	Stage III – Fuel Consumption (l/100km)
5,500 < GVW ≤ 7,000	-	15.0 ^b	13.3 ^b
7,000 < GVW ≤ 8,500	-	18.5	14.5
8,500 < GVW ≤ 10,500	-	21.0	16.0
10,500 < GVW ≤ 12,500	-	20.0	17.7
12,500 < GVW ≤ 14,500	-	21.5	19.1
14,500 < GVW ≤ 16,500	-	22.5	20.1
16,500 < GVW ≤ 18,000	-	24.0	21.3
18,000 < GVW ≤ 22,000	-	25.0	22.3
22,000 < GVW ≤ 25,000	-	27.5	24.0
25,000 < GVW	-	29.5	25.0
Urban buses			
3,500 < GVW ≤ 4,500	-	14.0	11.5
4,500 < GVW ≤ 5,500	-	15.5	13.0
5,500 < GVW ≤ 7,000	-	17.5	14.7
7,000 < GVW ≤ 8,500	-	19.5	16.7
8,500 < GVW ≤ 10,500	-	22.5	19.4
10,500 < GVW ≤ 12,500	-	26.0	22.3
12,500 < GVW ≤ 14,500	-	30.5	25.5
14,500 < GVW ≤ 16,500	-	34.0	28.0
16,500 < GVW ≤ 18,000	-	37.5	31.0
18,000 < GVW ≤ 22,000	-	41.0	34.5
22,000 < GVW ≤ 25,000	-	45.5	38.5
25,000 < GVW	-	49.0	41.5
Construction vehicles			
3,500 < GVW ≤ 4,500	-	15.0	13.0
4,500 < GVW ≤ 5,500	-	16.0	13.5
5,500 < GVW ≤ 7,000	-	17.5	15.0
7,000 < GVW ≤ 8,500	-	20.5	17.5
8,500 < GVW ≤ 10,500	-	23.0	19.5
10,500 < GVW ≤ 12,500	-	25.5	22.0
12,500 < GVW ≤ 16,000	-	28.0	25.0
16,000 < GVW ≤ 20,000	-	34.0	29.5
20,000 < GVW ≤ 25,000	-	43.5	37.0
25,000 < GVW ≤ 31,000	-	47.0	40.5
31,000 < GVW	-	49.0	41.5

Notes:

^a For gasoline vehicles, multiply by 1.3 and round to the nearest decimal place.^b For gasoline vehicles, multiply by 1.2 and round to one decimal place.

2.2.2.4.2.4 *Ministry of Transport Standard*

The MIIT Industry Standard was implemented in parallel with a fuel consumption industry standard issued by MOT. According to these standards, which apply to passenger (JT711-2008) and commercial (JT719-2008) vehicles, MOT will not issue commercial licenses to vehicles that do not satisfy the MOT's fuel consumption requirements. Testing for this standard is not applied over the WHVC, but at steady speeds with applied weighting factors. The limits are split into those for diesel articulated lorries, diesel rigid lorries and diesel off-highway vehicles. It is important to note that since the two sets of standards use different test cycles to verify compliance, comparison is not possible. The development of these standards was similar to that of the MIIT standards. Due to the high levels of uncertainty of the test methods, however, the assessment methodology of the standard is not representative of real world vehicle performance.

2.2.2.4.3 *HDVs present in the market that are not covered by the measure*

The scope of the Stage I standard did not cover all HDVs within the Chinese market. Stage I covered only industrial vehicles from the subcategories of rigid lorries (not including tipper/dump trucks), articulated lorry tractors and buses (not including urban buses). It was intended to use the first stage of the standards to assess the feasibility of the standards for the industry before applying a broader national standard in Stage II. Therefore, urban buses, dump trucks and specialised vehicles (including those using alternate fuel sources) were not covered by the first stage of this regulation.

The second stage of the standards expanded the scope to include urban buses and tipper/dump trucks (or construction HDVs) but continued to omit standards for specialised vocational vehicles (e.g. tanks, certain dump trucks, cranes and special structures), as well as vehicles that utilise alternate fuels such as natural gas or electricity. The specialised vehicles tend to be dual-operational, in that they serve additional purposes such as mixing and spreading of asphalt and lifting materials.

Stage III regulations maintained the scope of vehicle types for which the measures apply. The regulations are estimated to cover approximately 85% of the HDVs in the Chinese fleet. The rest of the market consists of 5% specialised vocational vehicles, and 11% using alternate fuels (ICCT, 2016).

2.2.2.4.4 *Testing and certification requirements*

The tests themselves are performed as either chassis dynamometer or vehicle simulations. These were the preferred methods of testing, since they were found to produce more consistent results and are not affected by ambient conditions and driver behaviour (Zheng, et al., 2011). Vehicles are either tested as base models or as variant models. Commissioned by MIIT, the China Vehicle Technology Service Center (CVTSC) issues definitions of what consists a base or a variant model. A whole vehicle family encompasses the base and its variant models. The base model is the vehicle with the highest gross vehicle weight within the vehicle family; the highest rated power for engines from the same manufacturer and same engine family, or model using an engine with the highest certified fuel consumption; the largest frontal area; the smallest net load tyre rolling radius, widest cross-section area; largest gross transmission ratio; or combination of the above (CVTSC, 2012). A variant is therefore defined as a member of a vehicle family that is not a base model, and shares common design parameters including: vehicle type, fuel type, power required to drive engine-powered accessories, chassis bearer, body style (for buses and coaches), type of lorry cab, type of drivetrain and position of axle, transmission type and number of gears, gross mass, or number of axles (CVTSC, 2012).

Base models are tested using a chassis dynamometer test cycle, whilst variants are modelled using computer simulations. The similarity between base and variant models allows for easy verification of model results in this case. For simulation modelling, manufacturers must also submit engine testing data.

2.2.2.4.4.1 *Simulation tool development, maintenance and upgrade policy, including high level cost estimations*

The simulation model was developed in 2012 by the Energy Efficiency Technology of Vehicles working group. The actual development of the model cost on the order of €100,000. However, the cost of collecting data to validate the model was much more expensive. This cost the government around 10

times as much, since the model required the testing of over 1,000 vehicles to help inform input parameters.

2.2.2.4.5 **Secondary systems coverage**

Secondary systems, such as air pollutants, fall outside of the legislative strand of MIIT. Air pollutants and air conditioning leakage are regulated by MEP, for example. The MIIT standards concern fuel economy solely.

2.2.2.4.6 **Main efficiency technologies targeted/incentivised by the measure**

There are no technologies explicitly incentivised by the measure. Non-technologically driven fuel economy improvements, such as driver training and logistic optimisation are not considered in either the MIIT or MOT standards. Since they are related to in-use fuel consumption they are under the scope of the MOT standards, but are not included due to the complexity of including them into already highly uncertain assessment methodologies.

Some technologies are being utilised by manufacturers which are not covered by the scope of the MIIT regulations. For example, hybrid powertrains and some specific engine components have been developed but, due to a lack of reliable assessment methods, are not being accounted for in the present test cycles (Jin, 2016).

2.2.2.4.7 **Flexibilities on compliance**

There is no flexibility in the standard. In reality, there are unwanted differences between regions because of the differences in technical capabilities, but this is not intended. Since the regulations are assessed on an individual vehicle basis, rather than an averaging method such as that used in the US, there can be no flexibilities to offer.

2.2.2.4.8 **Estimated costs and benefits of measure**

Information regarding the expected costs and benefits of the measure was distributed amongst the committees responsible for the development of the regulations, but are not publically available.

2.2.2.5 **Monitoring, reporting, verification and enforcement**

2.2.2.5.1 **Monitoring, reporting and verification**

China regulates new type approvals, conducts conformity of production testing and runs inspection and maintenance programmes as a part of its heavy-duty emissions regulation programme. The former two compliance mechanisms are the responsibility of the MEP. The institution implementing the programmes is the VECC under the MEP.

2.2.2.5.1.1 *Type approvals*

Manufacturers must submit vehicle prototypes to accredited testing laboratories for type approval testing prior to production. This is the same process for all highway vehicles, motorcycles, non-road, and agricultural vehicles. There are 24 accredited laboratories nationwide, of which 19 are equipped to conduct tests on heavy-duty vehicles.

Laboratories are certified by MEP's Department of Science, Technology and Standards, who inspect laboratories every year to assess whether it is appropriate to renew the testing certification. Reports produced by these laboratories are submitted to VECC for review. Typically, for conventional fuel-saving technologies, these reports are passed without requirements to provide further information or test data. For new emission control technologies, however, VECC may require additional verification, which can take the form of more comprehensive application materials, or repeated testing under the supervision of VECC staff.

2.2.2.5.1.2 *Conformity of production*

MEP commissions VECC to conduct a number of random conformity of production tests each year. These tests involve vehicles that are either taken directly off the production line, or are purchased. Test results are then summarised and submitted to MEP. If identified unconformity is too great, then a

vehicles' production line is found to be in violation of the standards. Section 2.2.2.5.2 describes the enforcement system and penalties in this case.

Additionally, vehicle and engine manufacturers are required to submit quarterly assurance reports to the VECC on the conformity of production. HDV manufacturers are required to randomly test at least three vehicles from each engine family or test group each quarter. The average of these must be lower than the standard limit values in order to be deemed compliant.

2.2.2.5.2 **Enforcement**

China's emissions regulatory programme primarily focusses on enforcing requirements at the pre-market stage, by requiring manufacturers to obtain emission type approvals and satisfying conformity of production. In-use compliance is paid little attention.

2.2.2.5.2.1 *Conformity of production*

If a vehicle is found to be in violation of the standards under a conformity of production test then MEP issues deadlines to the manufacturer to bring the production line into compliance. It also suspends any type approvals applications from that manufacturer. If the manufacturer is unable to meet the standards, the MEP has the authority to revoke the type approval certificate. There is no fine in this case, instead violations are published and certificates revoked.

2.2.2.5.2.2 *Inspection and maintenance*

The authority to enforce inspection and maintenance programmes falls with provincial- and municipality-level Environmental Protection Bureaus. EPBs entrust accredited test centres to conduct inspection and maintenance testing. These centres are monitored by provincial transport management authorities, and if centres are found to be fraudulent, the regulatory agency has the authority to issue fines of up to 50,000 RMB (roughly €7,000), and revoke certificates for conducting inspection and maintenance for more serious offences.

MEP provides overall inspection and maintenance guidance, including test procedures for loaded and unloaded tests. Local governments must adopt these guidelines, although local EPBs have the authority to set stricter emissions limits. Each inspection and maintenance testing facility must submit an annual report to their respective local municipal EPB with a description of the test facility and any emissions problems identified. The municipal EPB must then prepare a report for the provincial EPB for transmission to MEP.

2.2.2.5.2.3 *MOT standards enforcement*

The MOT standards are recognised as being very lenient. As a result, enforcement efforts for the MOT standards are not significant since all MIIT-compliant vehicles would pass.

2.2.2.6 **Evaluation and next steps**

2.2.2.6.1 **Evaluation activities undertaken**

A study was carried out after Stage I of the standards. The data collected from measurement activities in Stage I were used to compare modelled data for both base and variant HDV models. The results showed a close correlation between measured data and that of the modelling data. This encouraged the move to expand the scope of the regulations to a further two HDV regulatory subcategories. Additional work was carried out on rolling resistance, with adjustments filtering into the limit values for Stage II.

2.2.2.6.2 **Performance**

2.2.2.6.2.1 *Emissions reductions achieved*

It is estimated that fuel consumption in 2015 was 7 million tonnes lower than in 2013, despite growth in fleet size, a result of the standards set by the MIIT. This is equivalent to a 2 million tonne reduction in CO₂ emissions.

2.2.2.6.3 **Lessons learned**

The principle lesson learned as a result of the regulations in China is the need to regulate on a whole vehicle basis rather than on an engine basis. This is because engines, once certified, can be used in vehicle types unsuited to their use, and therefore fuel consumption is higher than the test assessments indicate.

2.2.2.6.4 **Future plans, including any changes**

There is a need for regulations to be measured on a whole-vehicle basis rather than on an engine basis, and so future regulations will be based mainly on the whole vehicle rather than engines, placing greater emphasis on the robustness and reliability of fuel economy simulation models.

2.2.3 Japan

2.2.3.1 Summary

2.2.3.1.1 **Introduction**

Japan implemented its HDV fuel efficiency measures in 2006, and was the first country to have such regulations. The measures are the responsibility of the Ministry of the Environment (MOE), the Ministry of Land, Infrastructure and Transport (MLIT) and the Ministry of Economy, Trade and Industry (METI). Japan's fleet is quite different from the US and EU, being composed largely of light lorries. Japan's HDV fuel efficiency measures follow the 'top runner' approach, which has been applied to a wide range of Japanese industries to achieve energy efficiency improvements.

2.2.3.1.2 **Background to measures**

Japan began pursuing fuel efficiency measures following a series of oil crises in the 1970s. As such, energy security has always been an important aspect of the measures. More recently, meeting global environmental targets has been a significant factor driving regulation. Japan adopted the Kyoto Protocol in 1997 and with industry emissions falling since 1990, transport, the next largest contributor to GHG emissions, was a target for further reductions.

As with other top runner approaches, the baseline was derived from the top performing product in the market. The regulations used the most fuel efficient MY2002 vehicle in each category to set targets for MY2015, also factoring for further improvement of the top runner vehicle over that time.

2.2.3.1.3 **Measure design**

Japan's fuel efficiency measures cover diesel fuelled vehicles with a gross vehicle weight rating (GVWR) in excess of 3.5 tonnes, broken down into 12 categories for buses and 13 categories for freight vehicles, including tractors. For each category, a target standard is given for MY2015. The fuel efficiency standards are part of a wider suite of energy saving measures, including subsidies for new vehicles, eco-driving, improved traffic management, efficient logistics and mobility management. The fuel efficiency standards are given in km/L and amount to a 12.2% fuel efficiency improvement by 2015 over 2002 levels.

Japan have a similar testing process to that of the US. An engine dynamometer is used, running two drive cycles in a ratio based on the vehicle category:

- The JE05 cycle, a transient cycle based on urban drive statistics; and,
- The Interurban Drive Mode cycle, which operates at a constant speed of 80km/h with varying grade.

The fuel map created by the dynamometer test is then fed into a simulation model that includes actual engine and transmission specifications, and standard values for aerodynamics, tyres and size. The top runner approach does not specifically incentivise any technologies. This allows manufacturers to reach the standards by any technology pathway.

The deadline for compliance was set in 2006 giving standards for MY2015. Unlike the US regulation, only a single MY standard is set for each vehicle category.

2.2.3.1.4 **Monitoring, reporting, verification and enforcement**

METI and MLIT monitor manufacturers through their corporate average fuel efficiency (CAFE). This average gives some flexibility across a manufacturer's range of products. The penalties for non-compliance are relatively loose. METI state that the measure is not to regulate manufacturers, but rather to improve fuel efficiency. The most notable enforcement mechanism is a public announcement by the authorities, which is considered a severe enough incentive to ensure compliance.

2.2.3.1.5 **Evaluation and next steps**

An evaluation of Japan's first standard is underway within MLIT. The results were not yet published at the time of writing.

2.2.3.2 **Introduction and broad market characteristics**

2.2.3.2.1 **Administrative framework**

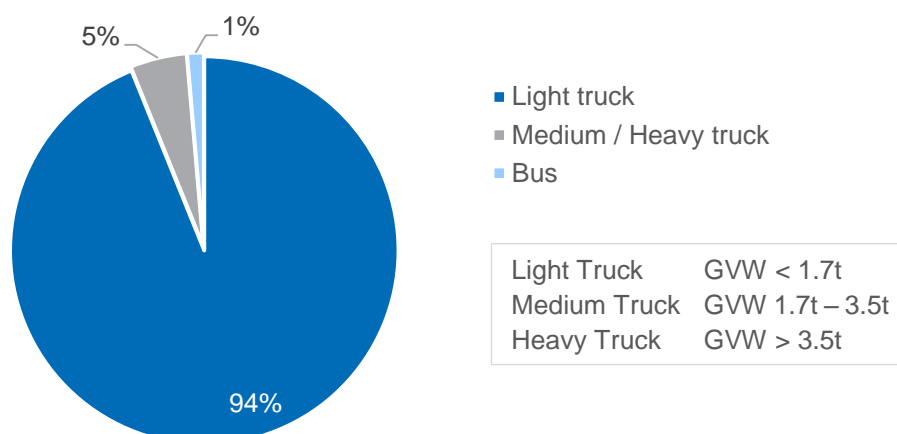
Japanese emission and fuel economy standards are the joint responsibility of the Ministry of Environment (MOE), the Ministry of Land, Infrastructure and Transport (MLIT) and the Ministry of Economy, Trade and Industry (METI). The Ministries create fuel economy regulations under the Energy Conservation Law, which was enforced in 1979 in the wake of two oil crises in Japan.

2.2.3.2.2 **Fleet composition**

2.2.3.2.2.1 *Vehicle Types, Weights, Sizes*

In 2013, over 813,000 lorries and buses were sold in Japan, making up 15.4% of the 5.3 million vehicle fleet sold that year. Due to the country's geography, largely consisting of mountainous regions and densely populated areas, the vast majority of HDV sales in Japan are of light lorries (Ward's Auto, 2014). These lighter vehicles, weighing under 1.7 tonnes, are significantly more popular compared to the medium and heavy duty classes over 1.7t and 3.5t respectively, which sold a combined 38,500 units in the same year at roughly equal shares. In total, Japan's fleet had approximately 300,000 long-distance lorries in 2015 (LNG World News, 2015). The significant use of light HDVs and scarcity of articulated vehicles results in a smaller average HDV than in comparatively advanced regions, leading to an increased number of journeys for an equivalent volume of goods delivered when compared to the other key markets under consideration.

Figure 2.13: Sales of lorries and buses in Japan, 2013 (Ward's Auto, 2014)



Although Japanese lorries are described as light, medium and heavy duty for annual sales, the Tokyo Metropolitan Government classifies diesel lorries into 9 types, covering 7 weight categories (Japan for Sustainability, 2012), displayed in Figure 2.14.

The overall market for road freight in Japan is undergoing considerable change, with a skew towards increasing efficiency. This change is primarily motivated by the severe lack of qualified drivers, which

is expected to be exacerbated by the increasing average driver age²⁵. The dearth of commercial lorry drivers in Japan is impacting vehicle design and logistical operations by moving away from popular smaller lorries. For example, the large delivery business Yamato Holdings has announced plans to introduce lorries with two linked trailers, boosting capacity by 80% compared with its single trailer lorries (Nikkei Asian Review, 2016). This particular instance is also fuelled by the increasing number of Japanese journeys involving home-delivery of parcels, which grew by 20% between 2010 and 2015 whilst the population remained relatively unchanged (Nikkei Asian Review, 2016).

2.2.3.2.2.2 *Typical Journeys and Duty Cycles*

Japan's road network is approximately 1.20 million kilometres of road, comprising 1.02 million kilometres of city and village roads, 0.13 million kilometres of prefectural roads, 0.06 million kilometres of general national highways and 7,600 kilometres of national expressways (GISTnet, 2016). In 2014, Japan's domestic freight transport volume amounted to approximately 420 billion tonne-kilometres (Statistica, 2015). Heavy duty vehicles in Japan tend to have a similar average urban/interurban mileage distribution despite their category and weight – a factor likely driven by the geographic and infrastructural reasons described above. Some slight differences do exist: a non-tractor lorry weighing over 20t will spend the most time of the heavy duty vehicles within interurban areas, at 30%, while non-tractor lorries under 20t and tractor lorries over 20t spend 90% of their routes in urban areas (Sato, 2008); this is shown in Table 2.17. The annual mileage of a vehicle depends on its duty cycle: a city delivery application lorry will typically reach 30,000 miles per annum and a long haul application could reach up to 150,000 miles (Daimler Trucks, 2011).

Because of Japan's geography and extensive urbanisation, long haul journeys of over two days are not common. A high proportion of journeys are likely to start or end in major cities served by either airports or seaports.

²⁵ Japan has more than two HDV driver openings per job seeker, and 70% of drivers are aged over 40 and 15% are over 60 (Nikkei Asian Review, 2016).

Figure 2.14: Japanese lorry classification (Japan for Sustainability, 2012)










No.	Proposed classification		Images
	Types of vehicles	Weight category	
1	Vans and armored cash transport cars	Small 1 (under 3.5 tons)	
2	Cabovers		
3	Refrigerator or freezer trucks	Small 2 (small freight vehicles from 3.5 tons up to 7.5 tons)	
4	Garbage trucks	Medium 1 (ordinary freight vehicles under 7.5 tons)	
5	Container trucks and arm roll trucks	Medium 2 (from 7.5 tons up to 8.0 tons or less)	
6	Dumper trucks or powder and granular material trucks	Large 1 (under 16 tons)	
7	Tank lorries or asphalt truck	Large 2 (from 16 tons up to 20 tons)	
8	Concrete mixer vehicles		
9	Trailers	Trailers (20 tons or more)	

Table 2.17: Proportion of vehicle mileage (Sato, 2008)

Vehicle Type	Non-tractor		Tractor	
	GVW < 20t	GVW > 20t	GVW < 20t	GVW > 20t
Urban	90%	70%	80%	90%
Inter-urban	10%	30%	20%	10%

2.2.3.2.2.3 Overview of operating costs and typical ownership profiles

Typical ownership profiles and operating costs of Japanese lorries are not well documented, though typical fleet sizes are available. The Tokyo Trucking Association reported in 2010 that 99% of Japanese companies own less than 100 lorries and that the most typical fleet size was between 5 and 10 lorries, (Tokyo Trucking Association, 2010). J D Power corroborate this in their annual studies, which disaggregate small, medium and large fleets by 10 or fewer vehicles, 11 to 30 vehicles and greater than 30 vehicles respectively.

Japanese road hauliers are operating with fewer vehicles and a lower replacement rate than in previous years, ensuring consistent demand for increased service life. Japan’s fleet has a service life marginally longer than that of EU and US vehicles.

Table 2.18: Japanese HDV average age and service life by year

	1995	2000	2005	2010	2012
Average Age [years]	5.76	7.14	8.36	9.60	-
Average Service Life [years]	9.60	10.50	11.70	12.70	12.81 (lorry)

					16.82 (bus)
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Source: Ricardo

There is limited public domain information on heavy-duty operating costs in Japan. Some information is emerging however in terms of lorry operators’ efforts to reduce operating costs, largely through collaboration and sharing business models. Lorries handle 90% of domestic shipments, according to DHL, but many vehicles are loaded to only 40% of capacity. DHL is therefore looking to load lorries with shipments from multiple companies in a bid to cut costs, and alleviate issues caused by the country’s continuing shortage of lorry drivers (Nikkei Asian Review, 2016).

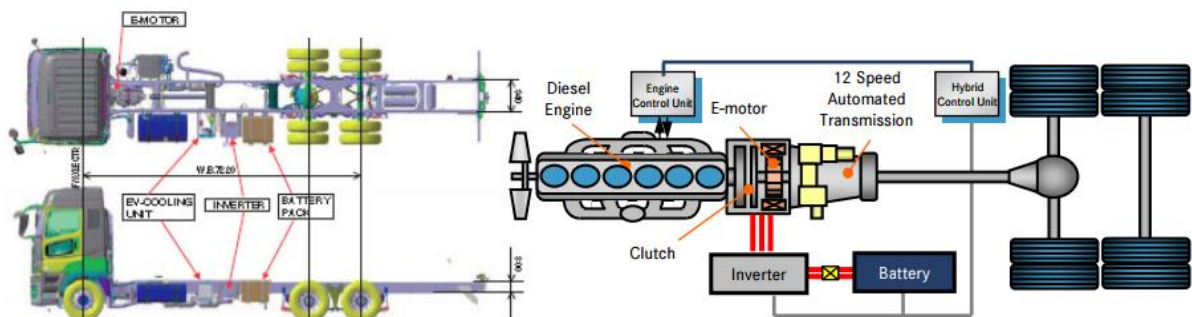
It is known, however, that fuel contributes a significant proportion of lorry operating costs in Japan. Fuel efficiency is thus the number one criteria for Japanese HDV purchasers, especially given rising fuel prices, and freight carriers are trying to address fuel costs by providing additional driver training and bulk buying fuels (JAMA, 2015).

2.2.3.2.2.4 Fuel efficient technology uptake

Stringent pollutant emission legislation is currently driving the adoption of new technologies in the Japanese fleet, which is technologically mature and uses many of the latest technologies found in the EU and US. Whilst some of these technologies are at odds with fuel economy, such as exhaust technologies used to achieve the severe 0.010g/kWh particulate matter limit, many OEMs have also started developing hybrid and electric powertrains in parallel. There is no public domain information for the uptake of these technologies nor HDV electrification overall. However, given the lighter average HDV and shorter average mileage of Japanese HDVs, electrification is a more attainable challenge than in markets such as Europe. Furthermore, the presence of electrified powertrains from a variety of Japanese manufacturers is indicative of the direction pursued by operators, who buy almost exclusively from domestic OEMs. Examples include:

- Daimler’s ‘Super Great HEV’, produced under their Mitsubishi Fuso Japanese brand²⁶. This offers a 10% fuel consumption reduction compared to a conventional diesel lorry based on a long haul application (Daimler Trucks, 2011). A schematic is displayed in Figure 2.15.
- Hino Motors’ ‘Cool hybrid’ refrigerated lorry which is equipped with a special purpose hybrid system used to provide electric power to the refrigerator rather than for driving (JSAE, 2014). The system provides a weight reduction of 150kg due to the removal of the auxiliary engine (Green Car Congress, 2014). A schematic is displayed in Figure 2.16.
- Hino Motors’ ultra-low bed electric lorry, with refrigerated cargo space. The vehicle is designed for driving in urban areas with a range of 60 km and is powered entirely by the battery, producing zero emissions (Toyota, 2013). A schematic is displayed in Figure 2.17.

Figure 2.15: Daimler Super Great HEV schematic (Daimler Trucks, 2011)



²⁶ See also the Mitsubishi Fuso Canter Eco hybrid (http://canter.co.uk/eco_hybrid), at 7.5 tonnes.

Figure 2.16: Hino “Cool Hybrid” (JSAE, 2014)

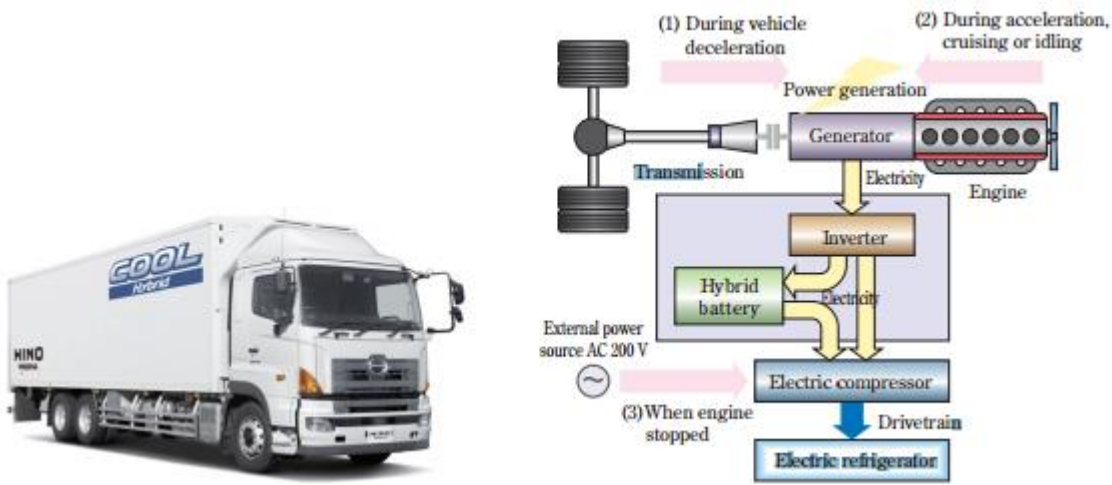
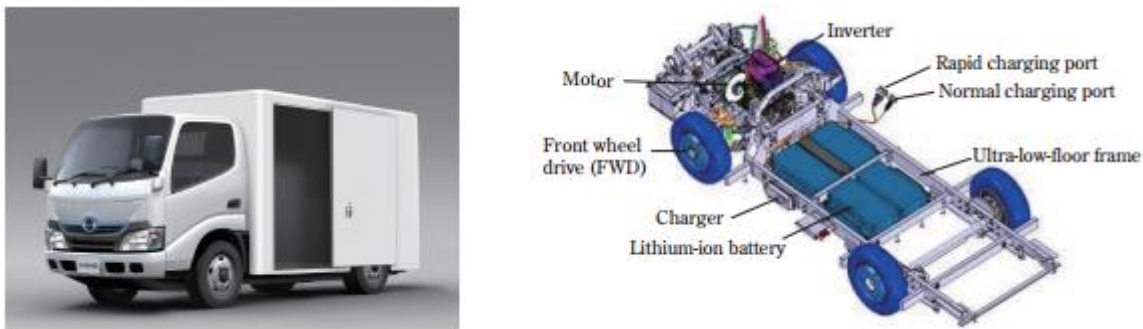


Figure 2.17: Hino electric truck (JSAE, 2014)

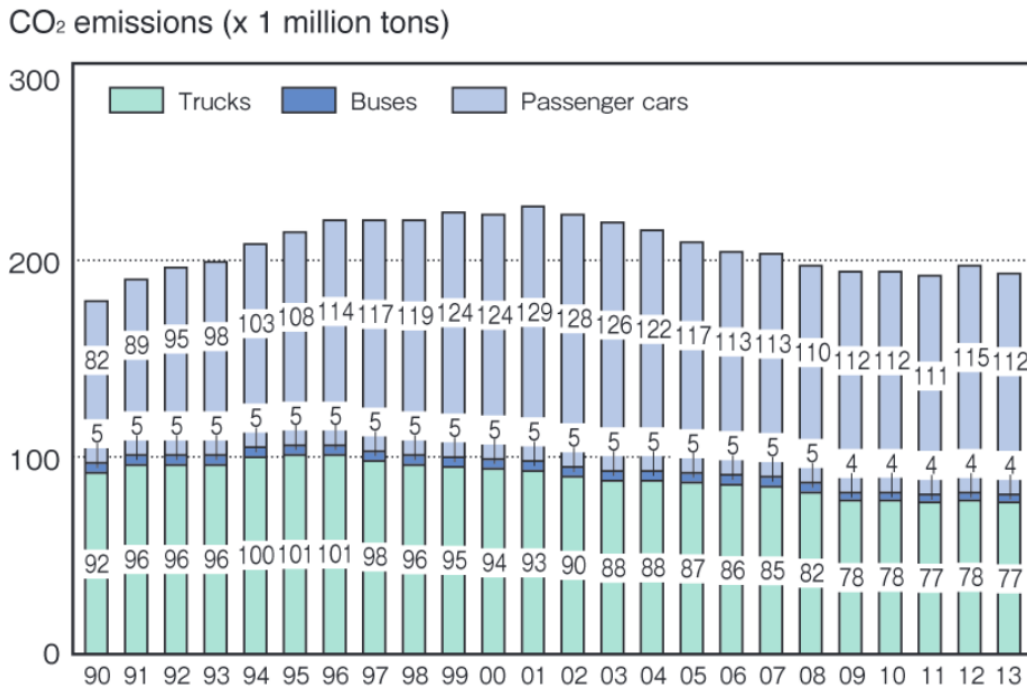


2.2.3.3 Background to measures

2.2.3.3.1 Rationale

There were two main motivations for Japan to consider HDV fuel economy standards in the mid-2000s: binding international CO₂ commitments and energy security pressures. Dominating the former, Japan had committed to a 6% reduction in CO₂ emissions by 2012 under the Kyoto Protocol which had been adopted in 1997 and brought into effect whilst the country’s HDV standards were being developed in 2005. CO₂ emissions from all industry, the largest contributor to Japan’s output (33.9% in 2009), had been steadily falling since 1990 and were on track to meet the future targets. Regulatory focus was thus directed at the next largest contributor, the transport sector, which accounted for approximately 20% of domestic CO₂ emissions (20.1% in 2009). Within this, 84% of transport emissions were emitted by road transport. Japan had already introduced and progressively tightened light-duty vehicle (LDV) fuel economy standards since 1979 which were successfully improving emission performance, focusing interest from regulators in savings from heavy-duty vehicles (see Figure 2.18).

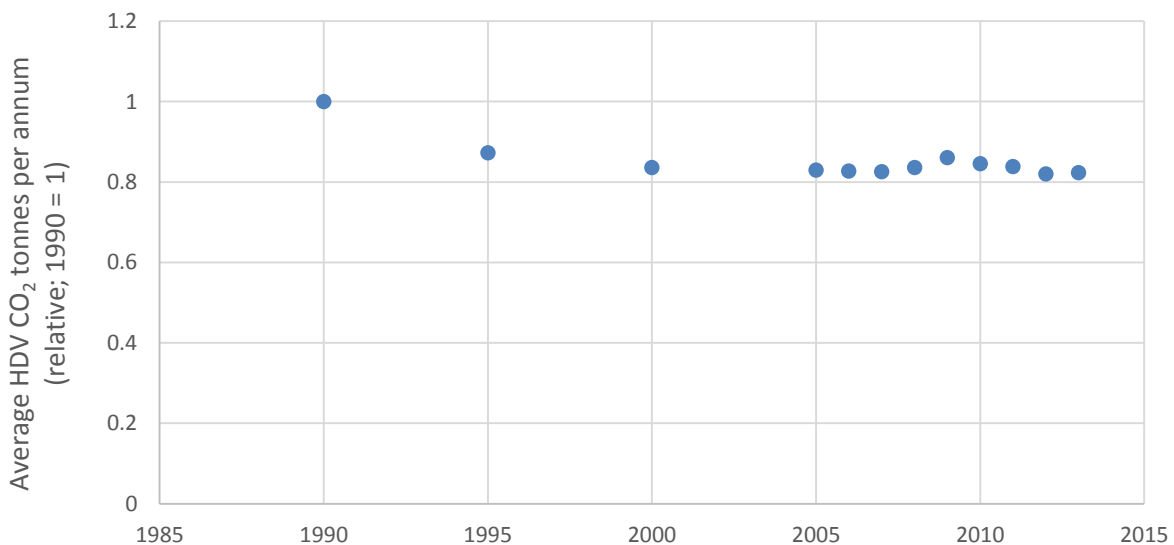
Figure 2.18: Japanese fleet CO₂ emissions by vehicle type (JAMA, 2016)



Note: these figures differ marginally from those recorded by MLIT, not pictured.

In 2005, commercial vehicles and buses accounted for roughly one-third of road transport emissions in Japan (recorded at 35.9% in 2009 (MLIT, 2011)). Their absolute contribution had been falling since their CO₂ emission peak in 1996 due to market-driven influences such as the a increasing preference for larger vehicles and expanding usage of freight carriers, which acted to improve overall efficiency and reduce the number of HDVs required in the Japanese fleet. The performance of the vehicles themselves had remained relatively unexploited as a source of emission reduction at this time, leaving heavy-duty vehicles as a prime candidate for fuel economy improvements to meet the international obligations. This is shown in Figure 2.19.

Figure 2.19: Approximate average annual Japanese HDV CO₂ emission output, relative to 1990



Source: Ricardo calculations; (JAMA, 2016), (JAMA, 2015).

A further incentive to introduce fuel efficiency standards was Japan's pursuance of a reduction in fossil fuel imports to increase its energy security. Prompted by fuel crises in the 1970s, when imported oil fuelled two-thirds of the country's demand, Japan has continued to diversify its energy supply via renewables and domestic nuclear power with heightened priority. Japan implemented the Energy Conservation Law in 1979, where transport was one of the four major areas addressed, along with industry, housing and appliances.

Efficiency improvements in transport directly affect oil imports in particular, and thus regulation of HDV fuel economy gave the country greater control and confidence in achieving its energy policy objectives. At the time of developing the standards the dominant strategic plan for energy was the Basic Act on Energy Policy (METI, 2002)²⁷, which references energy security in the first Article after the introduction. Successive Government plans such as (METI, 2008) also focused on energy security, culminating in the METI's current 4th Basic Energy Plan which was specified in 2010 and fully adopted in 2014. A core objective of the plan is to increase energy self-sufficiency to 70% by 2030, by when a 42% reduction in petroleum imports is envisaged. The country is still heavily dependent on fossil fuel imports to meet its energy demands, importing about 84% of total consumption in 2015 (World Nuclear Association, 2016), and hence the issue of energy security is likely to become an increasingly significant rationale for tightening fuel economy standards in the mid-term. This shift of balance to energy security as a driver for standards is further compounded by Japan's easing of international CO₂ agreements, withdrawing from 2020 targets under the Kyoto Protocol²⁸ (MOFA, 2010) and committing to less ambitious mid-term (2030) targets than other developed markets at the recent COP21 talks.

Japan was the first country in the world to regulate HDV fuel efficiency and as such were unable to consider implementation in other markets when designing their own measures. They did, however, have experience in designing and implementing fuel economy standards from both their own and international implementations for LDVs.

Japan's fuel efficiency standards were introduced as part of an integrated suite of policy measures, which in combination has been influenced and guided by experiences in other markets. These policy measures include the following:

- Vehicle technology and driving behaviour (fuel economy standards, fiscal incentives, CO₂ labelling) with an estimated 10% improvement in fuel efficiency
- Efficient logistics (deployment of larger lorries, shifting to freight carriers)
- Improved traffic management (removal of bottlenecks, ITS tolling)
- Mobility management and public transport improvements (new infrastructure, promotion of public transport)
- Other local measures

2.2.3.3.2 *Implementation timeline*

Fuel economy standards in Japan were first introduced for LDVs, published in 1999 with target years of 2005 and 2010 for diesel and petrol LDVs, respectively. Fuel economy standards for HDVs were first conceptualised in 2006 at a joint meeting between METI and MLIT. The Japanese Government thus set up the Heavy Vehicle Fuel Efficiency Standard Evaluation Group (HVFESG) for the purpose of developing suitable measures for HDVs. This group was formed within METI's Energy Efficiency Standards Evaluation Subcommittee, as shown in Figure 2.20.

The HVFESG Group were involved throughout the legislative drafting process, displayed in Figure 2.20. The other key Government body involved in the process was the Central Environment Council (CEC),

²⁷ The Ministry of Economy, Trade and Industry. This is also one of the two Japanese ministries responsible for setting the HDV fuel economy standards.

²⁸ Japan's statement regarding this decision is contained within (MOFA, 2010). Whilst Japan's retraction from the Kyoto Protocol does not indicate that it is less committed to reducing CO₂ output overall, it does reduce the penalties Japan would face for not meeting set targets and hence reduces the relative weight of international CO₂ commitments against other drivers for introducing HDV fuel efficiency standards.

an advisory body to the Ministry of the Environment (MOE) who had previously been involved in the setting of Japan's noxious emission standards and LDV fuel efficiency standards.

Figure 2.20: An organogram displaying the administrative position of the HVFESE Group

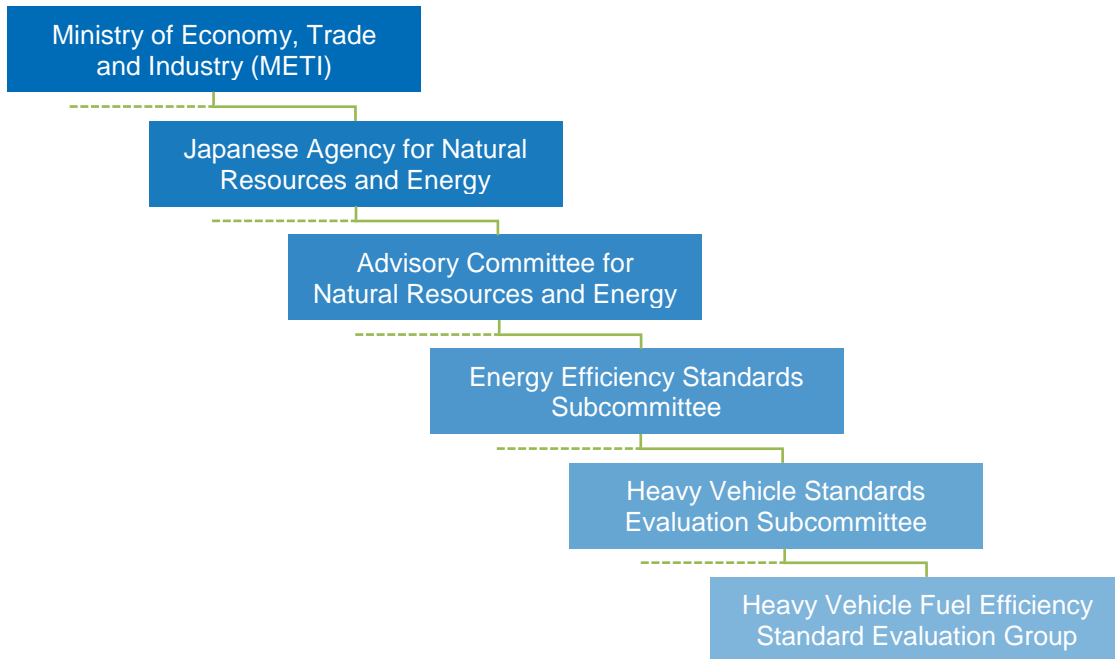
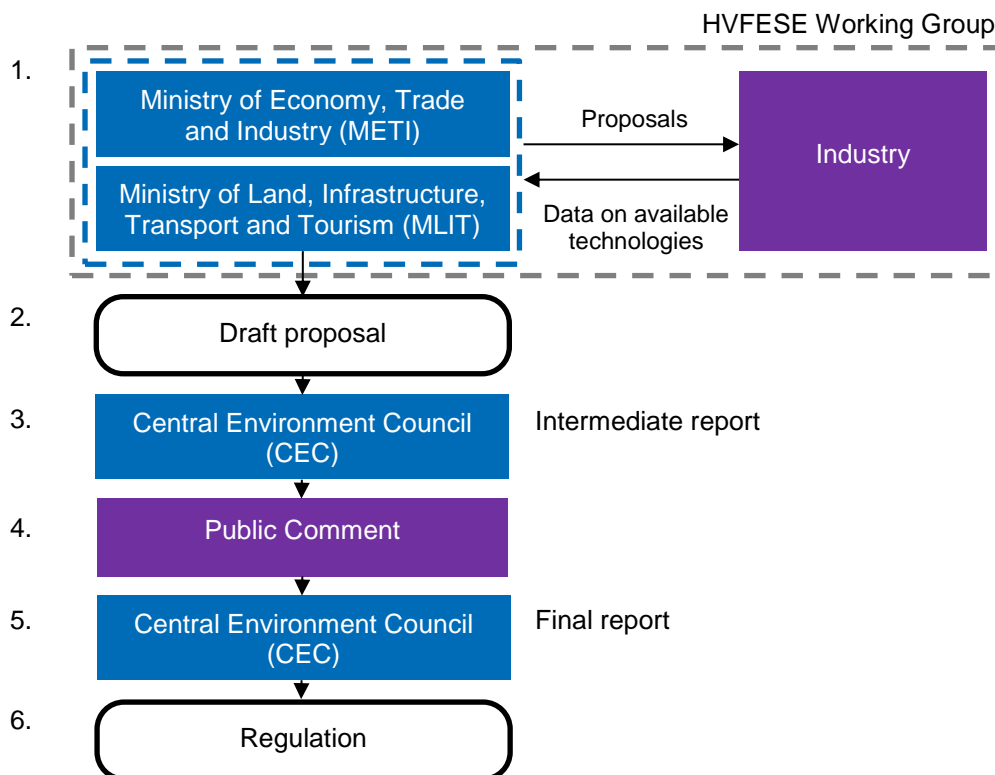


Figure 2.21: The legislative drafting process of the Japanese HDV fuel efficiency standards



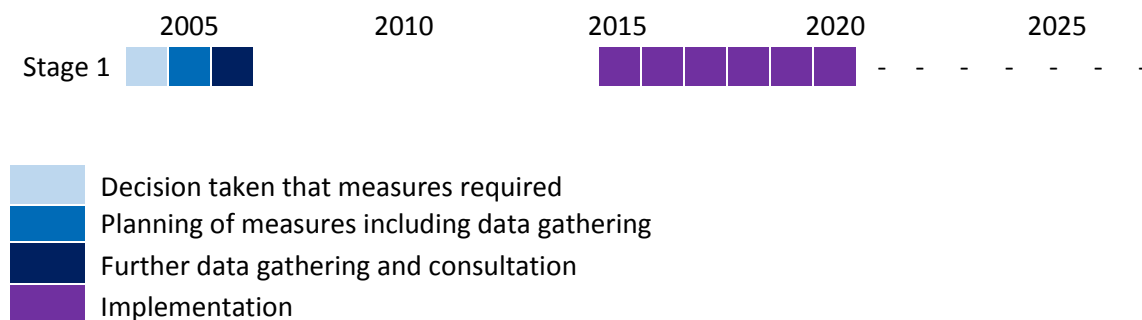
The drafting process proceeded as follows:

- September 2004: The HVFESE Group was first convened on 2nd September 2004 to discuss the current status of HDVs and the present fuel efficiency standards for LDVs. The Group's discussions were opened to the public.
- November 2004 - February 2005: The Group decided upon the range of target vehicles and the various classifications on which the standards would act. It was discussed how best to measure fuel efficiency.
- June 2005: OEMs and import trade organisations were invited to voice their opinions to the HVFESE Group.
- September 2005: The target year was decided upon, as was the approach for smaller HDVs less than 3,500kg. The fuel efficiency standard values themselves were debated. On the 22nd September, the Group reconvened to finalise their setting of the fuel efficiency standard values and produced a draft proposal for the CEC (2). The Council body, consisting of academic and key stakeholders, discussed the submitted draft proposal and produced an intermediate report for public consultation (3). Public comments were received on 30th September (4).
- November 2005: On the 10th November the CEC produced the final report (5). MLIT and METI produced their final draft of the regulation and test procedures.
- April 2006: The final regulations are published after notifying the World Trade Organisation and gaining approval from the Technical Barriers to Trade Committee (6). The standards are adopted under the 1976 Energy Conservation Law.

It took almost two years from conceptualisation to regulation of HDV fuel economy, which is typical for products under the top runner programme. The timeline is given in Figure 2.10.

The decision to set the target standard values for HDVs for the financial year 2015 was based on the need to give manufacturers enough time to develop new technologies and vehicle models to meet the targets. For HDVs, new model launching cycles are stated to be 5 to 10 years (HVFESE, 2005). Further complication was added by the 2009 exhaust gas emissions control requirements, which had first priority for manufacturers. Since exhaust emission reduction technologies are expected to negatively affect fuel efficiency for many of the most promising technologies, further time was required to allow manufacturers to meet both the gas emissions control requirements and the fuel efficiency requirements. Therefore, a 9-year target date from 2006 would allow manufactures time to release one or two new models that would meet or be on their way to meeting the target standard values, while also giving enough time following the 2009 exhaust gas emissions control regulations.

Figure 2.22: Timeline for the implementation of the Japanese HDV fuel consumption measures



2.2.3.3.3 Stakeholder Engagement

Japanese industry are directly involved in setting targets in Japan's top runner programmes (described in Section 2.2.3.3.4) since detailed engineering and market information on the targeted products is required, and the HDV fuel economy was no exception. The automotive industry played an instrumental role in the drafting of the standards from its inception, via committees such as the HVFESE Group. The

Group was formed of members from research bodies such as universities, ECCJ²⁹ and JARI³⁰; independent administrative institutions such as NTSEL³¹ and AIST³²; and, industry such as JAMA³³, JTA³⁴, and NBA³⁵, among others. This Group proposed the scope, methods and values for the standards, with regular information flow between governmental bodies and industry: data from manufacturers was used to generate proposals from METI and MLIT, as shown in Figure 2.21. The Group also scheduled specific points at which OEMs could voice their opinion on the progress of the standards. The literature provides clear evidence of this collaborative effort taking place regarding the target year (HVFESE, 2005). The target year of 2015 was decided by the committee of manufacturers and regulators so that OEMs were given “enough time for development toward better fuel efficiency.” It was envisioned that between 2005 and 2015 manufacturers would have “at least one or two opportunities” to launch models with improved fuel efficiency in line with achieving the target values.

The public and other organisations were also able to comment on the draft proposals following the CEC’s intermediate report, for a consultation period of one week.

2.2.3.3.4 *Data used to develop the baseline*

The 1979 Energy Conservation Law, under which the standards were implemented, dictates that the target values of energy efficiency standards should be determined in consideration of possible improvements in efficiency due to anticipated technical developments on the most efficient model in the current marketplace. As such, it is referred to as the ‘top runner’ principle, which had been applied to numerous other consumer products by the Energy Efficiency Standards Subcommittee (see Figure 2.20) since the 1998 Act Concerning the Rational Use of Energy (Cabinet Official Gazette Bureau, 2005) (ECCJ, n.d.).

The process of determining limits for the standard started with identifying the current (2002) performance of vehicles (Figure 2.23), and identify the best-performing HDV from all commercially available vehicles in each category. This vehicle is known as the ‘top runner’. The top-runner value then serves as a baseline from which targets for future years can be determined, assuming further improvements in fuel economy over time. Similar calculations were made for each vehicle category and vehicle type, including buses.

The expectation is thus that all vehicles on the market eventually catch up to top-runner performance, with the latter also improving over time.

²⁹ The Energy Conservation Centre, Japan. The ECCJ promote energy efficiency and were jointly-responsible for the introduction of the ‘top runner’ programme used in multiple industry sectors in Japan.

³⁰ Japan Automobile Research Institute. JARI engages in general research on vehicles.

³¹ National Traffic Safety and Environment Laboratory, an independent administrative institution.

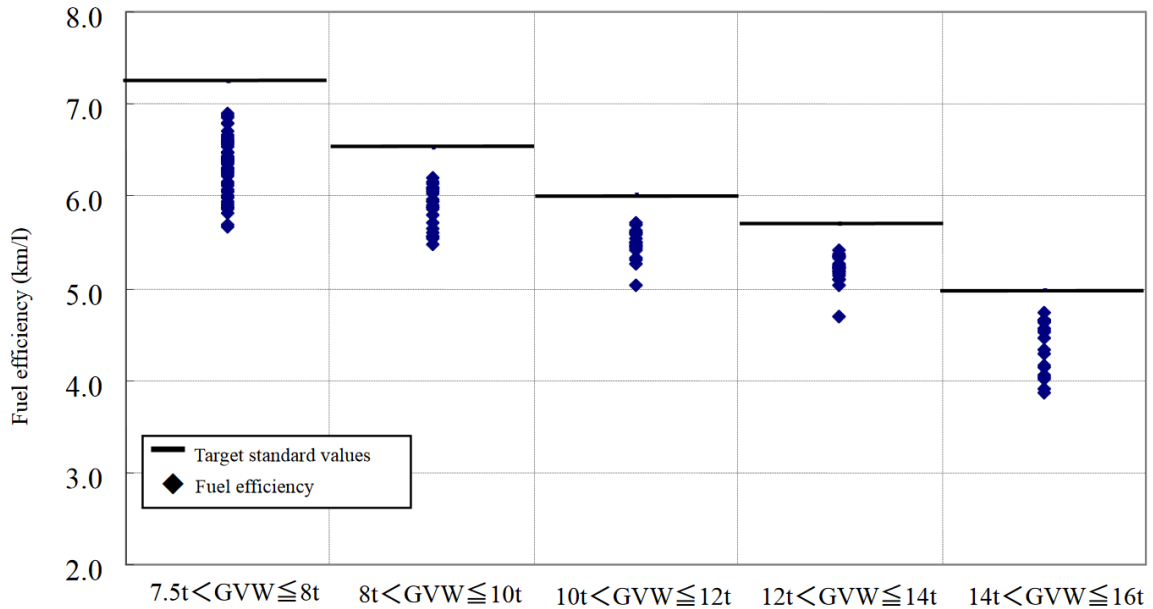
³² National Institute of Advanced Industrial Science and Technology, an independent administrative institution.

³³ Japan Automobile Manufacturers Association, the Japanese counterpart to ACEA.

³⁴ Japan Trucking Association, who represent Japanese commercial fleets.

³⁵ The Nihon Bus Association, who represent bus companies in Japan.

Figure 2.23: Fuel efficiency and target standard values for freight vehicles (other than tractor (GVW 7.5 to 16 tonnes)) (HVFESE, 2005)



2.2.3.3.5 Studies and Impact Assessments in support of the measure

The Heavy Vehicle Fuel Efficiency Standard Evaluation Group noted that technologies incentivised via the PNLT noxious emission standards set for introduction in 2009 would adversely affect fuel efficiency of HDVs. They took into consideration the emission reduction technologies in Figure 2.20.

Table 2.19: Considered fuel efficiency detriment attributed to the PNLT noxious emission standards

Pollutant targeted	System targeted	Component targeted	Fuel efficiency deterioration assumed
PM reduction technologies	Engine	Improved fuel injection systems (injection pressures) Improved combustion chamber and intake	2-3%
	Exhaust gas treatment	Continuous regenerative DPF	
NO _x reduction technologies	Engine	Improved EGR systems Improved duel injection systems (injection rate control)	5-7%
	Exhaust gas treatment	Occlusion NO _x reduction catalyst (LNT) Urea-additive NO _x reduction catalyst (SCR)	

Although alternatively fuelled HDVs are currently not within the scope of the regulations, Japanese top runner standards for passenger cars have managed to create standards taking hybrid vehicles into account. Top runner models for both conventional and hybrid powertrains are assessed, and combined based on the expected market uptake of hybrid vehicles for the future regulation year (MLIT, 2012). There is currently no consideration of hybrid vehicles in the Japanese HDV fuel efficiency measures. However, it is possible that this methodology could be applied for alternative HD powertrains in the future.

2.2.3.3.6 **Justification of the scope**

Japan chose to regulate only diesel HDVs. HVFESE stated that gasoline lorries were omitted from the regulations as they only account for a small part of the market (HVFESE, 2005). While only 15% of all Japanese lorries are over 3 tonnes and thus fall under the scope of the regulation, these are almost exclusively of diesel powertrains (JAMA, 2015). Smaller lorries, of which a large proportion are powered by fuels other than diesel, are regulated under light-duty vehicle efficiency regulations.

2.2.3.3.7 **Challenges/obstacles and solutions identified and avoided before implementation**

Under the Japanese approach, the future costs and effectiveness of technologies that are not yet on the market are not explicitly assessed and modelled. While this makes the approach more straightforward, it may provide only weak stimulus for further technological development and doesn't ensure that the energy saving measures encouraged by the standards are economically appropriate for consumers. For example, a study looking at the payback periods for energy efficient air conditioners suggested that efficient models often have a payback price longer than their expected lifetime (Kimura, 2010); this could also be an issue for HDVs using technologies with payback periods exceeding typical first-hand ownership durations. To address this, carrying out lifecycle analysis of the proposed technologies is important in the target-setting process. Also, in some areas the potential for technological improvement has been exhausted, making further standards cost-ineffective.

Another problem identified by the same study is that it is very difficult to accurately determine the rate of technological improvement by which to set the top runner standards. As a result of conservative assessments of the potential for technological improvement, several appliances included in the top runner approach achieved their targets long before the target date. This suggests that in some cases the top runner approach may not be effective in areas where forecasting of technological development is difficult (Kimura, 2010). In the case of HDVs this is a challenge rather than an obstacle.

Critiques of the top runner approach also note the large investment of civil servant's time, and the power of businesses to impact the targets set. Furthermore, the incremental nature of the improvements makes it difficult to gauge the progress that would be achieved without the measures. Another issue raised is the number of different standards based on the size of the product. For example, heavier cars or larger TVs are set less stringent standards. However, this could incentivise a market shift towards larger sized products. A proposed solution to this would be an obligation for each manufacturer to report average product efficiency over their full range of products (Futurepolicy.org, 2016).

One of the successes identified in Japanese measures is the disincentive for non-compliance. Manufacturers who fail to meet the standards are publicly named as non-compliant which, in light of Japanese culture and the limited number of domestic producers in most Japanese markets, acts as a strong compliance mechanism (Futurepolicy.org, 2016). However, this may not work so well when applied in other countries with either more diverse markets in terms of numbers of producers or in other cultural settings where public 'shaming' will not work as a tool for compliance.

2.2.3.3.7.1 *How was fairness between manufacturers ensured?*

The top runner approach ensures fairness for manufacturers primarily because it is based on evidence that the desired vehicle emission performance can be achieved with existing mass production technologies. Larger manufacturers, with the required facilities and capital, are able to research and pioneer new fuel efficiency improvement technologies; smaller manufacturers are still able to achieve the standards by implementing existing commercial solutions. The small percentage CO₂ improvement required in excess of the current top runner performance may be partially reached in the time between setting and requiring the standard. Furthermore, the regulation is technology neutral in that manufacturers can meet the standards through any technology pathway.

2.2.3.3.8 **Reasons for the division of administrative responsibilities described above**

The responsibilities of MOE, MLIT and METI in regulating fuel economy were set out in the Energy Conservation Law of 1979. The Japanese Government set up the HVFESE group in 2004 to facilitate the data intensive top runner programme, which requires manufacturers to submit detailed product information in order to set the baseline.

2.2.3.4 Measure design

2.2.3.4.1 Overview of measures

In April 2006 Japan became the first market in the world to introduce HDV efficiency standards by introducing limits to apply from the 2015 model year. There are three sets of approval systems in Japan:

- The Type Designation System: the type approval applying to mass produced vehicles of identical construction.
- The Type Notification System: used mainly for large heavy duty applications where there are many variants in configuration and for type approval of modified vehicles.
- The Preferential Handling Procedure: type approval of imported vehicles of less than 5,000 of each type, per year (JAIA, 2016).

Japanese standards specify a type approval limit and, additionally, a production average³⁶ which is lower. The mean limits are used for the Type Designation and Type Notification Systems. The maximum limits apply to individual vehicles and these are used for the Preferential Handling Procedure.

Japan’s fuel economy standards are set using the ‘top runner’ principle, which identifies the most energy efficient product available at the time of developing the standards and sets this as the requirement for the same class in the target year, after adjusting for external factors (i.e. further technical performance improvements over time within the top runner vehicle).

Further to the standards, the Japanese Government passed the Green Vehicle Purchasing Promotion Measures in 2009 (JAMA, 2014) to incentivise the purchasing of new environmentally friendly passenger and heavy-duty vehicles. The measure offers subsidies for the purchase of new vehicles to replace models older than 13 years, and also a subsidy for the purchase of new vehicles without the scrappage element. For the replacement subsidy, the new HDV must comply with the 2015 fuel efficiency standards and the vehicle’s NO_x or PM emissions must be less than 90% of the 2005 standards. The subsidy amounts are dictated by GVW and are given in Table 2.20.

Table 2.20: Subsidy amount by GVW for the purchase of a new HDV in Japan³⁷

	3,500kg < GVW ≤ 8,000kg	8,000kg < GVW ≤ 12,000kg	GVW > 12,000kg
New purchase replacing older model	JPY ¥400,000 (~£2,150)	JPY ¥800,000 (~£4,300)	JPY ¥1,800,000 (~£9,600)
New purchase (no replacement)	JPY ¥200,000 (~£1,075)	JPY ¥400,000 (~£2,150)	JPY ¥900,000 (~£4,800)

2.2.3.4.2 Scope

Originally, Japan classified a heavy duty vehicle as one with a GVW in excess of 2,500kg. This was brought in line with Europe to 3,500kg in 2005. All Japanese HDVs of over 3,500kg are treated equally in terms of current noxious emission limits (with minor deviations for buses) but not so for fuel economy standards where the categorisation is displayed in Figure 2.24 to Figure 2.27:.

The Japanese fuel economy regulations for heavy duty vehicles cover diesel fuelled freight vehicles and passenger vehicles with a riding capacity of 11 or more persons, with a gross vehicle weight of 3.5 tonnes or larger. Vehicles are either type designated under the Road Trucking Vehicle law (1951, Law No. 185) or equipped with a CO and other substance emission preventive device under the same law.

Spark-ignition vehicles are not regulated – only diesel fuelled HDVs (GVW > 3,500kg), including trucks and buses. Transit buses, non-transit buses, rigid trucks and articulated trucks are given separate fuel efficiency targets. Vehicles using other fuel types or not type designated or equipped with a CO

³⁶ This average is over vehicles of the same type which have already passed the type approval process.

³⁷ GBP figures are for illustration only. An exchange rate of GBP £1.00 = JPY ¥187.00 was used for these calculations, and the result rounded.

emission preventive device were excluded from the scope given the market size for such vehicles is very small, and there are technical problems regarding measurement.

Japan regulates fuel economy rather than CO₂ emissions. The standards effectively required an average HDV fuel economy improvement of 12.2% by 2015 over 2002 levels³⁸ (HVFESE, 2005), reducing the average CO₂ emissions from 415gCO₂/km to 370gCO₂/km. The targets and associated improvements are shown in Table 2.21.

The metric used in these regulations is that of fuel economy, implying fuel savings. However, it is noted that, depending on the technologies applied, there is normally a trade-off between improvement of fuel efficiency and reduction of exhaust gas emissions. The standards are monitored with this in mind.

Table 2.21: Fuel economy targets by vehicle class in the Japanese standards announced in 2006

Vehicle Type	Vehicle Class	Fuel Economy (km/L)		Improvement (%)
		2002 Baseline	2015 Target	
Lorry	Tractor	2.67	2.93	9.7
	Other lorry	6.56	7.36	12.2
	Total	6.32	7.09	12.2
Bus	Urban	4.51	5.01	11.1
	Other bus	6.19	6.98	12.8
	Total	5.62	6.30	12.1

As discussed in Section 2.2.3.3.1, Japan's HDV fuel efficiency regulations are part of an integrated suite of policy measures. Some of these measures are non-technological and could have a significant impact in countries that are not in a position to directly implement fuel efficiency regulations.

2.2.3.4.2.1 Vehicle categories and segmentation

For the purpose of the fuel efficiency regulations, the heavy duty sector is split into general buses, transit buses, rigid HDVs and tractor-trailers. Within each of these HDV-type splits are a number of categories, disaggregated by GVW, which are subject to different, discrete fuel efficiency targets. These are displayed in Figure 2.24 to Figure 2.27:.

2.2.3.4.2.2 Emissions covered

The Japanese standards concern fuel efficiency only.

2.2.3.4.2.3 Metrics used

The standards are expressed in kilometres per litre, are based on GVW and apply as a corporate average fuel efficiency across GVW ranges each year, though a credit system could be used between ranges until full enforcement in 2015.

2.2.3.4.2.4 Limit values

As described in Section 2.2.3.4.2.1, the limits are split by the type of HDV and then by the vehicle's respective weight. Small buses have limits differentiated by powertrain, but are below 3.5t and so are not considered here. The limit values are displayed in Figure 2.24 to Figure 2.27:., below.

Figure 2.24: 2015 Fuel efficiency targets for ordinary buses (>3.5t)

Category	GVW (t)	FE Target (km/L)
1	3.5 < GVW ≤ 6	9.04

³⁸ 12.2% for trucks, 12.1% for buses; 9.7% for articulated HDVs, however this makes little difference as they are a very small proportion of the fleet.

Category	GVW (t)	FE Target (km/L)
2	6 < GVW ≤ 8	6.52
3	8 < GVW ≤ 10	6.37
4	10 < GVW ≤ 12	5.70
5	12 < GVW ≤ 14	5.21
6	14 < GVW ≤ 16	4.06
7	16 < GVW	3.57

Figure 2.25: 2015 Fuel efficiency targets for route buses

Category	GVW (t)	FE Target (km/L)
1	6 < GVW ≤ 8	6.97
2	8 < GVW ≤ 10	6.30
3	10 < GVW ≤ 12	5.77
4	12 < GVW ≤ 14	5.14
5	14 < GVW	4.23

Figure 2.26: 2015 Fuel efficiency targets for freight vehicles (other than tractor)

Category	GVW (t)	Max Load (t)	FE Target (km/L)
1	3.5 < GVW ≤ 7.5	L ≤ 1.5	10.83
2		1.5 < L ≤ 2	10.35
3		2 < L ≤ 3	9.51
4		3 < L	8.12
5	7.5 < GVW ≤ 8	-	7.24
6	8 < GVW ≤ 10	-	6.52
7	10 < GVW ≤ 12	-	6.00
8	12 < GVW ≤ 14	-	5.69
9	14 < GVW ≤ 16	-	4.97
10	16 < GVW ≤ 20	-	4.15
11	20 < GVW	-	4.04

Figure 2.27: 2015 Fuel efficiency targets for tractors

Category	GVW (t)	FE Target (km/L)
1	GVW ≤ 20	3.09
2	GVW > 20	2.01

2.2.3.4.2.5 Drive cycles and payloads

The fuel efficiency results for each vehicle are derived from simulations using inputs from two engine dynamometer tests. The tests use torque / speed conversions from defined vehicle cycles: the JE05 urban cycle and an 80km/h constant speed cycle with a variable road gradient. The JE05 is a transient drive cycle based on urban drive statistics which has been used for testing exhaust gas emissions since 2005 and was therefore applied to fuel efficiency. The average speed over this cycle is 27.3km/h

(NTSEL, 2015). The constant speed cycle mimics interurban driving at a constant speed of 80km/h, chosen based on survey results of actual driving situations, whilst varying the road gradient. It uses the grade distribution from the Tomei Expressway, an interurban route with the most traffic in the country, as a representative profile in the simulation which is visualised in Figure 2.29. This longitudinal grade has a significant effect on fuel efficiency. Based on the survey results a load ratio of 50% is used for all vehicle types.

Figure 2.28: Urban driving mode (JE05) drive cycle (HVFESE, 2005)

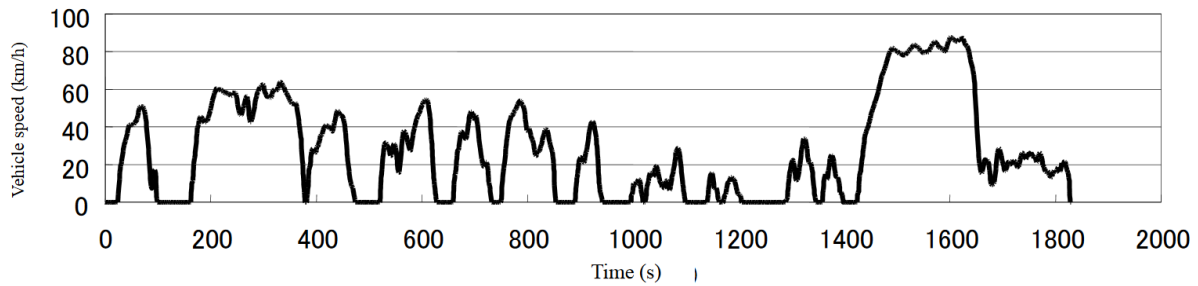
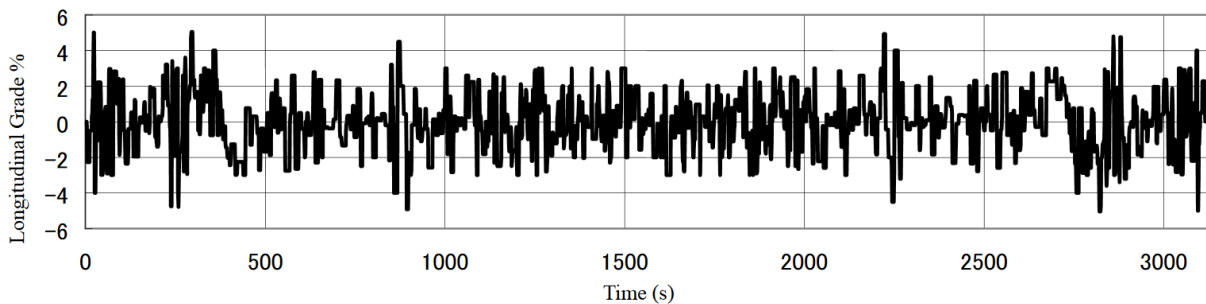


Figure 2.29: Interurban Drive Mode grade distribution (HVFESE, 2005)



Each of these simulated drive cycles are run with input from the HDV’s fuel efficiency map and vehicle specifications. Only one vehicle class is evaluated on a single test cycle, all others use a combination of both cycles with a weighting based on the expected vehicle use. The fuel efficiency calculated from the two driving modes are combined using the following formula (MLIT, 2011):

$$E = \frac{1}{\frac{\alpha_u}{E_u} + \frac{\alpha_h}{E_h}}$$

- E : heavy vehicle mode fuel efficiency (km/L)
- E_u : Urban driving mode fuel efficiency (km/L)
- E_h : Interurban driving mode fuel efficiency (km/L)
- α_u : Proportion of urban driving mode
- α_h : Proportion of interurban driving mode

Figure 2.30: 2015 Proportion of driving mode used for different vehicle type (HVFESE, 2005)

Vehicle type	Vehicle class	GVW (t)	% Weighting	
			Urban	Interurban
Other	Tractors	Up to 20	80%	20%
		20+	90%	10%

Vehicle type	Vehicle class	GVW (t)	% Weighting	
			Urban	Interurban
Bus	Other	Up to 20	90%	10%
		20+	70%	30%
	Route	-	100%	0%
	Other	Up to 14	90%	10%
		14+	65%	35%

The specifications used include engine related parameters (full load engine torque, idling engine speed, maximum output engine speed, maximum engine speed with load), drivetrain related parameters (number of transmission gears, gear ratios, final reduction gear ratio, tyre dynamic load radius), driving resistance parameters (rolling resistance coefficient, air resistance coefficient), and vehicle weight related parameters (complete vehicle curb weight, maximum load, riding capacity).

2.2.3.4.2.6 *Deadlines for compliance*

The fuel efficiency standards were set in 2006 with a compliance deadline of MY2015. This deadline was set to provide enough time for manufacturers to achieve 1-2 model cycles to meet the standards.

2.2.3.4.2.7 *Regulated entities*

The regulations only specify standards for vehicle manufacturers and importers in terms of the final vehicles produced. The regulation will impact all elements of the supply chain through competition between component manufacturers.

2.2.3.4.3 *HDVs present in the market that are not covered by the measure*

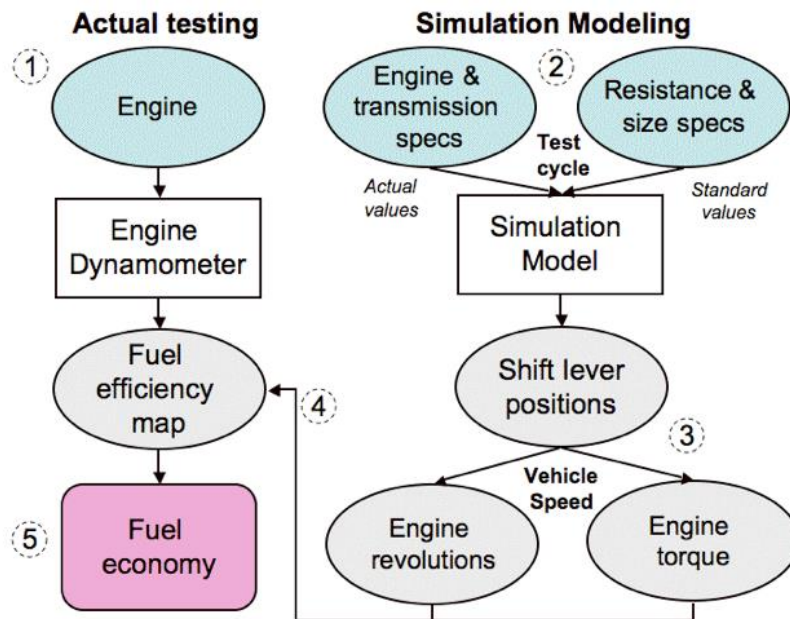
Any HDV that does not use diesel fuel, or is diesel fuelled but not “type designated” or “equipped with a CO and other substance emission preventive device” is excluded from the scope. There is no information provided on what vehicles might fall outside these requirements, but HVFESE suggests that the market for these vehicles is small and there were technical problems regarding measuring their emissions (HVFESE, 2005). Furthermore, HVFESE suggested that further studies would be performed to determine if these vehicles should be included in the scope.

2.2.3.4.4 *Testing and certification requirements*

Japan developed a new test procedure to assess vehicle fuel economy performance which centres on computer simulation, shown in Figure 2.31. The vehicle's fuel efficiency is derived from the simulation using inputs from the two engine dynamometer tests³⁹ described in Section 2.2.3.4.2.5. The simulation uses standardised values for curb weight, maximum load and riding capacity (MLIT, 2013) and takes into account other vehicle parameters such as tyre diameter, gear ratios, gear efficiency and approximates air drag based on the frontal area of the vehicle. Unlike the US, who use a ‘default’ transmission, and the EU, who could potentially use full manufacturer transmission data in VECTO, Japan sits half-way between and uses average transmission specifications from the manufacturer from the relevant vehicle category.

³⁹ For further detail see reference (HVFESE, 2005).

Figure 2.31: Japan's method of deriving HDV vehicle fuel economy (TransportPolicy.net, 2012)



Japan currently use engine dynamometers to test the fuel efficiency of their engines. A fuel efficiency map is created, which is then fed into a computer simulation that uses both the map and the vehicle specification to calculate vehicle fuel efficiency. This method was chosen in consideration of cost and time, as the fuel efficiency map for a given engine can be used for multiple vehicle designs which use the same engine. This differed from the US Phase 1 test procedure where a default engine map is used in the GEM computer simulation, rather than a map generated from testing. Conversely, Japan is the only country to use default figures for aerodynamics and low rolling resistance tyres, whereas all other countries with fuel economy or CO₂ standards use test-based figures.

2.2.3.4.4.1 Simulation tool development, maintenance and upgrade policy and high level cost estimations

No public information was available regarding the development timeline, costs or maintenance policy of Japan's simulation model. MLIT were unable to provide this to the project team in time for the draft final report.

2.2.3.4.4.2 Secondary systems coverage

Japan's measures cover only fuel efficiency; no secondary systems are regulated.

2.2.3.4.5 Main efficiency technologies targeted/incentivised by the measure

A number of technologies were identified in the measures as resulting in fuel efficiency improvements in the target year of 2015. It was noted that some of the technologies suggested will not be applicable to all types of HDVs and the expected diffusion rate of these technologies was taken into account in determining the target standards. The figures provided next to each technology indicate the expected improvement rate of fuel efficiency as a result of uptake. These technologies were considered as potential improvements in fuel efficiency, however they were not specifically incentivised through the measure.

However, it was also noted that the adoption of various exhaust gas emissions regulations will result in a decrease in fuel efficiency, and that these changes should also be considered in light of the technologies adopted to address the 2009 exhaust gas emissions regulations. This included a 2-3% decrease in fuel efficiency from particulate matter reduction technologies, and 5-7% decrease in fuel efficiency from NO_x reduction technologies.

Table 2.22: Technologies considered during the development of the standards and their estimated associated fuel efficiency improvement.

Technology	Improvement considered
Improvements in the thermal efficiency of the engines	
4-valve and centre nozzles	1.0% to 1.5%
Direct injection	4.0% to 5.0%
Fuel injection at higher pressure (200 MPa equivalent)	2.0%
Improved combustion chamber design	0.5%
EGR	1.0% to 1.5%
Higher supercharging (BMEP = 2.0 MPa or higher)	2.5% to 4.5%
Improved supercharging efficiency	0.3% to 0.5%
Variable supercharger	0.5%
Intercooler	1.5% to 2.5%
Turbo compound	Up to 1.5%
Optimised entire engine control system	3.0%
Improvements in engine energy loss	
Lower friction	1.0% to 1.5%
Lower idling evolution	0.5%
Lower loss of auxiliary equipment driving power	0.5% to 1.0%
Improvements through the optimisation of the operating range of the engine	
Larger number of transmission gears	1.0% to 5.0%
Tor-con (torque converter) AT	-9.0% to -4.0%
Differential gear having a lower gear ratio	0.5% to 3.0%
Direct coupling of the highest gear	0.5% to 3.0%
Other	
Idling-stop	Up to 4%

Through the use of the top runner approach, no technologies were specifically incentivised, leaving the market to find the most cost-effective means of achieving the target standards. As seen in other top runner programmes (Kimura, 2010), this leaves the possibility of new technologies that have not been accounted for in the analysis, making a significant impact on the ease of reaching the target standards. However, certain technologies may perform better within the parameters of the duty cycles, while other technologies have default values in the simulation and are therefore dis-incentivised.

2.2.3.4.6 *Flexibilities on compliance*

The top runner approach measures compliance with the standards by corporate average product sales. Manufacturers provide a weighted average efficiency for all products sold in a target year. This enables manufacturers to have products that do not meet the required standards, provided they are offset by other products that perform better than required by the standards.

2.2.3.4.7 *Estimated costs and benefits of measure*

No information was available at the time of writing regarding the costs and benefits of the measure. Japan's MLIT undertook a review of the measure in early 2017, which is set to be published later in 2017.

2.2.3.4.8 *Other measures*

Between 2008 and 2011 a tax incentive programme was established that facilitated reductions on both the acquisition and in-use 'weight tax' paid on heavy duty vehicles. Vehicles that met the 2015 fuel

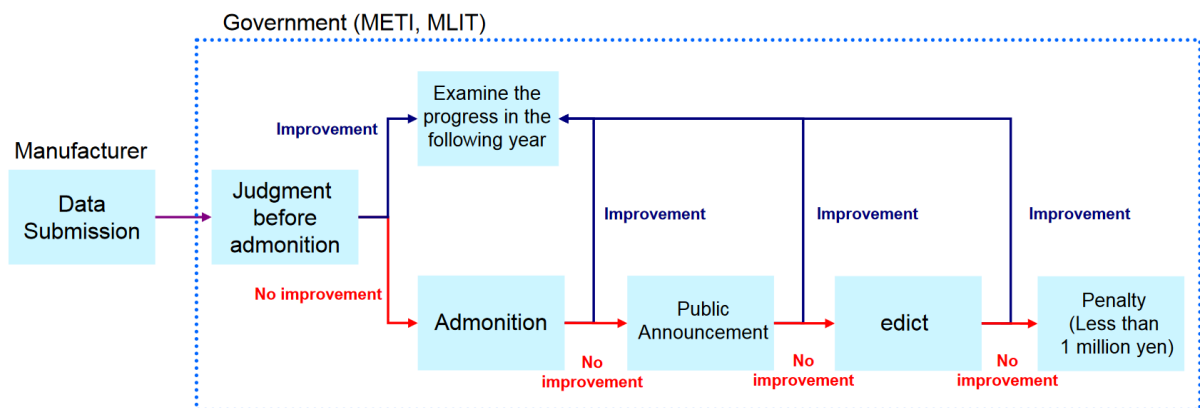
efficiency regulations and JP05⁴⁰ noxious emissions standards were given 75% of both taxes, while vehicles that met the 2015 fuel efficiency regulations but exceeded JP05 emissions standards by up to 10% were given 50% tax reductions (MLIT, 2011).

2.2.3.5 Monitoring, reporting, verification and enforcement

2.2.3.5.1 Monitoring, reporting and verification

The manufacturers are required to submit data on the corporate average fuel efficiency of all of their products. This data is then assessed by METI and MLIT to determine if they have complied with the standards.

Figure 2.32: Monitoring and Enforcement Procedure for Japan’s fuel efficiency measures (METI, 2007)



2.2.3.5.2 Enforcement

2.2.3.5.2.1 Who is responsible?

Enforcement is carried out by METI and MLIT.

2.2.3.5.2.2 Enforcement system

There are financial incentives to meet the mandatory standards in the form of tax reductions, though conversely, fines for non-compliance are not substantial. Indeed, METI described the penalties as “relatively loose”. Instead, enforcement relies on public announcements of non-compliance to incentivise manufacturers. The Energy Saving Law is meant to promote efforts by manufacturers to improve energy efficiency, rather than regulate the manufacturers (METI, 2007). This enforcement system is considered a unique aspect of the top runner programme, and is partly a result of Japanese cultural norms and the prevalence of large, well-known domestic manufacturers. The threat of public announcement has a greater significance in Japan than would be expected in other economic and cultural circumstances.

2.3 Subtask 1.2: High-level review of other relevant markets

2.3.1 Chile

2.3.1.1 Summary

There are currently no plans in Chile to implement HDV CO₂ or fuel consumption regulations. The Chilean government are considering an energy efficiency law that would include transport, however this is likely to take many years and would prioritise standards for LDVs.

⁴⁰ ‘JP05’ denotes Japan’s noxious emission standards introduced in October 2005.

2.3.1.2 Background to measures

2.3.1.2.1 Overview

Chilean vehicle emissions are governed by the Ministry of Transport and Telecommunications and the Ministry of Environment, and are supported by research institutions such as the Centro Mario Molina (CMMCh) who are extensively involved in transport emissions research and policy development in the region. Chilean emissions policy has been driven by poor air quality, especially in the three main metropolitan areas. The regulatory focus has thus been on noxious emissions rather than CO₂, and new HDVs sold in Chile must meet either the US EPA 07 or EURO V noxious emission standards. There is currently no legislation regarding HDV CO₂ emissions or fuel economy.

Chile has committed to a 20% reduction of its greenhouse gas emissions by 2020 from 2007 levels. As part of this, it is a pilot country in the Global Fuel Economy Initiative's (GFEI's) programme, however this is focused on light-duty vehicles (FIA Foundation, 2015). As such, the Chilean authorities have recently been working towards CO₂ emissions reductions and fuel efficiency in transport, but so far only regarding LDVs and medium-duty vehicles (MDVs). An initiative was set up in 2015 to address CO₂ emissions from LDVs and MDVs through a 'feebate' program, adding a tax to new vehicle purchases based on its CO₂ and NO_x emissions. With no standardised method of measuring HDV CO₂, however, a similar scheme is currently not viable.

The lesser focus on HDVs may be partly explained by the relatively small role HDVs play in the Chilean fleet (compared to other regions), where passenger cars represent approximately 70% of the market. HDVs (goods vehicles and buses) account for less than 10% of the market (which is significantly less than in markets such as the US and Europe). For Chile's cargo transport, maritime is the main transport mode, with a 51.6% share, followed by railway (32.4% share), road (15.7% share) and air (0.4%) (EMIS, 2016). As for other most other regions, the HDV market primarily uses diesel engines which are generally more efficient but yield higher NO_x and particulate matter emissions than petrol engines. This has also driven the authorities' prioritisation towards noxious emissions over CO₂.

2.3.1.2.1.1 Existing programmes and capabilities

Chile are currently involved with the International Energy Agency on their Advanced Motor Fuels Technology Collaboration Programme⁴¹. Within this is a project (under Annex 53) to develop a methodology for setting requirements for clean and energy efficient buses for use in tendering processes for public transport operators in South America. The project involves a collaboration between Canada, Chile, Finland, Israel and Sweden, and is being piloted in Santiago de Chile. As part of this work, CMMCh are reviewing driving cycles for regional buses and developing a common test methodology and protocols for the reporting of data. The project concludes in December 2017, and is considered Chile's greatest movement towards fuel consumption regulations for HDVs. Procurement measures on buses in Chile are becoming more feasible as vehicles from European OEMs increasingly permeate this segment.

2.3.1.2.2 Challenges, obstacles and solutions identified

The most considerable barrier for introducing fuel economy standards to Chile is that there is no legal basis on which to do so. The Chilean government are currently considering a law on energy efficiency which would encompass a wide range of areas, including transport, and allow the implementation of such regulation. It was initially believed that a Congressional decision on this law would be made by 2017, however it is now expected that this process will take far longer for political reasons. In any case, application of this law to transport would first concern LDVs, and not HDVs.

A further barrier identified in Latin America is the poor level of compliance with existing standards. Many of the lorries and buses have no documentation and there is not enough power or capacity to further enforce these measures. This lack of enforcement makes pursuing sophisticated policies prohibitively difficult.

⁴¹ See <http://iea-amf.org> for more information.

2.3.1.3 Measure design

2.3.1.3.1 Scope

Chile uses similar weight categorisations to those seen in other regions, displayed in Table 2.23. The HDV categories and segments to fall under any measure are not yet identified in Chile. Conversations with CMMCh suggest that public vehicles such as buses are the most likely candidates for standards at present. Indeed, buses in the Santiago Metropolitan Region have historically been required to meet new noxious emission standards earlier than other HDVs (DieselNet, 2013).

Table 2.23: Chilean vehicle weight classification (Transportpolicy.net, 2016)

Class	LDV (Light Duty Vehicles)	MDV (Medium Duty Vehicles)	HDV (Heavy Duty Vehicles) ^{a,b}
GVWR (kg)	< 2,700 kg	2,700 ≤ GVWR < 3,860 kg	≥ 3,860 kg

Notes:

^a Diesel HDVs of GVW ≤ 6,350kg are able to alternatively certify complete vehicles according to a chassis dynamometer test, with different limits either side of 4,536kg.

^b Noxious emission limits such as for particulate matter are applied at different stringencies depending on application.

At this time, no further information is available on potential fuel economy standards in Chile.

2.3.2 Brazil

2.3.2.1 Summary

There are currently no plans in Brazil to implement HDV CO₂ or fuel consumption regulations. The current economic situation in Brazil further limits the possibility of future vehicle efficiency regulations, as evidenced by the lack of renewal of the country's successful light-duty vehicle (LDV) Inovar-Auto programme from 2017. At present, all efforts in HDV performance are focused on implementing noxious emission standards.

2.3.2.2 Background to measures

2.3.2.2.1 Rationale

Currently, Brazil does not have regulations controlling fuel consumption and CO₂ emissions from heavy-duty vehicles (HDVs). Brazil leads the way in exhaust air quality legislation in South America, having successfully introduced PROCONVE (Programa de Controle da Poluição do Ar por Veículos Automotores) standards in 1986 and progressively improving them into their seventh phase today⁴².

Despite this, there is a reasonable case for introducing fuel economy or CO₂ standards for HDVs. Brazil's road freight sector is the fifth largest in the world and was reported by the Brazilian National Registry of Road Freight Transporters to contain 1.5 million active lorries in 2010 (World Bank, 2011). It therefore represents a large part of the Brazilian economy, accounting for 6.5% of GDP in 2011 (World Bank, 2011), and hence fuel consumption improvements would have a marked effect on the country's finances. This figure is continually rising due to increasing freight demand, and since Brazil does not have extensive rail or inland waterway networks it is largely reliant on road freight transport for the transport of goods: over 60% of freight tonne-kilometres are now delivered by road (World Bank, 2011). This is resulting in a greater number of vehicles and also heavier lorries in Brazil and is increasing the rationale for fuel economy standards.

Regarding environmental concerns, growth in the South American transport sector has caused carbon emissions to rise rapidly. The Brazilian road transport sector was responsible for approximately 27% of all energy consumption in 2007 (Ministerio de Minas e Energia, 2009) with a particularly large proportion

⁴² The PROCONVE air quality standards apply to all vehicles designed for the purpose of carrying goods or persons, with gross vehicle weight (GVW) >3,865kg, or kerb weight >2,720kg.

(41%) of transport fuel use resulting from freight transport of all modes (World Bank, 2011). As such, improvements in HDV emission performance would bring sizable reductions to the country's greenhouse gas emissions.

These drivers have recently been recognised by the Brazilian authorities, who have signalled their intention to begin regulating fuel consumption and CO₂ emissions from HDVs. They are voluntary participants in the G20 Energy Efficiency Action Plan, the work of which includes developing recommendations for strengthening domestic standards for clean fuels, vehicle emissions, and vehicle fuel efficiency (ICCT, 2015). It is evidenced, therefore, that a key driver for the development of regulations are the environmental benefits of improved fleet efficiency. Brazil has previously made use of fiscal incentive schemes such as the 'Inovar-Auto' scheme applicable to LDVs, which primarily aim to also encourage economic growth, job creation and technological advancement whilst improving fuel economy. Inovar-Auto is designed to foster competitiveness by encouraging manufacturers to produce more efficient, safer, and more technologically-advanced vehicles through tax reductions and is discussed further in Section 2.3.2.3.1.1.

Whilst Inovar-Auto is a scheme for LDVs, a scheme of similar design is likely to be favoured by the Brazilian government for heavy-duty vehicles. As the majority of the 574,000 businesses that registered HDVs in 2011 were independent owner-operators (World Bank, 2011), the Brazilian fleet is mostly formed of older, second-hand vehicles operating at substandard levels⁴³. The high up-front expense associated with upgrading to a more recent model for these users results in a slow turnover of the fleet. These individual owners would require a financial incentive to replace their vehicle with a more recent, cleaner model, analogously to the situation with LDVs preceding the successful Inovar-Auto scheme.

Overall, however, due to the current economic and political situation in Brazil, the development of fuel economy regulations is not being actively discussed, as summarised in the next section.

2.3.2.2.2 **Implementation timeline**

The current political and economic situation in Brazil suggests that HDV standards in Brazil are not imminent. In fact, this economic situation has been enough to deter policy makers from extending the successful light-duty Inovar-Auto programme beyond 2017. Conversely, Brazil's focus is on its acute air quality problems. This was demonstrated to be the case across the Latin American region in a recent workshop attended by policymakers in charge of HDV emission standards from each country, where open conversation was reported⁴⁴ to be solely directed towards the introduction of Euro VI-equivalent air quality standards, with no mention of fuel economy.

Intent from the Brazilian authorities is nonetheless present, however, and the market is beginning to consider the costs and benefits of fuel-efficient HDVs during procurement. Brazil may thus be a candidate for fuel economy standards in the mid-term.

2.3.2.3 **Measure design**

2.3.2.3.1 **Overview of measures**

As discussed, no measures currently exist to regulate fuel consumption and CO₂ emissions for heavy-duty vehicles in Brazil. The structure of any proposed model is likely to bear similarities to Inovar-Auto, the fiscal incentive scheme for light-duty vehicles.

As previously mentioned, Brazil are looking to introduce regulations relating to the fuel consumption of HDVs as a part of their commitment to the G20 Energy Efficiency Action Plan. They are currently gathering data which will be used to inform regulatory proposals (ICCT, 2015). A scheme which encourages the uptake of more energy efficient technologies was a part of a comprehensive strategy

⁴³ It is worth noting that the Brazilian HDV fleet is slowly improving organically due to the domination by European OEMs, which has led to increased market sophistication compared to similar markets elsewhere in South America (with the exception of Chile, which shares this feature).

⁴⁴ Information regarding the meeting of Latin American policymakers in 2016 was kindly provided by Centro Mario Molina, Chile.

recommendation issued by the World Bank for making the Brazilian road freight sector more energy efficient (World Bank, 2011). Other elements of the strategy include;

- Infrastructure – integrated multimodal infrastructure development, ensuring high quality roads, and supporting the use of low-carbon construction materials and methods.
- Fleet turnover – registration fees, control the use of older lorries in ports and cities, develop and finance scrappage programmes.
- Focus on improving fuel efficiency on existing lorries – adopt fuel saving technologies, management practices and driver programmes.
- Support innovations – Support lorries technology pilots, development of new-generation vehicles and fuels.

2.3.2.3.1.1 *Light-duty ‘Inovar-Auto’ scheme design*

In 2012, the Brazilian government approved a new programme to encourage vehicle technology innovation through tax breaks. It first increases a tax on industrialised production (Imposto sobre Produtos Industrializados; or IPI) by 30% for all light-duty vehicles, before imposing a series of requirements for manufacturers to qualify for an up to 30% discount in IPI - in other words, taxes will remain unchanged for manufacturers who manage to fully satisfy the requirements of the scheme. This programme is limited to vehicles manufactured between 2013 and 2017, after which IPI will return to pre-2013 levels, unless modifications to the decree are made.

Table 2.24: IPI rates before and after the implementation of the Inovar-Auto scheme (adapted from (ICCT, 2013))

Engine Displacement (L)	IPI before 2012	IPI 2012-2017
Less than 1L	7%	37%
1-2L Flex/Ethanol	11%	41%
1-2L Gasoline	13%	43%
Above 2L	25%	55%

It is predicted that the programme will spur an improvement in energy efficiency of 12% between 2012 and 2017 (ICCT, 2013). Manufacturers can also qualify for a further 2% discount if they meet stricter targets (up to a 19% improvement on 2012 levels). It is expected that by 2030 this will lead to a 10-15% CO_{2e} reduction (including well-to-wheel emissions for bio-ethanol sources).

To qualify for the 30% discount, the corporate average of vehicle fleet efficiency must meet the 12% target reduction. This is based on Europe’s average of 130g CO₂/km, but adapted to take into account differences in driving cycle, vehicles, fuel and road specifications within the Brazilian sector. Further IPI tax reductions are available for manufacturers who exceed these expectations.

Additionally, manufacturers must conduct a certain number of manufacturing processes in Brazil⁴⁵, and choose to comply with two of three further requirements.

These three requirements are;

- Investment in research and development
- Investment in engineering, industrial technology, and supplier capacity

⁴⁵ Manufacturers must conduct a minimum number of manufacturing and engineering infrastructure activities for at least 80% of produced light-duty vehicles in Brazil. The activities considered are; stamping; welding; anticorrosion treatment and painting; plastic injection; motor manufacturing; gearbox and transmission manufacturing; steering and suspensions systems assembly; electrical systems assembly; axle and brake systems assembly; monoblock manufacturing or chassis assembly; assembly, final review and testing; own laboratory infrastructure for product development and testing.

- Participation in the vehicle labelling scheme

By only meeting the vehicle efficiency target, a manufacturer does not qualify for the full 30% discount in IPI, but does qualify for a reduced tax break.

Due to parallels with the heavy duty sector discussed in Section 2.3.2.2.1, it is possible that Brazil would implement a similar measure for HDVs alongside or in place of fuel consumption limit values. This is not considered to be imminent, however, as the present economic crisis in Brazil has already stalled investments in the next cycle of the LDV scheme, reducing growth and the pace for new projects⁴⁶.

2.3.2.3.2 **Scope**

The scope of the PROCONVE standards for heavy-duty vehicles covers vehicles with greater than 3,856kg total weight, or with running weight greater than 2,720kg. This covers emissions for vehicles for transportation of passenger and/or goods. This is likely to form the basis of categorisation for any Brazilian fiscal incentive introduced for HDV CO₂ emissions.

Whether Brazil's measures will focus on fuel economy or CO₂ emission is unknown, however the Inovar-Auto scheme is based on fuel economy performance.

As the Brazilian authorities have only recently conceptualised tackling fuel consumption from HDVs it is too early for information on their intended testing and certification methods, potential flexibilities on compliance or the estimated costs and benefits of any such measure.

2.3.3 Mexico

2.3.3.1 Summary

Mexico is the world's leading exporter of heavy duty vehicles, but does not yet have any fuel consumption or CO₂ regulations. However, as most of the vehicles are exported to the US, Mexico's manufacturers most likely comply with US regulations. Regulations are expected to be implemented in Mexico in the future as part of an aligned North American standard, and would be in line with Phase 2 US regulations.

2.3.3.2 Introduction and broad market characteristics

Mexico is a major producer of heavy-duty vehicles, although sales to the domestic market are relatively limited. In 2015, Mexico exported 92,000 road tractors, overtaking Germany as the world's leading exporter of heavy vehicles. The US accounts for 83% of the exported lorries from Mexico (Mexico News Daily, 2015), while the domestic industry mostly draws on US imports of used lorries. The vehicles exported to the US are subject to US EPA fuel consumption regulations, suggesting that Mexico's manufacturers produce most of their vehicles to these standards. While Mexico currently does not have any domestic CO₂ and/or fuel consumption standards for HDVs, an aligned North American standard for HDV fuel consumption out to 2027 has been announced at the 2016 North American Leaders' Summit between Mexico, the USA and Canada. Moreover, the US/Canadian SmartWay programme will be expanded into Mexico.

2.3.3.3 Background to measures

2.3.3.3.1 **Administrative framework**

Transport emissions are regulated by the Secretary of Environment and Natural Resources (Secretaria de Medio Ambiente y Recursos Naturales; SEMARNAT). There is existing legislation on air pollutant emissions from HDVs but no regulations on fuel consumption and CO₂. The regulations are enforced by Profepa, an autonomous arm of SEMARNAT.

⁴⁶ One study has found that as a result of this uncertainty, some medium- and long-term investments have already undergone cuts, or have even been frozen (Mello, et al., 2016).

2.3.3.3.2 **Rationale**

Mexico has not yet introduced standards on HDV fuel consumption and CO₂ emissions. However, in 2012 Mexico passed its General Law on Climate Change⁴⁷ which amongst many other measures requires government to develop efficiency standards for new vehicles (Article 102(V)). A 2013 standard on light-duty vehicles was one of the first regulations implementing the General Law. The recent Paris Agreement is likely to have given new momentum to climate mitigation measures, as was also emphasised by the North American Leaders’ announcement of the Climate, Clean Energy, and Environment Partnership. The Partnership entails the plan for aligned North American efficiency standards for HDVs (The White House, 2016). A further rationale for Mexico to introduce HDV standards, put forward by the IEA, is that Mexico’s HDV stock is soaring along with overall oil demand, while domestic oil production is in decline (IEA, 2015).

2.3.3.3.3 **Implementation timeline**

Mexico has not yet published nor discussed a timeline for the introduction of Mexican fuel economy/CO₂ standards for HDVs. A presentation by the ICCT (held before the announcement of aligning North American HDV standards that was discussed in Section 2.3.3.4.1) estimated Mexican HDV standards to come into force by around 2020 (see Figure 2.33).

2.3.3.4 **Measure design**

Mexico has historically followed other markets for its HDV air pollutant emission regulations. Current standards for new lorries in Mexico are at the level of Euro IV/EPA 2004 (manufacturers can choose whether to comply with the European or US emission standard; approximately 90% of the market follows the US standard (ICCT, 2014)). Draft legislation published in 2014 for moving to Euro VI/EPA 2010 from 2018 is facing opposition from some lorry manufacturers, and has not yet been implemented. While the standards do not target fuel economy, the move to Euro VI/EPA 2010 powertrains is also expected to reduce lorries’ fuel consumption (as it has in the USA and the EU).

Figure 2.33: Overview over existing and expected HDV CO₂/efficiency standards (ICCT (2016a))

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	
Japan				Phase 1										Phase 2	
U.S.			Phase 1					Phase 2							
Canada			Phase 1					Phase 2							
China	Phase 1		Phase 2						Phase 3						
EU	Certification, Monitoring, Reporting														
India									Phase 1						
Mexico									Phase 1						
S. Korea									Phase 1						

Hashed areas represent unconfirmed projections of the ICCT

2.3.3.4.1 **Overview of measure**

The Mexican government is planning to introduce separate fuel economy/CO₂ standards for HDVs. Specifically, the action plan from the North American Leaders’ Summit of the US, Canada and Mexico in 2016 includes the commitment to implement aligned HDV fuel efficiency and/or greenhouse gas standards out to 2027 (ICCT, 2016). Consequently, the Mexican legislation is likely to follow the US Phase 2 standard (which was only finalised in August 2016). The latter represents the relevant HDV

⁴⁷ Ley General de Cambio Climático – available at: <http://www.diputados.gob.mx/LeyesBiblio/ref/lgcc.htm>

standard for the US out to 2027, so alignment would entail Mexico adopting largely the same requirements, similar to Canada, which has announced it would 'align with the Phase 2 emission standards, while considering specific implications for the Canadian heavy-duty vehicle, engine and trailer sectors' (ICCT, 2016). Even before the initiative, the development of Mexican fuel economy standards for HDVs appeared to be under consideration, as reflected in an IEA presentation providing recommendations to Mexico on the design of HDV-specific standards (IEA, 2015).

At the North American Leaders' Summit, an expansion of the US/Canadian SmartWay programme into Mexico was also announced. EPA and Natural Resources Canada are working with SEMARNAT to create a single North American SmartWay, and the launch of a Mexican pilot programme is expected soon (EPA, n.d.).

2.3.4 India

2.3.4.1 Summary

India currently does not have measures to reduce heavy duty vehicle fuel consumption but has been considering them in more depth since 2014. It is expected that HDV engine standards will be introduced in the next few years, whilst the likely end goal of full vehicle standards may take considerably longer.

2.3.4.2 Introduction and broad market characteristics

There are currently no heavy-duty vehicle fuel consumption or CO₂ standards in India. However, government authorities have been tasked with the development of proposals. It is expected that the government, which is currently consulting with stakeholders, will present a constant speed fuel consumption (CSFC)-based standard for the medium term in 2017.

Within the transport sector, HDVs are the largest contributor to GHG emissions in India and the fleet is very different to that of other countries. The most notable feature is small engines, with very few HDV engines exceeding a displacement of 7 litres. More widely, HDVs tend to be manufactured to a very basic standard, and so there is room for technological improvement. Moreover, the fleet is heavily customised, with vehicle bodies typically built or altered by independent mechanics (TERI, 2015).

While vehicle emissions are regulated by the Ministry of Road Transport and Highways (MORTH), India's fuel consumption regulations are overseen by the Ministry of Petroleum and Natural Gas. In 2014 the Ministry of Petroleum and Natural Gas delegated the task of formulating fuel consumption regulations to the Petroleum Conservation Research Association (PCRA) and the Bureau of Energy Efficiency (BEE).

2.3.4.3 Background to measures

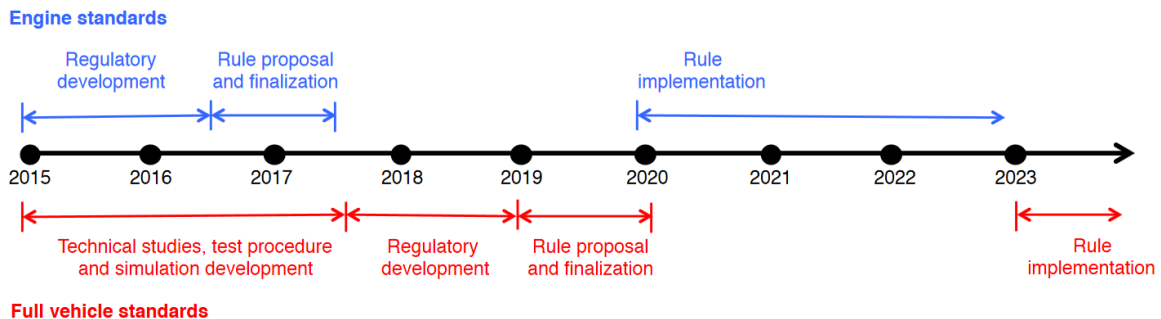
2.3.4.3.1 *Rationale*

In India, the leading rationale behind pursuing fuel consumption regulations is to reduce dependence on imported crude oil.

2.3.4.3.2 *Implementation timeline*

In 2014, the Ministry of Petroleum and Natural Gas tasked PCRA and BEE with developing HDV fuel economy standards (Ministry of Petroleum & Natural Gas, 2014). BEE subsequently commissioned Ricardo-AEA to carry out an analysis of potential improvements in fuel efficiency for India's two-wheeled and HDV fleets (Ricardo-AEA, 2014). Moreover, PCRA and the International Energy Agency held a workshop in April 2015 to discuss the development of fuel efficiency standards for heavy-duty vehicles globally, and implications for India. Figure 2.34 provides a summary of the expected timeline, suggesting that the first regulations may be finalised in mid-2017 with standards applying from 2020. More sophisticated full-vehicle-simulation-based standards, which may entail developing an Indian version of the European VECTO tool (that took around 5 years to develop), are unlikely to be ready before 2020, with implementation not expected before 2023.

Figure 2.34: expected timeline for the introduction of HDV fuel consumption standards according to the ICCT (ICCT (2015))



Note: As discussed below, the introduction of a constant speed fuel consumption standard rather than an engine standard for the shorter term now appears likely.

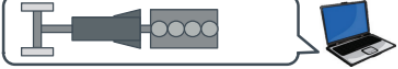
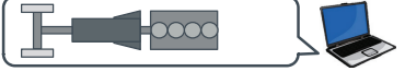


2.3.4.4 Measure design

2.3.4.4.1 Overview of measures

According to the Society of Indian Automobile Manufacturers of India (SIAM), BEE and PCRA are expected to present a constant speed fuel consumption (CSFC)-based standard in 2017 as an interim solution prior to the introduction of a full vehicle simulation tool (Autocar Professional, 2016). This type of test procedure is already used in the vehicle certification process on a subset of HDVs. Fuel consumption is tested on a test track at constant speeds of 40 and 60 km/h (ICCT, 2015b). Whilst the CSFC standards are not necessarily representative, it is expected to deliver some improvement to real-world HDV fuel consumption, and is seen as preferable to not having any standard prior to the introduction of a full vehicle simulation-based procedure.

In the longer term, full vehicle simulation is viewed as the best option for fuel consumption certification by most stakeholders (ICCT, 2015). Focussing on whole vehicle fuel consumption allows manufacturers to choose the most cost-effective combination of improvements to the vehicle for meeting a given fuel consumption/CO₂ target (across engine, gearbox, auxiliary loads, tyres, aerodynamics, weight reduction, etc.). However, the fleet composition and conditions in India are very different from other markets. India's HDV bodies are often radically altered by independent mechanics, making the actual fuel efficiency different from that at point of sale (TERI, 2015), and posing a challenge to reliable full-vehicle simulation.

Figure 2.35: ICCT's view on the suitability of different certification options in the short term (ICCT (2015))

Certification option	Ability to leverage existing testing facilities	Complexity of certification process	Timeline for regulatory implementation
 Full vehicle simulation - adapted version of VECTO, GEM, Japan or China model	Moderate	Moderate	5-7 years
 Full vehicle simulation - new India model	Moderate	?	5-7 years
 Chassis dynamometer	Unfavorable	Moderate	5-7 years
 Engine dynamometer	Favorable	Moderate	3-5 years

■ Favorable ■ Moderate ■ Unfavorable

Note: The figure does not include the option of constant speed fuel consumption testing which appears to be the most likely short term policy response. It would also allow a short timeline for implementation and use of existing testing facilities.

2.3.5 South Korea

2.3.5.1 Summary

South Korea does not currently have any HDV fuel consumption or CO₂ regulations. An HDV fuel efficiency programme is currently under consideration, although the timeline is not known. South Korean fuel economy regulations for LDVs are in their third iteration.

2.3.5.2 Background to measures

2.3.5.2.1 Rationale

The Ministry of Environment (ME) is South Korea's governing body for emissions regulations of HDVs. The Korea Energy Management Corporation (KEMCO) is responsible for the implementation of energy conservation policies and energy efficiency improvement measures, working with the Ministry for Trade, Industry and Energy (MOTIE) who also work towards fuel efficiency measures. These bodies have already developed and implemented several fuel efficiency measures for LDVs. Extending them to HDVs is the next step in addressing GHG emissions from the transport sector.

2.3.5.2.2 Implementation timeline

Whilst South Korea does not currently have HDV fuel efficiency or CO₂ standards, it is known that a fuel efficiency programme is in active development (ICCT, 2016). The ICCT estimates, based on unconfirmed projections, that implementation of HDV fuel efficiency regulations will be implemented in South Korea around 2020.

2.3.5.2.3 Stakeholders involved

No information was available on the stakeholders involved in the development of South Korea's HDV fuel efficiency programme.

2.3.5.3 Measure design

2.3.5.3.1 Current progress

South Korea define heavy duty vehicles as those with a GVW greater than 3.5 tonnes (8,500 lbs) with a current classification of HDVs as described in Table 2.25. For the purpose of its fuel efficiency regulations, however, South Korea is also considering the classification approaches taken by other countries, including the US, Japan and China (Hwanjung Jung, 2015). South Korea has a similar fleet composition to Japan, with medium duty vehicles dominating the HDV fleet.

Table 2.25: South Korean HDV categories

Vehicle Category	Definition
Large passenger vehicle	3.5 ≤ GVW < 15 t; designed to carry persons
Large lorry	3.5 ≤ GVW < 15 t; designed to carry cargo
Extra-large passenger vehicle	>15 t GVW; designed to carry persons
Extra-large lorry	>15 t GVW; designed to carry cargo

South Korea appear to be considering drive cycles and payloads based on international experiences from Japan, the US, China and the EU (Hwanjung Jung, 2015), and in particular are looking at how the various drive cycles differ from real world fuel efficiency.

Both chassis dynamometer and simulation based testing are being considered (Hwanjung Jung, 2015). From the information presented, it is unclear whether South Korea would consider using existing simulation tools or to develop new software.

2.4 Subtask 1.3: Stakeholder interviews

Subtask 1.3 aimed to test and refine the information collected in the country fiches through a series of in-depth stakeholder interviews. The targeted stakeholders were representatives from the relevant authorities, including government departments and non-governmental organisations who had played a core role in the design, implementation and monitoring of the respective HDV GHG reduction measures. It was assumed that, in general, the task would require two stakeholders for each key market and one stakeholder for each secondary market.

The core objective of the subtask was to understand the decision process which led up to the introduction, or decision to introduce, the measures. The information sought in each interview thus varied by market. Extensive literature reviews were possible for most markets with regulations in place hence the interviews were focused on confirming the findings in the market fiche and further refinement in areas where information was considered lacking. For markets in the process of developing regulations or less transparent markets such as China, significantly less information was publically available and so the interviews focused on investigating either the progress in regulatory development or the decision process which led to the measures.

Prior to the interview, a bespoke list of questions and the market fiche were sent to the stakeholder. Each interview was designed to last up to two hours so that a suitable level of detail could be ascertained and notes were taken during the interview, for later confirmation by the stakeholder. Finally, the information gained from the interview was integrated into the relevant fiche.

Contacts were predominately identified by the significance of their role, or that of their organisation, in setting up the measure.

Some difficulties were experienced in contacting the stakeholders and scheduling interviews for both key and secondary markets, hence the interviews marked as 'Interview not possible' in Table 2.26. In some cases, such as in India, this was due to upcoming announcements whereby the organisation was not able to discuss the content publically beforehand.

The interviews with most of the key markets (USA, Canada, California and China) yielded valuable information, and allowed further refinement of the country fiches. However, authorities from the secondary markets interviewed had little to add as HDV GHG or fuel efficiency measures were not yet being pursued, with passenger vehicles taking priority.

Table 2.26: List of stakeholder interviews with key and secondary markets

Country	Organisation	Name of contact	Role	Interview status
Key markets				
Canada	Transportation Division, Environment Canada	Joanna Bellamy	Chief Officer, GHG Regulatory Development Section	Completed
		Julie Deschatelets	Senior Program Engineer, GHG Regulatory Development Section	Completed
California	California Air Resources Board	Jack Kitowski	Division Chief, Director of Mobile Source Control Division	Completed
	CalEPA	Mark Wenzel	Climate Change Adviser, Climate Change Unit	Completed
China	Ministry of Transport/Ministry of Communications Highway Research Institute (CATARC)	Mr Yue Fu Jin	Formerly of CATARC	Completed
Japan	MLIT NTSEL			Interview not possible
USA	EPA	Matthew Spears	Centre Director, Heavy-Duty Diesel Standards	Completed
Secondary Markets				
Brazil	Centro Mario Molina Chile	Gianni Lopez	Director	Completed
Chile	Centro Mario Molina Chile	Gianni Lopez	Director	Completed
India	PCRA			Interview not possible
Mexico	(CONUEE) Comisión Nacional para el Uso Eficiente de la Energía			Interview not possible

Country	Organisation	Name of contact	Role	Interview status
South Korea	KEMCO			Interview not possible

3 Task 2: Comparative analysis and lessons learned

Box 2: Key points for Task 2

Task outline:

1. **Task 2.1: Finalise the analytical framework for the comparative assessment**
2. **Task 2.2: Preliminary comparison of approaches to inform the finalisation of work in Task 1**
3. **Task 2.3: Comparative analysis, lessons learned and benefits of alignment**

Key outputs:

- A detailed definition of the ‘measures’ which make up individual country/market HDV GHG reduction / efficiency programmes, and their constituent elements, to ensure the compatibility of data collected in Task 1 with the analytical framework in Task 2.
- An agreed definition of the analytical framework to enable a comparison of measures and their constituent elements for relevance to the EU context.
- A comparative assessment and scoring of the measures in place in other markets, including particular elements of these, as to their overall relevance to the EU.
- A summary of the various lessons learned from measures implemented in other markets, which may be relevant to implementation in the EU.

3.1 Overview and progress

As part of this task, an analytical framework is developed and applied. It is used to assess the suitability of various elements of measures in other countries to the EU context. The information collected in Task 1 is processed through the framework, which provides a scoring methodology in order to select and combine the most promising elements into policy options under Task 3.

3.2 Subtask 2.1: Analytical framework for comparative analysis

As was outlined in the inception report, this task entails the development of a framework for a comparative analysis, rather than a multi-criteria analysis, of existing regulations on CO₂ and fuel economy for HDVs in other world regions. This comparative analysis entails scoring the relevant attributes of the different regulatory systems against a set of criteria, using an unweighted, 5-level tick / cross system. Each international regulation is scored in a framework taking the form of a standardised table, where:

- **Columns include:** scoring criteria
- **Rows include:** elements of the measure/regulation – measurement, monitoring and enforcement, etc.

These are described in more detail in the following sub-sections.

3.2.1 Scoring criteria (columns)

The individual scoring criteria are grouped into a number of categories, which are summarised in Table 3.1. The extra-EU measures/regulations are scored first on their transferability and replicability to the EU context, in terms of their technical content, legal content and administrative effort required. Moreover, the category of ‘alignment and equity’ captures any potential first mover advantages or disadvantages to manufacturers as well as the question of whether regulatory alignment between different world regions could lead to cost savings for manufacturers. The regulations are also scored against several policy option screening criteria from the Better Regulation Guidelines (European

Commission, 2016), namely efficiency and effectiveness as well as coherence, consistency with EU principles, and the need to avoid perverse incentives.

Table 3.1: Summary of the comparative analysis scoring criteria categorisation

Criteria Category	Specific criteria
Transferability and replicability (technical)	Vehicle types
	Technologies
	Coverage of EU market
Transferability and replicability (admin/legal)	Administrative implications for the Commission
	Coherence
	Consistency with EU principles
Effectiveness	Length of time for design and implementation
	Delivering GHG reduction in line with long-term objectives
Efficiency	Avoiding perverse incentives
	Administrative costs
Alignment and equity	Cost of GHG reductions
	Implications of alignment
	Equity between manufacturers
Explicit Barriers	Impact on first movers
	Barriers to implementation

3.2.2 Elements of the international regulations (rows)

The combination of the individual elements of the extra-EU regulations are scored according to the above criteria, with a short description provided against each element, where relevant to the assessment. The focus is on the form in which the targets are defined, as well as the procedures around measurement, monitoring and enforcement. The actual stringency/ambition level of the targets is not a priority for the comparative analysis. Specifically, the following elements of each international policy are individually assessed, using a qualitative description, which feeds into the overall measure's score. These elements are based on the review categories for the individual country/region case study fiches:

- Vehicle standards.
- Engine standards.
- Test cycles used.
- Test procedure: simulation (+ component testing), dynamometer (whole vehicle) testing or 'real-world' testing (e.g. PEMS, etc.).
- Standard fuel-specific or technology neutral.
- Standard only for fuel consumption/CO₂ or further GHGs.
- Flexibility mechanisms.
- Innovation/ technology credits.
- Monitoring and enforcement.

Based on the rating of each element, an overall score for each criteria category is made using the aforementioned un-weighted, 5-level tick / cross system.

3.3 Subtask 2.2: Preliminary comparison of approaches prior to Task 1 interviews

Subtask 2.2 entailed comparing the analytical framework (as presented in Section 3.2 above) to the country fiches developed as part of Task 1. The aim was to ensure that the country fiches comprehensively capture all of the elements to allow for a meaningful comparative analysis and make additions to the fiches where needed. This subtask resulted in several revisions to the initial analytical framework such as the introduction of a consistent set of elements by which to describe each international regulation (see Section 3.2.2).

3.4 Subtask 2.3: Comparative analysis, lessons learned and benefits of alignment

This section provides the analytical framework tables for the three detailed market case studies (USA, China, Japan), Mexico and India, as well as a comparison of the different country policies. The comparison discusses any lessons learned from existing regulatory frameworks for HDVs' CO₂ emissions as well as any potential benefits that could result from future EU policies/regulations aligning with elements of one or several international regulatory frameworks.

3.4.1 Completed analytical framework for each country

In this sub-section, the completed analytical frameworks for the three detailed case studies are presented. Table 3.2 provides a summary of the key for the scoring system used, followed by the completed country frameworks provided in subsequent Table 3.3: through Table 3.6. The assessments for the United States plus Canada, California and Mexico are presented together, since they are all fundamentally based upon the US' system with some regional revisions. These country-specific revisions are also assessed towards the bottom of the table.

Table 3.2: Key for 5-level tick / cross system used in the analytical frameworks below

XX	Strongly negative effect / likely barrier to EU implementation
X	Weakly negative effect / potential barrier to EU implementation
-	No or questionable effect / typical difficulty in EU implementation
?	Unknown effect / difficulty in EU implementation
✓	Weakly positive effect / potentially suitable for EU implementation
✓✓	Strongly positive effect / likely suitable for EU implementation

Table 3.3: Analytical framework: United States plus Canada, California and Mexico

		Transferability and replicability							Effectiveness in	Efficiency	Alignment and equity			Explicit Barriers		
		Technical			Admin/legal											
		Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation	Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation
Vehicle standards	Measure	✓	✓✓	✓	-	✓	✓✓	✓	✓	✓	✓	✓✓	?	✓	✓	
	Whole Vehicle (simulation based) CO ₂ and fuel economy standards	HDV definition is equivalent to EU, however segmentation is by body type and GVWR: vocational (LHD, MHD, HHD), tractor (MHD, LHD) and HDPUs.	Includes aerodynamics, reduced rolling resistance tyres and light-weighting. Applicable to EU market. Simulation models (both GEM and VECTO) cannot yet model hybrid, electric or hydrogen powertrains.	US have more vehicle categories, and cover all of EU market by weight categories. US and EU have similar fleet compositions.	EPA certificates include before sale and ongoing testing. Administrative framework needed at EU level and for manufacturers.	Differentiated standard by vehicle/weight class, conceptually similar to EU LCV utility parameter (kerb weight)	Integrated nature of single market requires EU wide regulations on vehicle standards. Monitoring, verification and enforcement would need to be undertaken at the EU level in the same way as for the passenger car CO ₂ Regulation. Administration of any trading would bring added complexity.	Took US 7 years between the decision to create measures and implementation of Phase 1. However, EU already advanced in simulation software development.	Yes, ambitious targets set by EPA/NHTSA. Reductions given for each vehicle type - amounting to approx. 20%.	None identified and regulations into second iteration	Low cost simulation once tools are set up and data has been collected	Phase 1: Cost of \$8bn to industry, saving of \$50bn to vehicle owners, and another \$49bn to other social factors. Phase 2: Cost of \$29bn to industry, saving \$169bn in fuel, and \$88bn in social factors.	No information on export market	Vehicle categories ensure similar requirements for manufacturers of similar vehicles	As the standards are absolute figures per class, these do not adversely impact on first movers	Long timeframe for implementation
Engine Standards	Engine (dynamometer) CO ₂ and fuel economy standards	Engine dynamometer used in EU already for HDV emissions	Incentivises more efficient engines, where improvements are often expensive but cost effective.	Engine dynamometer used in EU already for HDV emissions	See above	Engine dynamometer used in EU already for HDV emissions	See above. However, separate engine standards do not incentivise whole vehicle improvements.	Can be rapidly implemented using emissions testing procedures	See above, plus separate CO ₂ standards maintains line between criteria pollutants and CO ₂	Separate engine standards limit the incentive for OEMs to tune their engines for low NO _x , high CO ₂ .	Same cycles as for emissions testing, but adds additional procedures to develop and audit	N/A	Separate engine standards aligns with current market structure	N/A	N/A	
Test cycles used	Vehicle standard: GEM-specific cycles (mild 55 mph, mild 65 mph, ARB transient) Engine standards: FTP, SET.	Veh. standard: similar VECTO-specific cycles for EU. Engine standard: similar cycles currently used in EU (ESC, ETC) for AQ testing.	N/A	Similar cycles available for EU	Engine: minimal, cycles already in use. Vehicle: VECTO still in development	Test cycles used different from EU, but analogous cycles at EU level	Consistent with EU principles	Vehicle standard: medium -- VECTO still in development.	N/A	N/A	Minimal, cycles already in use	N/A	N/A	N/A	N/A	
Dynamometer vs simulation vs 'real-world' testing	GEM simulation model for whole vehicle and SET and FTP cycles for engines	Used for all lorries/buses (not pickups/vans)	Simulation allows inclusion of new technologies in model	Simulation useful in markets with significant vehicle modification	Vehicle standard: VECTO still in development but will provide similar simulation procedure to GEM. Engine standard: similar testing procedures used for engines in EU.	Consistent with EU principles	Engine standard: minimal -- engine dynamometer cycle + testing already in use for AQ testing	N/A	N/A	Significant one-off development costs, very low testing costs vs chassis dynamometer	N/A	N/A	N/A	N/A		

		Transferability and replicability							Effectiveness in		Efficiency		Alignment and equity			Explicit Barriers
		Technical			Admin/legal				Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation
		Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation								
Standard fuel-specific or tech neutral	Separate standards for gasoline engines	Different standards for diesel and gasoline HDVs in US -- not easily transferable to EU	Not tech neutral: less stringent standards for gasoline engines	EU HDVs almost all diesel, would be well covered by US diesel standards	No issues	Incoherence on having separate CO ₂ standards for gasoline engines	Lack of technological neutrality inconsistent with EU principles	Possible within a reasonable timeframe due to prior experience	N/A	No major perverse incentives expected. Ratio is higher than difference in energy content, meaning that gasoline engines allowed to be slightly less efficient. However, diesel engines are generally more efficient than petrol engines.	N/A	N/A	N/A	N/A	N/A	
	N ₂ O and methane (0.1g/bhp-hr)	Covers vocational (LHD, MHD, HHD), tractor (MHD, LHD) and HDPUs - same minimum weight for HDV but more differentiation than EU	N/A	N/A	Methane is regulated for the EU for gas vehicles, N ₂ O may be implemented in EURO VI at a later stage	Methane is already measured in EU standards, but with weaker maximum emission levels.	Consistent with EU principles	CH ₄ already measured so shorter timeframe to implementation. N ₂ O measurement is currently in its infancy, so this may take longer.	Methane is a significant GHG and its regulation contributes to GHG reduction targets.	Avoids perverse incentives as Methane leakage relevant for natural gas vehicles	Methane already measured, so administrative costs concern the addition of N ₂ O	No costs given	N/A	N/A	N/A	
Other GHGs	Air-conditioning leakage	All vehicles in regulations	Air conditioning technologies are equivalent in the US and EU.	Assumed applicable to all EU market	Additional checks required. Refrigerant regulations are separate from vehicle regulations in the EU.	N/A	Consistent with EU principles	Possible within a reasonable timeframe due to prior experience	Air-conditioning leakage has high GHG potential, so in line with objectives	N/A	Low administrative costs	No information	N/A	N/A	N/A	
Flexibility mechanisms	ABT provisions	Covers vocational (LHD, MHD, HHD), tractor (MHD, LHD) and HDPUs - same weight starting point for HDV but more differentiation than EU	Complete coverage, if all technologies which offer real-world improvements are awarded credits.	Complete coverage	Creating and running administrative framework to manage ABT	Credit systems already used in LDV regulations.	Consistent with EU principles	Administrative implementation may not be trivial.	Allows flexible development cycles and investment timings, helping OEMs to justify the development of more efficient vehicles.	Allows manufacturers to phase in improvements over full range of products.	No information, administrative costs could vary depending on how the scheme is run. Overall, likely to be cost-effective.	N/A	N/A	ABT system only allows trading within vehicle category - prevents trading overachieving HHD for advantage in L/MHD. Allows improvements to fit duty cycle.	First movers can offset gains in one area against deficit in another	Implementation of EU-wide administrative framework could be time consuming and expensive
Innovation/tech credits	Early credits	All, including alternative powertrains	Receive x1.5 multiplier in ABT scheme to incentivise early adoption.	Complete coverage	See above	N/A	Consistent with EU principles	Could be difficult to determine level of early adoption credits as not to negatively disrupt the market.	Encourages OEMs and suppliers to develop more efficient vehicles and technologies sooner, yielding a more swift CO ₂ reduction.	Level of credits given will need to be well balanced.	No information	N/A	Promotes development of similar technologies between the US and EU, after accounting for different duty cycles	Provides incentive to manufacturers who take action early or develop new technologies.	Provides incentive to OEMs who take action early	

		Transferability and replicability							Effectiveness in		Efficiency		Alignment and equity			Explicit Barriers
		Technical			Admin/legal				Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation
		Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation								
	Advanced tech credits	All, including alternative powertrains	Encourages adoption of new technology by providing a credit multiplier x1.5 for the ABT scheme. Advanced technology credits suitable for EU fleet technologies.	Complete coverage	See above	N/A	Consistent with EU principles	Could be difficult to determine level of credits for innovative technologies as not to disrupt the market.	Incentivises innovative technologies and thus helps OEMs to justify development of more efficient vehicles. Prevents technology stagnation.	Level of credits given will need to be well balanced.	No information	N/A	N/A	Credits here can be traded in any averaging set - potential to give competitive advantage with different vehicle categories	Provides incentive to manufacturers who adopt advanced tech	
Monitoring and enforcement	EPA and NHTSA certification and enforcement	All vehicles in regulations	N/A	Complete coverage	Requires a governing body to monitor and certify compliance, and enforce through penalties.	Monitoring uses same methods as existing emissions standards. Certificates already provided for LDVs - adapt to HDV	Consistent with EU principles	Synonymous with existing EU enforcement practices; not a limiting factor	N/A	Penalties given based on manufacturers' end of year emissions. Enforces non-compliance effectively	Neutral. Certificates required for all sales must be collected.	N/A	N/A	N/A	N/A	
Canada-specific standards	Measure	✓	✓✓	✓	-	✓	✓✓	-	✓	✓	-	✓	-	✓	-	
	Certification for HDVs over 80,000lbs up to 140,000lbs	HDVs >80,000lbs are common to Europe, especially if the Weight and Dimensions Directive is relaxed	See above	Covers all EU lorry sizes	Not a significant addition to the above regulations	Ensures all vehicle sizes are regulated	Consistent with EU principles	See above	Ensures all vehicle sizes are regulated	Reduces likelihood for potential distortions due to larger vehicles	See above	See above	N/A	Ensures all vehicle sizes are regulated	N/A	
California-specific standards	Measure	✗	✓	-	-	✓	✓	-	✓	-	?	✓	?	?	?	
	Mandatory SmartWay technologies	SmartWay is for tractors with trailers 53ft or longer. This is uncommon in EU and would have smaller GHG reductions when applied to smaller trailers	Aerodynamics, LRR tyres. Applicable to longer trailers and longer journeys	Max. EU vehicle length is 61.5ft but some MS allow longer vehicles to operate nationally. However, max. trailer length is 40 ft.	Further administrative setup required to monitor trailers	EU currently allows derogation of longer vehicles provided they have aerodynamic technologies	Not technology neutral, but otherwise consistent with subsidiarity and proportionality	Took CARB 3 years between inception and implementation.	Provides further reductions beyond Phase 1 regulations	N/A	No breakdown of total costs	\$10bn costs for \$14bn fuel savings	N/A	N/A	N/A	
	HVIP (vouchers for hybrid vehicles)	Lorries and buses - new sales with eligible technologies	Battery-electric, fuel cell, hybrid, electric PTO, ultra-low-NOx natural gas engines. Also available in EU.	Do all vehicle categories have these technology options?	Minimal administration - voucher given at point of sale	EU currently allows derogation of longer vehicles provided they have aerodynamic technologies	Not technology neutral, but otherwise consistent with subsidiarity and proportionality	No information	Provides further reductions beyond Phase 1 regulations. Estimated 0.5 MMt of CO _{2e} by 2020	N/A	No breakdown of total costs	No costs given	N/A	N/A	N/A	
	Measure	✓	✓✓	✓	-	✓	✓✓	✓	✓	✓	✓	✓✓	?	✓	✓	

	Transferability and replicability							Effectiveness in	Efficiency	Alignment and equity			Explicit Barriers		
	Technical			Admin/legal											
	Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation	Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation
Expected to align with US Phase 2 but with a later phase in date	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Harmonised NA standards	N/A	N/A	

Table 3.4: Analytical framework: China

		Transferability and replicability						Effectiveness in			Efficiency		Alignment and equity			Explicit Barriers
		Technical		Admin/legal				Length of time for design and implementation	Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation
		Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles									
	Measure	✓	-	✓	✗	-	-	-	-	-	?	✗	?	-	-	
Vehicle standards	Separate FC (l/100km) standard for different GVW categories	Covers most major vehicle types, weight classes	Does not target particular technologies; chassis dynamometer testing incentivises engine efficiency, aerodynamics and rolling resistance. No incentive for weight reduction as testing performed at GVW.	Covers all major vehicle types, weight classes	Whole vehicle chassis dynamometer testing not common in EU for HDVs	Differentiated standard by vehicle/weight class, conceptually similar to EU LCV utility parameter (kerb weight)	Generally consistent, proportionate if burden evenly split by weight category	Potentially lengthy process as a different standard is set for each weight category	Targets maximum fuel consumption, might not be effective at reducing average fuel consumption, unless average is close to maximum. Stage III (effective from 2019-2021) delivers 21.7% to 27.2% reduction over Stage I (effective from 2012-2014) standards.	No obvious perverse incentives. Uneven target stringencies between weight classes could incentivise manufacturers to move to a higher GVW class to face lower compliance costs.	Depends on number of base models, potentially lots of vehicle testing required	Effectively a minimum standard which vehicle configurations with highest fuel consumption have to meet. No averaging/flexibility to ensure efficient performance across all lorries sold.	Little info on export markets -- no major impacts expected	OK as long as the fuel standard for each weight category is equivalent in terms of the improvements required	No separate incentives for first movers. No penalisation of first movers through distinct baselines etc.	
Engine Standards	no separate engine standard	N/A	Allows OEMs to meet standards flexibly. On the other hand, does not incentivise engine improvements which are often expensive but cost-effective.	N/A	N/A	N/A	Focuses on real-world, whole vehicle improvements (if gaming strategies are not employed). Minimises regulatory burden.	N/A	N/A	Lack of separate engine standards could facilitate gaming: tuning engines for low NOx, over engine cycles, low CO2 over vehicle cycles.	Reduced cost in comparison to separate engine standards.	N/A	Could slow R&D in engines, reducing IP advantages internationally	N/A	N/A	
Test cycles used	WHVC test cycle adapted to local conditions (reflecting different urban-rural split and lower presumed power-to-weight ratio)	Test cycle used is adapted to suit Chinese market, diverging from typical drive cycles experienced by EU vehicle types. In principle, however, the cycle can fit EU vehicle types given it was originally made for them.	N/A	Test cycles used different from EU, but analogous cycles at EU level. Could apply broadly across EU market	N/A	Test cycles used different from EU, but analogous cycles at EU level	Consistent with EU principles	N/A	Test cycle adapted to local conditions - probably effective	Test cycle relevant to local conditions -- no obvious perverse incentives	Not clear	Test cycle relevant to local conditions good for keeping costs low	N/A	N/A	N/A	
Dynamometer vs simulation vs 'real-world' testing	Dynamometer testing for base model, simulations for variants; consistent criteria for base and variants	Principle transferable and replicable, potential need for adjustments in detail	Principle transferable and replicable, potential need for adjustments in detail	Principle transferable and replicable, potential need for adjustments in detail	Current base model definition may need revising for EU -- potentially difficult discussions with OEMs on appropriate definition	Different from existing emission testing procedures	N/A	Current base model definition may need revising for EU -- potentially difficult discussions with OEMs on appropriate definition	Procedure should generally be effective	Procedure should generally be robust against perverse incentives	Compromise between accuracy and administrative cost of testing 1,000s of different vehicle types. Engine dynamometer testing plus simulation modelling probably cheaper but less accurate in some circumstances.	N/A	Current base model definition could have unequal impact on OEMs depending on the heaviest, most powerful models in their range.	N/A	Chinese base model definition (the model with the highest GVW, tire friction, air resistance, most powerful engine, etc.) may lead to niche models being defined as base models when applied in the EU.	

		Transferability and replicability						Effectiveness in			Efficiency		Alignment and equity			Explicit Barriers
		Technical		Admin/legal				Length of time for design and implementation	Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation
		Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles									
Standard fuel-specific or tech neutral	Fuel specific: Fixed ratio of gasoline to diesel consumption standard (1.3 in Stage I; 1.2 in Stage II)	Doesn't seem to cover alternative fuels, but diesel by far most important	More generous towards gasoline engines vs diesel, [Diesel has ~1.1x higher energy content per litre] reflecting the current state of technology; diesel engines tend to be more efficient]	Doesn't seem to cover alternative fuels, but Diesel by far most important	N/A	N/A	Lack of technological neutrality inconsistent with EU principles	N/A	Gasoline engines are effectively allowed higher CO ₂ emissions. However, there may be other reasons for making emission targets less stringent (e.g. AQ considerations)	No major perverse incentives expected. Ratio is higher than difference in energy content, meaning that gasoline engines allowed to be slightly less efficient. However, diesel engines are generally more efficient than petrol engines.	Not clear	No alternative fuels covered, this could lead to omission of lower cost solutions but impact probably marginal	N/A	N/A	N/A	
	Other GHGs	no other GHGs covered	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	Flexibility mechanisms	no flexibility mechanisms	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No flex mechanism -> higher GHG reduction cost	N/A	N/A	N/A	
	Innovation/ tech credits	no credits	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No credits, fewer first mover incentives	
	Monitoring and enforcement		N/A	N/A	N/A	No major admin burden. Inspection of labs providing type approval every year; random conformity of production testing. No procedure for in-use conformity.	N/A	N/A	Straightforward, probably uncontentious procedures	Monitoring: Absence of in-use conformity testing could compromise effectiveness in practice. However, potential for increase in air pollutant emissions over time much more significant than fuel consumption. Enforcement: uncertain whether fines around production conformity can be imposed -- could compromise effectiveness.	N/A	No major costs expected due to limited extent of monitoring and enforcement	N/A	N/A	N/A	

Table 3.5: Analytical framework: Japan

		Transferability and replicability							Effectiveness in		Efficiency		Alignment and equity			Explicit Barriers	
		Technical			Admin/legal				Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation	
		Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation									
Vehicle standards	Measure	✓	-	✓	-	✓	-	-	-	✓	?	?	✓	✓			
	Vehicle fuel efficiency (km/L) for various weight categories and vehicle types	Covers all diesel fuelled HDVs over 3.5t. No regulations for gasoline HDVs, although not a major segment of the fleet	No set tech pathway. Uses standard values for aerodynamics and tyres, disincentivising improvements in this area	Coverage of EU market	Requires engine mapping test procedure as input to simulation. No ongoing enforcement required.	Separate weight categories similar to LDV emissions framework that allows heavier vehicles to have different standards	Fuel economy standard specific to Diesel vehicles. No wider GHG standard. Thus not tech neutral Proportionate if burden evenly split by weight category	Shorter length of time for design and implementation, but potentially longer timeframe for results (9 years)	Depends on the ambitiousness of the targets set. In general, targets are set under the assumption of modest, gradual technical improvements to the 'top runner' product, which would not guarantee compatibility with GHG targets	'Top runner approach': Potential perverse incentive to not bring new tech to the market as it could then become new standard.	Probably limited	No data - wait for stakeholder interview	Little info on export markets -- no major impacts expected	By using Top Runner models for each vehicle category, improvements should be proportionate	Tax breaks available for early compliance with standards, subsidies for CNG, hybrid vehicles (though CNG not covered by standard)		
	Engine Standards	No separate engine standard	N/A	Allows OEMs to flexibly meet standards. No specific incentive for engine improvements	N/A	N/A	N/A	N/A	N/A	Focuses on real-world, whole vehicle improvements (if gaming strategies are not employed). Minimises regulatory burden	N/A	Could facilitate gaming: tuning engines for low NO _x over engine cycles, low CO ₂ over vehicle cycles	Reduced cost in comparison to separate engine standards	N/A	Could slow R&D in engines, reducing IP advantages internationally	N/A	N/A
	Test cycles used	JE05 and Interurban Drive Mode cycles	Test cycles used different from EU. The cycles and weighting by type & GVW could be replicated for EU HDVs, though the interurban drive cycle speed and gradients are not suitably representative.	N/A	Test cycles used different from EU, but are suitable for covering all of the HDV market	N/A	Test cycles used different from EU, but analogous cycles at EU level	Consistent with EU principles	N/A	N/A	N/A	Minimal, cycles already in use	N/A	N/A	N/A	N/A	
	Dynamometer vs simulation vs 'real-world' testing	Dynamometer engine fuel maps used in vehicle simulation	Transferable, US Phase 2 will be using fuel map input also	Engine dynamometer already in use. Simulation being developed	Transferable, US Phase 2 will be using fuel map input also	Development of VECTO and input of fuel map data from manufacturers	Coherent with engine dynamometer testing for emissions	Consistent with EU principles	VECTO already being developed and engine dynamometer tests already used	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	Standard fuel-specific or tech neutral	Diesel standards	Covers the majority of EU lorries, but not gasoline or AFVs	No incentive to improve non-diesel vehicles	Does not cover gasoline/AFV HDVs, though these are limited in number	Further cost to develop separate standards	N/A	Not wholly consistent due to lack of coverage of gasoline/AFV HDVs	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

		Transferability and replicability							Effectiveness in		Efficiency		Alignment and equity			Explicit Barriers
		Technical			Admin/legal				Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation
		Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation								
Other GHGs	Only concerns fuel efficiency	Neglects AFVs which use fuels of different energy content	N/A	N/A	N/A	N/A	Focus on CO2 rather than GHGs	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Flexibility mechanisms	Use of corporate average fuel efficiency	All vehicles in scope	Flexible application of tech		Less complicated than US flexibility mechanisms - less admin	N/A	N/A	N/A	N/A	Allows averaging over corporate fleet	N/A	N/A	N/A	Allows averaging over corporate fleet	N/A	
Innovation/ tech credits	Subsidies for AFVs, tax breaks for early compliance with FE regulations.	All vehicles in scope	N/A	N/A	Further admin costs	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Incentivises meeting standards before deadline	
Monitoring and enforcement	METI and MLIT monitoring and enforcement	All vehicles in scope	N/A	N/A	Manufacturers submit CAFE for review. Enforcement significantly less burdensome than US equivalent	Very different enforcement structure from other EU programmes	N/A	Easy to implement and only one MY standard to meet	Effectiveness a result of enforcement method which may not be applicable to EU	N/A	No data but expect minimal costs due to "loose restrictions"	N/A	N/A	N/A	N/A	Highly dependent on Japanese culture – unlikely to provide similar incentive to meet the standards in the EU.

Table 3.6: Analytical framework: India

		Transferability and replicability							Effectiveness in		Efficiency		Alignment and equity			Explicit Barriers
		Technical			Admin/legal				Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment	Equity between manufacturers	Impact on first movers	Barriers to implementation
		Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation								
Vehicle standards	Measure	XX	X	XX	-	X	-	✓	-	-	-	?	?	?	?	
	Proposed constant speed fuel consumption (CSFC)	Vehicle types significantly different from EU fleet	Low constant speed, so weight, aerodynamic and transmission improvements unlikely to be incentivised	Method largely unsuitable for EU market - very different speeds; unlikely to be representative of real-world CO ₂ emissions	Unknown	Not coherent with existing test procedures	Generally consistent, proportionate if burden evenly split by weight category	India to implement in 2017 - short timeframe	CSFC is interim measure but still expected to deliver some real-world improvements	Unrepresentative testing conditions create incentive to optimise for test, not real world	Test track standards would entail higher costs than engine testing	Unknown	No impact - most Indian lorries are made domestically	Unknown	Unknown	Non-representative of real-world emissions
Test cycles used	40 and 60 km/hr (CSFC); track testing	Does not cover typical speeds of large HDVs.	N/A	Too slow for EU market; does not cover typical speeds of large HDVs.	N/A	Not coherent with existing test procedures	N/A	N/A	N/A	Unrepresentative testing conditions create incentive to optimise for test, not real world	Requires large investments to adopt in EU	N/A	N/A	N/A	N/A	Not suitably representative, even if EU HDV characteristics are taken into account.
	Stationary and transient (Bharat)	Two cycles similar to EU	N/A	N/A	Minimal, cycles already in use in EU	Fairly coherent; separates vehicles performing different duties	Consistent with EU principles	N/A	N/A	N/A	Minimal, cycles already in use	N/A	N/A	N/A	N/A	
Dynamometer vs simulation vs 'real-world' testing	CSFC and future simulation plans	CSFC expected to largely differ from real-world conditions	No CSFC testing in EU	N/A	N/A	Not coherent with existing test procedures	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Track testing is prohibitively expensive
Standard fuel-specific or tech neutral	No information	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Other GHGs	No information	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Flexibility mechanisms	No information	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Monitoring and enforcement	No information	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

3.4.2 Comparison of extra-EU policies and lessons learned

Table 3.7: Results overview of the comparative analysis

	Transferability and replicability							Effectiveness in	Efficiency	Alignment and equity				
	Technical			Admin/legal						Delivering GHG reduction in line with long-term objectives	Avoiding perverse incentives	Administrative costs	Cost of GHG reductions	Implications of alignment
Vehicle types	Technologies	Coverage of EU market	Administrative implications for the Commission	Coherence	Consistency with EU principles	Length of time for design and implementation								
USA	✓	✓✓	✓	-	✓	✓✓	✓	✓	✓	✓	✓✓	?	✓	✓
China	✓	-	✓	✗	-	-	-	-	-	?	✗	?	-	-
Japan	✓	-	✓	-	✓	-	-	-	-	✓	?	?	✓	✓
India	✗✗	✗	✗✗	-	✗	-	✓	-	-	-	?	?	?	?

Except for India, none of the reviewed standards suggest any particular issues regarding vehicle types covered; definitions of a heavy-duty vehicle tend to be fairly consistent across most countries. Notably, Japan, India and to a lesser extent China have very different HDV fleet compositions to North America and the EU. Typically, average HDVs are lighter in the case of Japan and China, and significantly lighter and using much smaller/less powerful engines in the case of India, than other markets.

Regarding the testing procedures, there are significant differences. India appears likely to temporarily implement constant speed fuel consumption testing before there is an established EU standard (e.g. VECTO-based) which India can follow. This form of constant speed measurement on a test track is fairly unrepresentative of real-world driving and would also be fairly costly to implement at EU-level. In China, whole-vehicle dynamometer testing of base model vehicle fuel consumption is required (with simulation used for variants). The base model is defined in a way that generally makes it the least favourable in terms of its fuel consumption within a model family. There is a defined fuel consumption standard (in l/100km) for each vehicle type and GVW category. Producing a vehicle for which fuel consumption exceeds this standard is prohibited. In this sense, the standard is effectively an upper limit on fuel consumption performance of the worst-performing vehicle in each GVW category of a given manufacturer, which might bear little resemblance with the average vehicle’s fuel consumption, and reduces the flexibility of manufacturers to offer in some circumstances vehicles that exceed the standard (for example to meet special customer requirements). In addition, the approach taken is unlikely to incentivise the early adoption of more advanced technologies, since there is no obvious benefit (i.e. more efficient vehicles cannot be traded off against less efficient ones). This approach, while conceivable at EU level, is likely to compromise the efficiency of the standard. Moreover, depending on the number of base models, testing requirements might be extensive.

In Japan, fuel efficiency limits in terms of km/l are set for each vehicle type and GVW category, similarly to China. However, fuel consumption is determined by a combination of engine dynamometer testing and whole vehicle simulation, where engine performance parameters are fed into the simulation.

The US take a very similar testing approach, which is documented in much greater detail than the Chinese and Japanese procedures. In the US approach, engine manufacturers are required for their engines to meet standards over an engine dynamometer cycle. In Phase 2, they are also required (as in Japan) to feed their engine map into the GEM simulation tool for whole vehicle testing, while in Phase 1 a standard engine map was used. The weight parameters of vehicles in the simulation continue to be standardised, i.e. all vehicles of a given class/category are assumed to weigh the same. However, standardised weight reduction allowances can be made for use of lightweight parts, such as alloy wheels or composite body parts. This high level of standardisation helps manage the amount of input parameters required (especially as lorries tend to be customised, so kerb weights vary almost between every unit) and thus disincentivises gaming. In Phase 2, new trailers are also required to meet fuel economy standards, simulated on a standardised tractor unit.

Both the US and Japan allow for manufacturers to **average fuel efficiency over the fleet** (at least within a vehicle category), providing manufacturers with a level of flexibility in meeting standards.

However, the US targets are specified in terms of payload in the case of goods vehicles, i.e. in grams per tonne mile for GHG emissions or gallons per tonne mile for fuel consumption. This accounting procedure is in effect not very different from the whole vehicle approach but has the advantage of capturing the direct benefits of increased payload through weight reduction.⁴⁸

Complementary policies in the US and Japan incentivise early adoption of standards; however, such provisions do not appear to exist in China. In the US, the incentive for early adoption takes the form of a multiplier, so such vehicles count more than they otherwise would in the determination of compliance, while in Japan the incentive takes the form of a tax break for vehicles that are compliant before the deadline. The use of specified technologies is also incentivised in the US and California. The US incentive again takes the form of a multiplier, while in California there are vouchers to encourage the adoption of advanced alternative powertrains (e.g. hybrid and electric powertrains).

In terms of delivering GHG reductions in line with long-term standards, the Japanese top runner approach may have some disadvantages in practice. Although the targets are based on an improvement upon the top runner vehicle, the process for determining the level of reduction appears to be less analytical than in the US and presumes gradual technological improvements. It does not appear to be directly tied to cost-effective technological potential and market uptake analysis. In contrast, US authorities develop targets based on cost-benefit criteria which should, in principle, take into account wider national GHG reduction targets.

The US system is the only one that covers other greenhouse gases, such as N₂O and methane, as well as air-conditioning leakage. Methane is already regulated in the EU for gas vehicles, but the standards in the US legislation are more stringent. In both the US and Japan, there are flexibility mechanisms to help with compliance, although in Japan these are limited to averaging over a company's fleet. The US system allows for averaging, banking and trading, so manufacturers are allowed to spread emissions reductions over their fleets, bank over-compliance for future years or trade these with manufacturers who are not in compliance. Such a system brings more administrative complexity in order to keep track of the operation of the flexibilities and to ensure that the target is still achieved.

All of the comparisons had limited information on the implications of alignment. Any such implications would largely be based on manufacturers being able to trade with countries with aligned standards, however no information has been given on the international lorry or component market between the countries.

The US test procedures are designed so as to limit the amount of testing required, while still being fairly comprehensive in the fuel consumption assessment techniques it takes into account. From the comparative analysis, it appears that the US standards are the most adaptable to the EU context in terms of administrative implications, time required for implementation (given that engine testing procedures already exist as part of the EURO emission standards and the VECTO simulation tool is at an advanced development stage) and efficiency in ensuring the standard incentivises cost-effective strategies that lead to reduced CO₂ emissions in the real world.

⁴⁸ Given the observation that roughly 1/3 of transports are weight-limited, one-third of the weight reduction is added to the 'test' payload, while the other two thirds are simply deducted from the vehicle's 'test'-weight.

4 Task 3: Options for the EU

Box 3: Key points for Task 3

Task outline:

1. Task 3.1: Review of the VECTO tool and information relating to the forthcoming regulation on certification.
2. Task 3.2: Development of a short list of potential HDV GHG/efficiency options for the EU, based on the results of the analysis of sub-tasks 2.3 and 3.1

Key outputs:

- A review of the VECTO tool and information relating to the forthcoming regulation on certification (see Appendix A1).
- A shortlist of potential HDV GHG/efficiency options for the EU, with detailed characterisation including an assessment of the pros and cons and high level costs and benefits of each option.

4.1 Task 3 methodology

Task 3 was comprised of the following two subtasks:

- Subtask 3.1: Review of the VECTO tool and information relating to the forthcoming regulation on certification.
- Subtask 3.2: Develop a shortlist of possible options for the EU.

The review of the VECTO tool resulted in the production of Appendix A1, which highlights the status and current capabilities of the European HDV simulation tool. This appendix will assist the review of policy options by providing information to assess the compatibility of the option with existing EU material.

The main activity in Task 3 concerned the development of policy options for the EU. In total, four detailed policy options for HDV efficiency measures for the EU were developed, guided by Impact Assessment tools contained within the Commission's Better Regulation toolbox (European Commission, 2016). An outline is provided in the following subsections on the methodological process followed for this activity.

4.1.1 Selection of policy options

The policy options were developed through consideration of:

- **The need to incorporate different levels of policy intervention, including soft approaches, in order to show the added value of any interventions.** In accordance with the Commission's Better Regulation Guidelines (European Commission, 2015), this study has sought to consider instruments of regulatory and non-regulatory means. This allows an understanding to be developed for the comparative impacts of non-legislative intervention as compared to packages that include regulatory components.
- **Application of legislative approaches that are used internationally:** in order to incorporate different approaches to the current regulatory approach used in Europe. Analysis of alternative regulatory approaches that mimic the legislation in key competitor countries (i.e. the USA and Japan) will provide insights into whether these alternative approaches would be more or less beneficial to the European market compared with amendments to the existing legislation or BAU.

4.1.2 Process for construction of measures sourced from international policy approaches

It was recognised that existing international policy options are neither inherently transferable nor replicable to the unique European market situation, as demonstrated in the comparative analysis. As such, new combinations of the most promising elements and measures from various markets analysed in the preceding task were constructed as options for the EU. These could be near-complete implementations of currently used measures, partial implementations of current measures with slight modifications, or entirely new measures constructed of elements from various markets. These options are being developed using a selection process consisting of six steps:

1. Select the most relevant markets where HDV efficiency standards are in place.
2. Verify the overall scoring performed in Task 2.
3. Identify specific elements which perform poorly in any criteria within the analytical framework, paying particular attention to the transferability / replicability category.
4. Replace these elements with feasible, better performing elements from other programmes (including those from markets not identified in Step 1).
5. Evaluate the compatibility of each programme element with the existing EU policy framework, such as VECTO, and identify those which are likely to be incompatible. (*Note: this is not necessarily a basis for exclusion.*)
6. Select feasible programmes as policy options for a high-level assessment.

4.1.3 Policy option case study format

For each of these four shortlisted policy options a case study for its fictive implementation is being developed and written up, which will consider the following:

- **Design**
Loosely following the categories within the market fiches in Task 1, the team is reviewing the suitability of the option's design for the EU.
- **Timeline, feasibility and practicalities**
Taking into account the time needed for the EU decision process, such as lead in time, phased deployments and the need for any additional legislative powers.
- **Advantages and disadvantages**
A preliminary assessment of pros and cons of each element will be performed, categorised where possible by each stakeholder.
- **Lessons learned and best practice**
Best practice relating to the elements used in the fictional measure are restated as part of the case study.
- **High-level impact assessment**
A high-level qualitative assessment of the option costs and benefits has been performed, under typical impact assessment headings.

4.2 International standards considered

4.2.1 International approaches: determination of the most relevant markets

In this early stage of assessing the mechanisms by which CO₂ from HDVs can be best reduced, it is imperative that the widest possible range of policy alternatives are considered so that a globally-optimal solution is reached. As such, the international markets used as a 'baseline' for the development of international policy element combinations (Step 1 of the selection process) have two principal objectives: to be relevant to the EU market and to be suitably diverse as to be able to qualitatively differentiate their impacts. Following the comparative analysis in Task 2 it was decided that US and

Japanese markets best satisfied these criteria and would act as a baseline on which to continue the measure construction process, hence options 3 and 4 are based on measures used in the US and Japanese markets, respectively. The following sections explain the rationale for including or excluding each market's measure from forming the basis of an option.

4.2.1.1 United States

From the comparative analysis summary in Section 3, the US approach seems to align most readily to the EU market. Setting standards on a CAFE basis gives a wide flexibility for HDV manufacturers and ensures that any European-level ambition is more likely to be achieved. As described in Section 3.4.2, the US test procedures are comprehensive but not unnecessarily extensive or burdensome to manufacturers. Whilst the typical duty cycles are not wholly equivalent, the fuel efficiency technologies used in both regions are comparable and the US procedures are capable of assessing these well. Further, the costs of GHG reductions in the US measures are reasonable. As such, the US approach to regulation could be a good choice on which to base an option for the EU, subject to suitable amendments for regional differences.

4.2.1.2 Japan

Japan's top runner approach has the advantage of ensuring that targets are correlated with progress made by the top-performers in the market. Further, the approach does not contradict the European legal system, but would require new legislation.

Conversely, the method requires regulators to collect a significant amount of data from manufacturers, which takes a considerable amount of time. Though manufacturers value the marketability of achieving a 'top runner' vehicle, and so are incentivised to produce efficient vehicles, it is not clear whether it gives an equal or greater motivation to develop novel technologies in comparison to the US HDV or EU LDV approach in the technological areas covered by the regulation⁴⁹. Given that limits are set based upon existing technological capabilities in the marketplace, the breadth of technologies incentivised could be lower under this approach than a US-style standard, though if used in the EU it is likely that this would be countered through increasing the stringency of the limit over the top runner performance (using typical EU limit setting processes, i.e. through assessment of upcoming technology cost and performance). Enforcement of the top runner approach is also more difficult as regulators are unable to take small production samples, but rather must test many vehicles. The success of Japan's enforcement process is unique to the region's deeply engrained culture, enabling the 'naming and shaming' punishment for non-compliance to be particularly effective.

The disadvantages were not determined to be sufficient to discard the measure, hence a measure based upon the top runner standard was maintained.

4.2.1.3 China

China's approach to HDV fuel efficiency improvement is tied to market progress as the standards are set by understanding the current fleet's ability to meet the standard, ensuring that limits are set at attainable levels. China's pairing of chassis dynamometer results with simulation has the potential to provide more confidence in the reliability of the test procedure result, depending on a number of factors including the representativeness of the drive cycle. The process of measurement and simulation is compatible with the EU's legislative framework, though the decision on any limits would require increased transparency.

There are several disadvantages with the Chinese system, however. Principally, selection of the worst-performing models for chassis dynamometer testing is not necessarily reflective of the actual fleet characteristics, and raises concerns regarding the number of tests to be performed if many vehicles qualify as base vehicles. Even if this selection process was replaced, Europe has very few dynamometers capable of measuring HDVs and thus the costs of setting up the required facilities for the extensive testing would be substantial.

⁴⁹ It could be argued that Japan's prominent development of hybrid and electric HDV powertrains provides evidence against this, however Japan experiences other domestic stimuli such as urbanisation and increasingly stop-start duty cycles which play a large role in this development.

As the technological improvements are tied to the current fleet and are on a vehicle-by-vehicle basis (thus no flexible credit schemes are offered) the incentive to innovate by developing new technologies is limited. Innovation is further discouraged by the limit-setting process, which effectively sets an upper bound on the emissions from the worst performing vehicle in the product range (see Section 3.4.2). In the absence of the setting of appropriate exemptions/flexibilities within a given mass band, e.g. for certain vocational vehicles with naturally higher fuel consumption compared to equivalent freight versions, the approach will also either disfavour certain vehicle segments or be overly lenient on those more able to achieve the maximum limit value. A credit-based system could potentially confront these intrinsic flaws, however this adds additional complexity, especially given the simple pass/fail result at the time of testing.

Whilst the test procedure results could be more reliable from the chassis dynamometer's excellent test-to-test repeatability, it is not necessarily any more representative than engine dynamometer testing with simulation and will rely heavily on the choice of drive cycle for test and real-world disparity. Further, vehicle-by-vehicle chassis dynamometer testing is extremely expensive for both manufacturers and regulators.

Overall, China's worst-performer improvement approach is considered to be unsuitable for the EU, and has thus been discarded from this study. This decision was made due to the large differences between the EU HDV fleet and Chinese fleet. The EU fleet is more technologically advanced, requiring different and stronger incentives for innovation than are provided from the Chinese approach. Other differences that were considered likely to be unsuitable for EU adoption are in relation to certain vocational vehicle segments, and the intense financial burden it places on both manufacturers and regulators.

4.2.1.4 India

India is in the process of adopting a simplified approach to HDV CO₂ regulation. The standards are yet to be published by the Petroleum Conservation Research Association, but are thought to comprise of a constant speed fuel consumption (CSFC)-based test as an interim solution prior to the introduction of a full vehicle simulation tool (Autocar Professional, 2016). The latter is expected to be based on European policies, once in place. The interim solution of CSFC testing is already used in the vehicle certification process on a subset of HDVs in India. Fuel consumption is tested on a test track at constant speeds of 40 and 60 km/h (ICCT, 2015b).

The study team considered this approach to be unsuitable for the EU, primarily due to its unrepresentativeness. Constant speed testing covers only one single engine speed-load combination and is therefore not representative of the significant transience in engine speeds and loads encountered in most real-world operation. Moreover, requiring test-track-based testing of the large number of different vehicle models would be expensive, while test-to-test replicability of results tends to be poor. The Indian approach was thus discarded.

4.2.1.5 International approaches taken forward

In light of these observations on the core framework of each market's measure, it was decided that the US' approach and Japan's top-runner approach would be taken forward for modification as base options for the EU (Step 1 of the option construction procedure given in Section 4.1.2). India's simplistic standards are too unrepresentative for the EU context and so are discarded from this study. China's worst-performer improvement approach is considered to be unsuitable for the EU due to its fundamental lack of incentive for innovation, likely problems in relation to certain vocational vehicle segments, and the intense financial burden it places on both manufacturers and regulators.

A possible secondary benefit of selecting the Japanese market on which to base a measure is the potential for a greater degree of market harmonisation, given Japan's adoption of the World Harmonised Transient Cycle (WHTC) in 2016 which is also used for the European HDV market to assess noxious emission compliance. Although European and Japanese HDVs have different operational duty cycles, road conditions and infrastructure, utilising common testing procedures in this area to characterise vehicles from both markets could theoretically provide benefits for both markets. The benefits might include allowing regulators to better compare vehicles in different markets and a significant reduction in OEM development costs during certification, development and integration of technologies and calibration. If the benefits of harmonisation also exist for HDV CO₂ policy between the two markets then

it may be important to explore this further. However, adopting a more simplistic approach (in terms of test-cycles) may not be optimal in terms of providing information that is useful for vehicle purchasers/operators to cover a range of different real-world duty applications, i.e. the different cycles that have been developed in Europe for this purpose.

4.3 Policy options

The shortlist of options was created through discussions regarding the various possible options within the project team, and are summarised in Table 4.1, below. These were developed also in consideration of a review of the findings and recommendations in previous studies, in particular: (ICCT, 2015), (Transport & Mobility Leuven, 2014) and (Ricardo-AEA, 2011). Responses to the recent public consultation on monitoring and reporting of HDV CO₂ emissions were also analysed and taken into account (European Commission, 2016). Further details of the measures included in each policy option are given in the following sections.

Table 4.1: Policy options to be considered for the EU in this study

# Option	Role of European Commission	Principal action level	Alt. policy instrument?
1 Business as usual	Monitoring; non-regulatory	None	No
2 Technology performance requirements and soft measures	Partial regulation; market assistance	National / EU	Yes
3 International approach 1	Full regulation	EU	Yes
4 International approach 2	Full regulation	EU	Yes

4.4 Business as usual

4.4.1 Summary

This option assesses the expected trajectory of the fleet in the absence of European HDV CO₂ measures, taking into account existing policy action and organic improvements.

4.4.2 Timeline

As no additional action is taken, the timeline for the BAU scenario is ongoing.

4.4.3 Design

European heavy duty vehicle manufacturers have historically responded well to market demand for increased vehicle fuel efficiency, stemming from relatively high fuel prices in Europe compared to other world regions. Market demand for fuel (and thus operating cost) savings tends to drive incremental improvements in HDV fuel economy over time, even in the absence of regulatory measures. It is hence important to compare expected improvements from any of the proposed regulatory packages described in the following sections against a business-as-usual (BAU) trajectory in order to gauge the measures' relative effectiveness.

The BAU trajectory will consider the rate of CO₂ improvements achieved in the European fleet in recent years. Moreover, it will take into account the ongoing implementation of, and changes to, complementary measures which result in the reduction of heavy duty vehicle CO₂ emissions. These include upcoming regulations on certification and monitoring and reporting of heavy duty vehicle fuel

consumption and CO₂ emissions⁵⁰ (which does not include any mandatory improvements to these elements). This is likely to become a requirement for HDV categories⁵¹ 4, 5, 9 and 10 in 2019 – the categories we are predominately considering in this study – with other categories (including buses) following in later years. Although the BAU trajectory does not consider mandatory improvements, the certification and monitoring requirements will provide increased transparency and more information for prospective buyers and regulators on the efficiency of the vehicles. This will enable consumers to make more informed procurement decisions and, with fuel efficiency at the forefront of market preference, is likely to incentivise further fuel efficiency improvements through more effective competition in this area.

Other initiatives being proposed by the Commission in the context of the Eurovignette Directive, such as road user charging (e.g. with a CO₂-related component), are considered under the BAU option.

Moreover, the reform of the Weights and Dimensions Directive is expected to facilitate the introduction of aerodynamic lorry designs (without loss to load space) from around 2022.⁵²

The BAU trajectory also considers the increasing prevalence of city-specific measures. Air quality measures such as low emission zones (LEZs) and ultra-low emission zones (ULEZs) in European cities often require heavy duty vehicles to meet a minimum EURO air pollutant standard. As HDV CO₂ emissions have improved alongside air pollutant emissions, the vehicles encouraged by LEZs are also likely to have better CO₂ performance. Some cities are considering rules that would require zero-emission operation of certain vehicle types within particularly sensitive zones, which is also likely to facilitate market uptake of such vehicle types.

4.4.4 Advantages and disadvantages

Table 4.2: Advantages and disadvantages of the BAU

Stakeholder	Advantages	Disadvantages
General	<ul style="list-style-type: none"> No additional costs, either for administrators or manufacturers. 	<ul style="list-style-type: none"> Fuel consumption improvements are left to the market, where total HDV CO₂ emissions currently are growing. Other options likely to deliver stronger improvements. Member States are left to take action on HDV CO₂, the scope of which is limited and very unlikely to be implemented consistently across the EU.
European Commission	<ul style="list-style-type: none"> No need for additional action, so no additional administrative costs. 	<ul style="list-style-type: none"> High risk that CO₂ reductions from HDVs (consistent with the delivery of the long-term, Europe-wide CO₂ reduction targets) are not delivered. HDV CO₂ regulations may deliver secondary benefits, e.g. reduction in noise and air pollutant emissions from electrified powertrains, which are missed.
Member State authorities	<ul style="list-style-type: none"> No need for additional action, so 	<ul style="list-style-type: none"> As for European Commission.

⁵⁰ Described further in Appendix 1.

⁵¹ See Table 7.1, Appendix 1 for category descriptions.

⁵² <http://www.euractiv.com/section/transport/news/parliament-backs-the-introduction-of-safer-trucks-in-2022/>

		no additional administrative costs.	<ul style="list-style-type: none"> Limited scope for Member State action to reduce HDV CO₂ as vehicle emissions are principally within the remit of EU policy.
OEMs / Supply chain		<ul style="list-style-type: none"> No additional costs. Freedom to determine CO₂ reduction approach. 	<ul style="list-style-type: none"> Risk that more stringent action will be required / imposed in the long-term. Development of more fuel-efficient vehicles (and technologies) in the EU risks not keeping pace with other major markets, which could impact on competitiveness.
Fleet operators / Drivers / SMEs		<ul style="list-style-type: none"> No additional costs relating to vehicle purchase (for those who buy HDVs). 	<ul style="list-style-type: none"> Not all cost-effective technical measures may be implemented, which would mean missing out on potential fuel cost savings.
Consumers		<ul style="list-style-type: none"> Negligible impacts. 	<ul style="list-style-type: none"> Would not benefit from reduced transport costs (from lower total cost of ownership) resulting from implementation of CO₂ reduction measures.

4.4.5 High level impact assessment

Table 4.3: High level impact assessment of the BAU

Criterion	High level impacts
Cost-effectiveness and economic efficiency	No costs incurred nor savings gained.
Effectiveness, particularly in delivering GHG emissions reductions	Likely to continue to be improvements in fuel efficiency of new vehicles, and consequently reductions in CO ₂ emissions per tonne-km, as a result of market pressures. Unlikely to be consistent with economy-wide EU GHG reduction trajectories.
Administrative costs, including monitoring and reporting	None, beyond that already considered in existing monitoring and reporting legislation.
Coherence with EU policy objectives	Incoherence with delivering long-term, economy-wide CO ₂ reduction targets; potential contribution to improvements in air quality not delivered.
Other environmental and social impacts	Potential additional reduction in costs to wider society – resulting from lower total costs of ownership – not realised.
EU added value	None, as no measures implemented.

4.5 Technology requirements and performance requirements with soft measures

4.5.1 Summary

An option which both mandates minimum performance (efficiency) standards for specific technologies and imposes certain technology requirements has been developed as an alternative to whole vehicle performance requirements. This option could help accelerate improvements in components which are either not currently regulated or are commercially available but underexploited. Further, a package of softer measures is also included to ensure a holistic approach to reducing HDV CO₂ emissions, helping buyers, drivers and logistical planners to better exploit the full potential of the vehicle. Whilst this measure is unlikely to achieve the same CO₂ reduction as vehicle limit values, it is likely to yield a faster reduction than the BAU scenario.

4.5.2 Timeline

- 2019-2020: Best-practice dissemination (non-legislative)
- 2020-2021: Driver training requirement introduced; mandatory introduction of selected driver assistance technologies
- 2021-2023: Extension of VECTO-based CO₂ certification and monitoring to semi-trailers and trailers.
- 2022-2024: Mandating technology performance standards/technologies

4.5.3 Design

This option takes two approaches with regards to HDV technologies: imposing minimum efficiency standards on certain components and requiring the use of certain classes of technology on each HDV.

Minimum efficiency standards entail the identification of suitable limits and the set-up of appropriate testing methodologies and certification processes for particular HDV components. A wide range of components were considered for minimum efficiency standards, taking into account reduction potentials and previous analyses in recent literature. The resulting list of components to be included in this measure were decided upon by relevant experts from Ricardo and TEPR, having considered their CO₂ reduction potential across the four vehicle categories considered and the anticipated costs of implementation.

Mandatory technology classes for new HDVs are also considered under this measure. These are designed in order not to limit manufacturer options by restricting to single a technology, but rather to require the use of a technology from a class of solutions for the given application. It also considers additional benefits given by certain technologies, especially for safety.

Further to technological considerations, the option introduces holistic 'soft' measures, described in Section 4.5.3.2.

4.5.3.1 Technologies considered

The technologies currently considered as part of this option include the following:

- Minimum efficiency/performance standards:
 - Refrigeration auxiliary power units (APUs)
 - Insulation performance for temperature controlled vehicle bodies and trailers
 - Tyre rolling resistance
- Mandatory implementation of certain technology classes:
 - Tyre rolling resistance: OEM application
 - Driver aids (tyre pressure monitoring systems (TPMS), fuel consumption and gear shift indicators)
 - Aerodynamic features

- Advanced cruise control
- Other measures
 - Extension of HDV certification to include refrigerant leakage
 - Trailer certification
 - Facilitation of best practice dissemination
 - Enhanced driver training

Driver assistance technologies are included in order to provide a feedback loop to the driver or fleet manager on the driver's performance. In combination with the driver training also included in the option, the influence of the driver on fuel economy can be deduced when compared with other equal HDVs in the fleet and promotes re-training initiatives when required to maintain training effectiveness.

4.5.3.1.1 **Refrigeration APUs**

Temperature control devices for refrigerated vehicles can be powered using a variety of methods, though the vast majority use a diesel engine independent of the powertrain system known as an auxiliary power unit (APU). Although the refrigeration performance of these secondary systems is tested via 'ATP' testing (UNECE, 2016), their emissions performance is not currently considered under either the certification procedure using VECTO, nor the air pollutant emission EURO standards. As such, the units must meet minimum refrigeration performance standards but fuel consumption performance is dictated by consumer demand. Little real-world data is available for the in-use energy consumption of refrigeration units, however (S. A. Tassou, 2008) estimated the proportion of fuel for refrigeration in a 2004 average refrigerated vehicle to be approximately 8% of total consumption. The EURO regulations have since encouraged HDV engine technology innovations resulting in cleaner HDVs, though as secondary systems have not come under regulatory scrutiny this percentage is likely to have increased since the 2008 study. When it is considered that refrigerated transport accounts for approximately 5.8% of all HDV CO₂ emissions in Europe (Ricardo-AEA, 2011), it is evident that refrigeration unit performance improvements could have a notable impact on European fleet emissions.

This element of the option thus proposes to set minimum CO₂ performance standards on refrigeration APUs.

Another relevant issue is coolant leakage from both trailer refrigeration units and HDV cab air conditioning systems. HDV mobile air conditioning (MAC) systems are not comprehensively covered by regulations regarding leakage of refrigerant gases. There are two regulations which concern vehicle refrigerants; the MAC Directive 2006/40/EC, which covers the use of refrigerants in passenger cars and light duty trucks (<3.5 tonnes), and Regulation 517/2014 which stipulates the requirement for, and frequency of, leakage checks for equipment containing fluorinated GHGs in quantities of greater than 5,000 kgCO₂e. The latter is the only European-level standard regulating coolant leakage from cab air conditioning systems for vehicles of categories greater than N₁ and M₁⁵³ and includes refrigeration units for trucks and trailers (European Commission, 2014).

MAC units used in HDV cabs normally have a charge size of 0.7 to 1.5 kg (Oko-Recherche, 2011), and typically use HFC-134a, which has a global warming potential (GWP) of 1430. As such, HDV MAC units normally contain gases of 1,000 to 2,100 kgCO₂e, which is outside the scope of Regulation 517/2014.

Using these figures, assuming 6.3 million lorries in the EU (Anfac, 2015) and a leakage rate of 15% (Oko-Recherche, 2011), HDV MAC units result in an estimated leakage of 1040 tCO₂e a year (lower bound: 662 tCO₂e, upper bound: 1418 tCO₂e). When compared with a total HDV direct CO₂ emissions in 2015 of 288.3 MtCO₂e (Ricardo-AEA, 2015), this figure accounts for less than 1/1000th of a percent of total emissions. This explains the lack of regulation with regard to HDV MAC units, and suggests that further regulation in this area should not be a priority, compared to other options.

⁵³ See Annex I of (European Commission, 1970) for European vehicle category definitions. Standards exist for categories N₁ and M₁.

4.5.3.1.2 **Insulation performance for temperature controlled vehicle bodies and trailers**

Similarly to APUs, the performance of insulation in temperature controlled vehicles has a big impact on the fuel consumption/CO₂ emissions performance of such vehicles. Foam or fibre insulation is currently used within the majority of refrigerated freight vehicles, which typically degrades by 3-5% per year, reducing CO₂ performance by approximately 50% in the latter case after 9 years of operation (S. A. Tassou, 2008). As insulation performance degrades, refrigeration systems must be used more heavily to compensate, thus increasing consumption. It has been proposed that significant energy savings (between 25% and 60%) could be achieved via the deployment of vacuum insulation panels. One study finds that the additional costs of vacuum insulation on refrigerated trailers can pay back in fuel savings within one year (Ricardo, TEPR, 2016).

4.5.3.1.3 **Tyre rolling resistance**

Tyre rolling resistance standards could drive improvements in the uptake of low rolling-resistance tyre options. Low rolling resistance tyres are considered in both (Ricardo-AEA, 2011) and (Transport & Mobility Leuven, 2014) as having the potential for significant impact on HDV CO₂ emissions, stating an average of 5% CO₂ reduction in the former and 4% in the latter. Having been identified as a cost-effective option for reducing fuel consumption, the European Commission has put in place an EU-wide labelling scheme for new tyres (European Commission, 2009) based upon the Energy Labelling Directive. This covers HDV tyres (class 'C3') which are ranked on a scale of 'A' to 'G' on fuel efficiency among other parameters. Further, the Commission have introduced the Tyre Type Approval Regulation to remove the worst performing units from the market (European Commission, 2009), where rolling resistance limit values are given in Part B of Annex II. Under this option, tighter maximum rolling resistance standards are imposed. This is likely to result in significant real-world benefits as HDV operators commonly apply cheaper, less-efficient tyres to hard-wearing axles which see the most wear. Further, 'retreaded' second-hand tyres, which do not currently require labelling, are no longer exempted but must be re-tested and labelled to allow operators to make better informed decisions. Some work was performed to this effect under the ReTyre project (ReTyre, 2012), which was set up to find a valid and cost-effective methodology for the classification of re-treaded HDV tyres. (Viegand Maagøe A/S, 2016) highlights potential problems with the ReTyre tool; this option assumes that these are solved and that the tool is representative of real-world tyre performance before the inclusion of re-treaded tyres. This option would seek to set standards on tyre rolling resistance at a safe progression, aware of the trade-off between rolling resistance, wet-grip and noise generation.

This option also includes the requirement for manufacturers to fit tyres exceeding a rolling resistance performance threshold which is above that of this minimum performance standard. This would apply only to the first set of tyres used on the HDV, leaving market based mechanisms and the best practice dissemination to encourage operators to continue with their use on subsequent fittings. Whilst potentially increasing the initial purchase price of the HDV, this carries multiple benefits. Foremost, it exposes fleet operators to the improvements offered by tyres with lower rolling resistance than they may otherwise have experienced, increasing the chance of the operator opting for tyres with lower rolling resistance when they are replaced. Secondly, this guarantees a market for premium (or, non-entry level) products for tyre manufacturers, encouraging the development of better performing units. The threshold for such a requirement would need to be carefully selected.

4.5.3.1.4 **Driver aids: TPMS, fuel consumption and gear shift indicators**

TPMS is already mandatory for new cars, though no requirement yet exists for HDVs. A recent European Commission study on TPMS for LCVs and HDVs (TNO & TU Graz, 2013) estimated that the GHG and fuel consumption reduction potential from mandatory TPMS to be around 0.2% to 0.3%, the greatest impact being found for HGVs in long haul operation, and the lowest impact found for city buses. Considering the additional safety benefit offered by TPMS systems, this option would include mandatory TPMS application in all HDVs.

Fuel consumption indicators are also mandatory for new cars. Along with gear shift indicators, these assistance technologies are aimed at improving driver behaviour by providing live information on driving style. The technologies could complement holistic measures such as driver training for greater fuel economy, acting as a training reinforcement. Many new HDVs already include fuel consumption indicators and some provide further data through increasingly sophisticated telematics systems, hence

the effect of this requirement is likely to be limited, yet cost-effective. Although approximately 60% of the European HDV market use automated manual transmissions (AMTs), the remainder principally use manual transmissions which depend heavily on driver input, hence HDVs using a manual transmission would additionally be required to fit a gear shift indicator under this option.

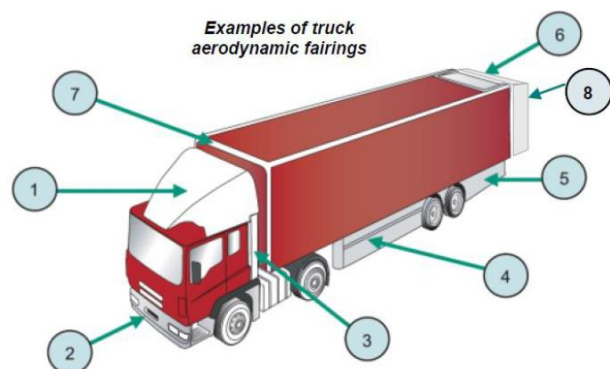
4.5.3.1.5 *Aerodynamic features*

Aerodynamic features are another cost-effective and widely-applicable CO₂ reduction technology. The ICCT recently estimated that a 5% reduction⁵⁴ in fuel consumption could be achieved for €850 for the typical HDV (ICCT, 2014). Market penetration of aerodynamic cab features is reasonably good, however the penetration of certain trailer features has been more limited due to potential loss of load volume and hence competitiveness due to trailer dimension restrictions, as well as additional upfront costs. This has been recognised by the European authorities in the recent modifications to the Weights and Dimensions Directive to allow manufacturers to exceed current weight and length limits if changes improve safety and environmental performance (European Parliament, 2015). Among other changes, the amendments require more aerodynamic HDV cabs, allow an increase to the weight limit by one tonne for alternative powertrains or aerodynamic features, and allow new HDVs to make use of aerodynamic 'tail-extension' flaps at the rear of the vehicle that will not count within the permitted length restrictions.

This alternative option would build upon the momentum of the revised Weights and Dimensions Directive and would require mandatory installation of certain aerodynamic features by European manufacturers for some vehicle classes, in an analogous sense to CARB's Tractor-Trailer regulation (almost a mandatory implementation of the US EPA SmartWay programme). The specific features that could be considered for inclusion in this option are displayed in Table 4.4. The aerodynamics of a vehicle are particularly complex and change substantially depending on the vehicle configuration; features can degrade performance or manoeuvrability if not used properly. They are also highly visible and change the aesthetics of the vehicle. As not to force manufactures to design around the features, but rather design with them, the degrees of freedom in any requirement would need to be carefully developed. For example, OEMs could be regulated to fit a given number of aerodynamic improvement technologies from a list of options, which they could tailor depending on the duty cycle of the vehicle as the saw fit. In addition, some consideration would need to be included on the intended use of the vehicle/trailer – for example, certain aerodynamic features might not be suitable/applied to certain vehicle types (e.g. construction, where they might be particularly prone to damage).

Table 4.4: Aerodynamic features for HDVs⁵⁵

#	Feature	CO ₂ saving ^a
1	Cab deflectors / fairing	2.4-6.0% ^b
2	Cab air dams	0.3-0.7% ^b
3	Cab collars	0.6-6.5% ^b
4	Cab and trailer side skirts	0.4-1.0% ^b
5	Trailer rear quarter panels	-
6	Trailer tapered shape	~10% ^{b,c,d}
7	Trailer front fairings	1.8-3.0% ^b
8	Trailer tail extensions	3-8% ^e
-	Spray-reduction mud flaps	3.6-3.8% ^f
-	Active aerodynamics ⁵⁶	<8.7% ^g



⁵⁴ This study concerned US trailers, hence this figure is illustrative of the reduction magnitude.

⁵⁵ Image source: (Transport & Mobility Leuven, 2014)

⁵⁶ Active aerodynamics include those which are controlled by the vehicle ECU or driver. These commonly include grill deflectors, which can close at high speeds to improve air drag; an active fifth wheel, which adjusts the tractor-trailer gap automatically based on vehicle speed (Transport Canada, 2015).

Notes:

- ^a The CO₂ saving ranges cover both rigid and articulated vehicles. Figures are illustrative and are not consistently reported over drive cycles, as reported in the relevant source.
- ^b Source: (Department for Transport, 2010); based on rigid and articulated vehicles on a cycle comprised of [56mph:motorway:typical:A/B-road:mountainous] driving at a ratio of [40:20:20:5:15].
- ^c Considering information from (ICCT, 2014); based on average US trailers.
- ^d Source: (Don-Bur, 2015); 11.3% fuel saving based on an average of independent third party case studies.
- ^e Source: (Transport & Environment, 2010); based on 'long haul' HDVs over 'long haul duty cycles'.
- ^f Source: (The Engineer Online, 2008); based on a 6x2 articulated HDV at 40 and 52mph.
- ^g Source: (Ricardo-AEA, 2011); based on a HDV at constant 65mph.

4.5.3.1.6 **Advanced cruise control systems**

Advanced or 'predictive' cruise control systems are able to consider GPS tomography data to improve the fuel efficiency of HDVs by mitigating harsh driver actions and overly-variable pedal application, and selecting gears appropriately over hills. Fuel economy benefits are estimated to be approximately 5% for long-haul applications with Daimler's current PPC and Volvo's I-See systems (Daimler, 2015) (Volvo, 2017). Whilst vehicles can be fitted or retro-fitted with low cost components, infrastructure costs are not easily quantified and increased journey times (reportedly by between 0.3-1.9% for Daimler's PCC system) hamper immediate adoption. Advanced cruise control systems thus warrant further investigation for compulsory introduction in certain vehicle classes. However, it is noted that consideration of the potential to adequately define such measures in a legal framework would also be necessary, to ensure that the solutions met certain qualification criteria.

4.5.3.2 **Other measures**

The option also includes the following softer measures, which would in most cases require Member State-level interventions to implement:

- **Facilitation of best-practice dissemination.**

Whilst the operations of larger fleets are increasingly streamlined, smaller fleets of less than five employees often do not have access to logistical planning tools and are less well informed when purchasing vehicles. This measure would aim to assist Member States in setting up 'best practice portals' which provide applications to help smaller logistics businesses better plan their operations through telematics and to offer general assistance tools for vehicle buyers. However, whilst the potential benefits of optimisation in freight handling are significant, existing evidence indicates that in practice it is very difficult to quantify and implement measures to achieve this, as concluded at a recent IEA/JRC workshop (IEA & JRC, 2016).

Also included under best practice dissemination is the creation of a pan-European framework for hauliers to measure, track and publish their fleet fuel economy performance. This would allow hauliers to track information about fuel use across their operation and enables benchmarking against their competitors. It would also allow companies who wish to use freight handling services to factor environmental performance into their procurement decision. This could work in a similar way to the US SmartWay programme where participation is voluntary. As part of the programme, fuel reduction technologies could be demonstrated and proven (given that the fuel economy of participating lorries/operators is measured) and this information can feed into Member State level best-practice portals.

- **Enhanced driver training for economical driving.**

This measure is concerned with the expansion of current fuel consumption rationalisation material into a dedicated and complete energy efficient driving training module under the EU driver certification process. This option modifies Directive 2003/59/EC to make this additional module a requirement as part of the licencing for commercial vehicle drivers and will build upon the proposal recently adopted by the Commission to amend the Directive (European Commission, 2017). A periodic retesting will be required to maintain the qualification, in line with the CPC retesting every five years.

The option further includes extensions to the upcoming HDV certification legislation:

- **Extension of the HDV CO₂ certification regulation to trailers and semi-trailers, including the setting of limit values**

The monitoring, reporting and certification regulations will bring increased transparency of HDV CO₂ and fuel economy performance to buyers and regulators. One mechanism by which this is achieved is mandatory provision of fuel consumption and CO₂ information prior to the purchase of the vehicle. The extension of this information to trailers and semi-trailers may further incentivise improving their efficiency, especially in terms of aerodynamic performance, and will give fleet operators a better understanding of the CO₂ performance of their vehicles as a whole.

As a large proportion of trailer manufacturers are small and medium enterprises (SMEs), costs relating to the certification of their products are likely to have a disproportionate impact on their operations versus the situation for HDV manufacturers. It is important that the process for testing the trailers is designed in such a way as not to overburden the manufacturers whilst still enabling operators to understand the real-world performance of the product. As such, Section 4.5.3.10.3 proposes an outline for a testing and certification procedure which takes this into account, inspired by the US approach, stakeholder feedback and conversations with experts at TU Graz.

Initially, a labelling scheme analogous to those for light duty vehicles was proposed as part of the soft measure package. The purpose of labelling would be to interpret the VECTO simulation outputs on fuel consumption and CO₂ in the form of, for example, an A to G rating. While this labelling approach may well assist consumers to make a more informed decision when purchasing a car (or any other consumer good), it is generally expected that purchasers of HDVs already have substantial technical knowledge on the vehicles, including the implications of expected fuel consumption on their operating costs. Best practice dissemination activities will also help buyers who do not have the resources to investigate the vehicles to make optimal procurement decisions. Therefore, the provision of a file summarising an HDV's fuel consumption and CO₂ simulation results, as foreseen as part of the certification regulation, should be sufficient in informing potential buyers of the vehicle's CO₂ performance. As such, it was decided that the extension of the HDV CO₂ certification regulation to trailers and the creation of limits would better aid commercial buyers to understand trailer performance than a dedicated labelling scheme.

- **Extension of the HDV CO₂ certification regulation to include refrigerant gas leakage.**

As is done within the US HDV regulations, refrigerant gas loss is to be certified from the vehicle. This option covers refrigerant gas systems on both vehicles and trailers, with different limits for each.

4.5.3.3 Vehicle categories

Table 4.5 lists the HDV categories which are subject to each technology requirement, and the rationale for this decision.

Table 4.5: Identification of vehicles most affected by technologies considered in this option

Option	Application	Vehicle categories most affected	HDV categories regulated
Refrigeration APUs and insulation performance	Standards	Benefits are achieved from vehicles (and trailers) which use APUs for refrigeration. This requirement is independent of vehicle category.	All refrigerated HDVs
Tyre rolling resistance	Standards	Benefits are dependent on mileage and hence are most beneficial for regional delivery and long-haul applications. These tend to be the largest HDVs, though standards would be applied to the tyre and so are independent of vehicle category.	None; the tyres are regulated

Tyre rolling resistance – first fit	Requirement	The requirement for HDV manufacturers to fit LRR tyres applies to all vehicle categories.	All
Driver aids	Requirement	Benefits are dependent on mileage and level of driver interaction. Regional and long-haul applications typically undergo the largest mileages, however driver input is maximised during urban operations with frequent stop-starts. As such, categories with regional, long-haul and urban delivery applications are regulated. Gear shift indicators are required only for HDVs using a manual transmission.	1-5, 9, 10
Aerodynamic features	Requirement	Benefits are greatest at higher speeds, hence are most suited to regional and long-haul applications. These tend to be the largest HDVs.	4, 5, 9, 10
Advanced cruise control	Requirement	Benefits are achieved when cruise control is active, typically for long distances at relatively stable speeds, hence are most suited to long-haul applications. These tend to be the largest HDVs.	4, 5, 9, 10

The package of soft measures proposed is inherently broad, requiring holistic improvements across the entire fleet. Some measures within the package will likely yield greater CO₂ reductions from certain vehicle classes or types, however, and so a focus should be placed on these. For example, Figure 4.1 displays the estimated share of total CO₂ emissions from various HDV categories and reveals that 4x2 tractor vehicles of >16t (category 4 HDVs) emit almost 50% of the European fleet's CO₂ output, hence targeting best practice material first at these vehicles is likely to have a greater influence on fleet CO₂ performance than in equivalent rigid vehicles.

4.5.3.4 Emissions covered

CO₂ and refrigerant gas emissions are directly targeted by the measure. The softer measures attempt to improve the efficiency of the fleet, indirectly reducing air pollutant emissions also.

4.5.3.5 Metrics used

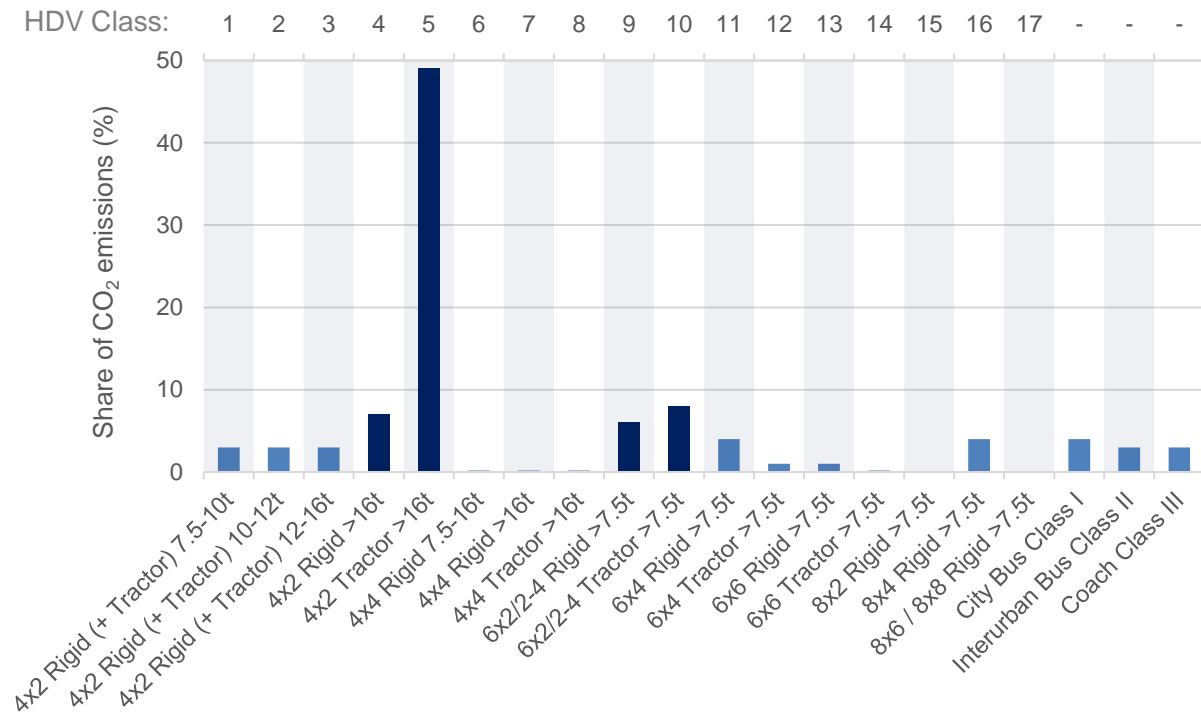
The metrics used to determine the performance of technologies with standards imposed under this option remain undecided and will need to be investigated before the construction of any regulation. If no standard is yet defined to measure the performance of each of these technologies then new standards would need to be developed.

The lack of limit values for the softer measures means that the performance of the entire option would be assessed against a fleet-wide CO₂ performance baseline, with information for this sourced from HDV certification.

4.5.3.6 HDVs present in the market that are not covered by the measure

As can be seen in Figure 4.1, the option is skewed towards the largest heavy duty vehicles which travel long distances at relatively high speeds. This is because larger HDVs contribute a significantly greater proportion of CO₂ emissions than their smaller counterparts - Figure 4.1 highlights the 70% of European HDV fleet emissions attributed to vehicles in HDV categories 4, 5, 9 and 10. Urban delivery vehicles in categories 1, 2 and 3 are required to use driver aids given their greater impact on the CO₂ performance of these vehicles through more driver interactions. The CO₂ benefit for HDVs with utility or construction duty-cycles would be negligible for the technologies considered and so are not covered.

Figure 4.1: Estimated share of total CO₂ emissions from different HDV categories (dark blue indicates primary categories considered under this measure; adapted from (TU Graz et al, 2012))



4.5.3.7 Drive cycles and payloads

The trailer certification scheme would use standard European drive cycles and payloads from VECTO.

4.5.3.8 Deadlines for compliance

Deadlines for technologies meeting certain performance standards would depend on the stringency of any limit values. If the limits values were such that compliant technology was already commercially available, then compliance could be achieved after suitable lead in time to allow for any supply chain mass-market scaling and integration work to be performed by the OEMs. If the limit values were sufficiently stringent that compliant technologies were not yet commercially available, then the deadlines would need to take into account the time for their development, testing and supply chain integration in addition to this. For performance standards, suitable testing cycles would need to be developed by regulators to assess the technologies and set limits, extending the introduction further. As such, if technology performance standards with stringent limits were set, the time needed for regulatory and technological development, and lead in, could be many years.

Through a similar logic, deadlines for manufacturers to install certain technologies would also depend on the availability of the technologies. This measure currently proposes only technologies which have achieved mass market adoption and have well-documented benefits. For example, the implementation of driver aids such as TPMS and fuel consumption indicators could be performed readily by manufacturers as the technologies are available and in regular use. Aerodynamic features are commonplace and are often 'bolt-on' options when procuring larger HDVs, though if such components have not yet been designed for a particular HDV then a fully optimised solution may require manufacturer development. In any case, some years of lead time would be necessary to give manufacturers time to engineer or integrate suitable mass-market solutions into their vehicles. In the proposed case, the deadline for compliance would not need to be as long as for the technology performance standards, however.

In the context of the arguments above and assuming that the stringency of any technology performance standards was not sufficiently severe as to require non-commercially available technologies, this option proposes to introduce technology performance standards in 2023. Assuming that the required technologies are also commercially available, this option proposes to require the implementation of the selected technology in 2022.

Enabling logistical improvements and facilitation of best-practice dissemination measures are proposed to start shortly before 2020 and run for the duration of the package implementation. Enhanced driver training could potentially be introduced as a requirement in existing licencing, however sufficient time would be needed to develop the requirements and to ensure that the requisite resources were in place to provide the training. This is likely to lead to an introduction of additional driver training shortly after 2020. The introduction of trailer standards is likely to require a longer lead time to allow the relevant legislation to be drafted and approved, and could then scale with VECTO's capabilities (i.e. with the segments which VECTO can model). Excluding the computational fluid-dynamics (CFD) model, a reasonable estimate would consider its introduction for the 2021 model year. Stakeholders believe a CFD model could take up to five years to develop and validate; if this is accurate and development started imminently, the standards could be expanded from a limited subset of trailers to include the majority of the new market from 2023.

4.5.3.9 Regulated entities

This option concerns the regulation of multiple parties: vehicle manufacturers, body/trailer builders, tyre manufacturers and drivers. The former three thus affect demands on component suppliers within the supply chain; the latter requires drivers to pass a further efficient driving module within the EU certification process. The package of soft measures mainly focuses on the use of the vehicle and as such is primarily directed at fleet operators, though these are not regulated.

Trailer manufacturers who produce less than a certain number of trailer per year are exempt from the trailer standards. The threshold should protect SMEs who would be disproportionately affected by the regulation, but allow coverage of a significant proportion of the trailer market.

Enforcement would remain with Member State authorities. Various enforcement provisions are conceivable (anywhere from no enforcement through requiring independent certification, to randomised checks carried out by regulators).

4.5.3.10 Testing and certification requirements

4.5.3.10.1 **Technology performance standards**

Testing and certification requirements for technology efficiency standards remain to be determined.

4.5.3.10.2 **Technology requirements**

Use of required technologies for certain vehicle classes will be checked during the type approvals process.

4.5.3.10.3 **Trailer certification and standards**

This option proposes certification and standards for trailers, which are to be assessed in VECTO. The US evaluate trailer performance by simulating the specific trailer as 'coupled' to a generic (pre-defined) tractor. The same approach is adopted for this option. The model would report results in terms of a percentage CO₂ change against a reference generic tractor-trailer combination⁵⁷, averaging over the same drive cycles used for tractor certification. The parameters required for the simulation to model the trailer include the trailer's coefficient of aerodynamic drag (C_d), cross-sectional area (A_x) and other dimensions, the trailer weight, tyre rolling resistance and the CO₂ performance of any refrigeration APUs. It is recognised that experimentally determining the C_d of a trailer is likely to dominate the cost of compliance and could lead to an excessive burden on SME trailer manufacturers. This option proposes the development of a computational fluid-dynamics (CFD) simulation⁵⁸ to model trailer C_d

⁵⁷ Using the generic tractor in combination with a generic trailer. The generic trailer could be, for example, an un-optimised trailer of the same type (curtain-sider, box, etc).

⁵⁸ The CFD simulation would need to demonstrate that the C_d values reported are within a certain tolerance of that found by physical testing.

values. This, or a separate model, would also be able to extrude 2D diagrams into 3D models to minimise the cost burden on trailer builders. Trailer manufacturer-borne costs of certification would thus reduce to the costs of producing a model of the trailer in a common format and testing of refrigeration APUs, likely to be a factor of ten less than full wind tunnel testing.

Trailers would need to comply with standards based upon the *family* which they belong to. A disaggregation system similar to that used in the US is proposed: aero box trailers, partial-aero box trailer and non-aero box trailers, with long/short and refrigerated options (which could also potentially include accounting for minimum performance standards of the APU and insulation, as in Option 1). The requirements for trailers will apply as a CAFE standard within each family of trailer, based on trailer sales.

This mechanism has the additional benefit of allowing certification with real-world parameters, if this is determined to be useful in reducing emissions in the future. For example, in the case of a HDV- and trailer-OEM joint venture, where a trailer is designed for a specific tractor, the organisations may wish to stress the environmental credentials or fuel economy performance of the combination. This approach, using the VECTO simulation, allows the joint venture to swap the generic tractor used to certify trailers for their specific tractor, and to use experimentally determined C_d values. Note that this option does not include modification to VECTO to enable specific-tractor, specific-trailer certification, as the advantages and drawbacks of doing so have not been suitably explored.

4.5.3.11 Secondary systems coverage

This option sets standards on the performance of auxiliary power units, such as those used for refrigeration. Other components required or regulated in this option are already covered under the monitoring and reporting and certification regulations.

4.5.3.12 Main efficiency technologies targeted/incentivised by the measure

This option concerns the setting of standards for APUs, insulation performance of temperature controlled HDVs and tyre rolling resistance, hence these technologies are directly targeted for improvement. The technologies incentivised by the option thus include approaches to refrigeration which consume less power, low-weight insulation materials and low rolling resistance tyres.

The option directly mandates the use of aerodynamic features, advanced cruise control and driver aids such as fuel consumption indicators and TPMS in certain vehicle classes.

The (semi-)trailer certification scheme incentivises manufacturers to reduce the CO₂ emissions from their vehicles at minimum cost without targeting any particular technologies. The soft measures also encourage improvements but do not target any technologies implicitly.

4.5.3.13 Flexibilities on compliance

No flexibilities are proposed under this option. The potential for exemptions and derogations for specialist vehicles, such as emergency vehicles, would be included.

4.5.4 Advantages and disadvantages

Table 4.6: Advantages and disadvantages of technology requirements and minimum performance standards with soft measures

Stakeholder	Advantages	Disadvantages
General	<ul style="list-style-type: none"> • Multiple secondary benefits, including reduction of air pollutant emissions, noise, congestion, etc. • Targets existing, untapped potential at low cost to industry. • Penetration of select technologies will increase rapidly, making buyers aware of their advantages and disadvantages. 	<ul style="list-style-type: none"> • CO₂ reductions from soft measures are less certain (and likely smaller in magnitude) than for options with standards. • Best practice dissemination is particularly difficult to coordinate / implement effectively. • Specifying the use of specific technologies restricts the CO₂ reduction options to be applied, thus reducing the incentive to innovate more widely and to deliver CO₂ reductions in other parts of the vehicle. • Emissions reductions from driver training and driver assistance technologies are not guaranteed, as they require a driver response and behavioural change. • Does not build as much as it could on the CO₂ values arising from VECTO, thus unlikely to be sufficient to meet long-term, Europe-wide CO₂ reduction targets.

Stakeholder	Advantages	Disadvantages
European Commission/ Member State Authorities	<ul style="list-style-type: none"> • Familiar regulatory development process which has been successful previously. • Some elements will accrue benefits independent of VECTO coverage. • Technology performance requirements amend existing legislation, thus lower administrative costs than new, broader legislation / processes. • Relatively simple additional monitoring requirements for MS authorities. 	<ul style="list-style-type: none"> • CO₂ reductions unlikely to be sufficient to meet European targets. • Benefits tied to VECTO coverage (certification). • Requires extension of VECTO to trailers and possibly the development of a CFD model, adding cost. • Some additional monitoring / enforcement required over baseline. • Administrative cost of managing soft measures could be very high, requiring full-time staff. Burden of managing portals.
OEMs	<ul style="list-style-type: none"> • Soft measures require less investment and lower regulatory burden than options with fuel economy standards. • Technology performance standard means setting out straightforward requirements. 	<ul style="list-style-type: none"> • Incurs (probably low level) additional costs. • Technology requirements may not fit OEM styling intentions; allows for reduced distinction in offerings. • Marginal improvement of European vehicle performance, at a lower rate than international HDV performance, means products become less attractive (relatively) in other markets (e.g. South America).
Supply chain	<ul style="list-style-type: none"> • For those supplying required technologies, a guaranteed market for their products. 	<ul style="list-style-type: none"> • For those supplying regulated devices, costs associated with meeting performance standards.
Fleet operators	<ul style="list-style-type: none"> • Increased transparency of vehicle performance during procurement. • Potential for more optimised vehicle usage. • Would benefit from fuel savings with only marginal increases to the cost of a vehicle. 	<ul style="list-style-type: none"> • Additional driver training cost burden. • Mandatory technologies may not fit operator's duty cycle if the requirements are not carefully designed. • Would potentially miss out on fuel savings resulting from other innovations which would be incentivised under standards.

Stakeholder	Advantages	Disadvantages
Drivers	<ul style="list-style-type: none"> Increased skill; improved perception of the profession. Increased transparency of fuel usage. 	<ul style="list-style-type: none"> Some of the additional fuel economy training costs may be passed on to drivers, increasing entry barriers.
Consumers	<ul style="list-style-type: none"> Could benefit from lower transport costs. 	<ul style="list-style-type: none"> Would potentially not benefit as much compared to situation where more innovation was encouraged.
SMEs	<ul style="list-style-type: none"> The trailer certification scheme is particularly useful for businesses who do not have sufficient resources to perform their own trials or undertake specific review processes. Procurement assistance available via online best practice portals. 	<ul style="list-style-type: none"> The cost of trailer certification will be predominately borne by SME trailer builders, though the option is designed as to minimise this. Additional training cost burden, though likely to be offset by other measures and fuel savings.

4.5.5 High level impact assessment

Table 4.7: High level impact assessment of technology requirements and performance requirements with soft measures

Criterion	High level impact assessment
Cost-effectiveness and economic efficiency	<p>Trailer certification, best practice dissemination and driver training improve efficiency using existing vehicle technology, hence low cost with potential CO₂ improvements potentially in line with standards. The option could yield many secondary benefits.</p> <p>Regarding technology performance mandates, cost estimates suggest that at least some of the measures would be relatively cost-effective. However, in comparison to allowing the market to develop and apply CO₂ reduction technologies organically this option is unlikely to be cost-effective.</p>
Effectiveness, particularly in delivering GHG emissions reductions	<p>Those measures that set performance standards for APUs, insulation and tyres would deliver modest emissions reductions. Impacts of best practice dissemination, driver training, driver aids and tyre pressure monitoring systems will depend on operator and/or driver response to the additional information provided, and is therefore more uncertain. Trailer certification will increase awareness among operators; standards will remove the worst performing trailers from the market and hence yields more predictable improvements.</p> <p>In comparison to placing limit values on HDVs themselves, however, the effectiveness of the option is likely to be much reduced and less certain.</p>
Administrative costs, including	<p>Moderate to high administrative costs for Member States; management of best practice portals will require full time staff to manage. Trailer testing and certification will require development and on-going monitoring.</p>

Criterion	High level impact assessment
monitoring and reporting	Enforcement activities can use existing channels, and so costs are expanded minimally.
Coherence with EU policy objectives	<p>Risk of incoherence with delivering long-term, economy-wide CO₂ reduction targets, given the expected limited effectiveness of the package.</p> <p>Requiring the use of components from given classes of CO₂ reduction technology would not be fully in line with the principle of technology neutrality.</p> <p>Including trailer standards reinforces the pursuance of whole-vehicle improvements and better shares responsibility across the industry.</p>
Other environmental and social impacts	<p>Limited secondary impacts include reduced air pollutants and reduced noise. Congestion may be reduced from optimal use of the vehicle (encouraged via best practice dissemination), though any effect of this is likely to be very small.</p> <p>Safety may be positively impacted through the use of driver aids such as TPMS, but may be positively or negatively impacted from improvements to tyre rolling resistance.</p> <p>Any potential additional reduction in costs to wider society – resulting from potentially lower total costs of ownership resulting from higher levels of innovation – are not realised.</p> <p>Enhanced CPC requirements position professional driving as a more qualified job, potentially increasing its attractiveness as a career.</p> <p>Employment may slightly increase due to increased manufacturing output for certain technologies, but predominately from administration of the soft measures.</p>
EU added value	<p>The European Commission is required to set criteria for drivers and best practice portals, to promote homogeneity across the EU. It is important to have a pan-European approach to preserve the functioning of the single market for certification and driver aids.</p> <p>The proposed package ensures that performance standards for some technologies are standardised, and that other devices that have the potential to deliver GHG and fuel savings are included in new vehicles across the EU.</p>

4.6 International approaches: US-based measure

As discussed in Section 4.2.1, the US measures will be used as a base standard from which to construct an option formed of international experiences for the EU via the process described in Section 4.1.2. The following section describes some of the core elements of the US approach and substitutes for those elements which are least replicable or suitable for the EU.

4.6.1 Summary

The first of the international options will use a standard inspired by the US example on which to construct a measure for the EU. This system uses a combination of engine testing and simulation (via the EU VECTO model in place of the US GEM model) to calculate/certify the emissions performance of regulated vehicle categories. Both engines and whole vehicles (via simulation) must meet the standards.

4.6.2 Timeline

- 2018-2022: Data collection and lead-time
- 2023-2024: Implementation of US-like standards

4.6.3 Design

4.6.3.1 Basis for setting standards

The US EPA and NHTSA determined their standards through the definition of typical model year baseline vehicles (i.e. including a range of characteristics, the technology level, and an estimated average fuel economy performance) which then underwent a detailed analysis of the technical options that could be applied to improve their performance. This included a detailed cost analysis and the development of estimates for the market deployment of the technologies hypothesised. The process involved extensive consultation with stakeholders at all stages of the process. This was used to define the overall targets and trajectory for improvement for the different vehicle classes covered in the rulemaking.

This approach is aligned with that which is currently applied in the EU for LDVs. As data for the baseline vehicles and technologies are not yet available for European HDVs, this option includes sufficient time to capture and analyse the HDV certification values on which to create a baseline and set any limit values.

4.6.3.2 Vehicle categories

US and EU lorries share many characteristics and traverse comparable duty cycles, hence many of the methods of CO₂ reduction and testing could also apply in the EU. The US standards apply separately by duty cycle, however, with different testing procedures and limits for combination tractors, vocational vehicles and heavy duty pick-ups. The VECTO model being developed by the European Commission for CO₂ and fuel consumption certification already provides its own vehicle categorisation and a number of different duty cycles. This option will use these existing categorisations rather than adopting the three US streams.

The US also differentiates standards between diesel and gasoline-engined vehicles. There are not significant numbers of gasoline HDVs operated in the EU, so it would likely not be appropriate to provide a differentiation for the different internal combustion powertrain fuel types, also given the focus on CO₂ emissions rather than fuel economy. As such, gasoline HDVs would be subject to the same requirements as their diesel counterparts.

HDVs with powertrains not currently measured by VECTO are not required to meet the standards. In California, manufacturers of heavy duty hybrid electric vehicles are able to perform voluntary certification of the whole vehicle in addition to the required engine testing (CARB, 2017). As VECTO is not currently able to simulate some alternative powertrains, this option proposes that hybrid and electric HDVs would not be included under the whole vehicle simulation but would be able to voluntarily certify vehicles using a chassis dynamometer in an analogous way to CARB.

4.6.3.3 Emissions covered

The US standard takes into account GHGs under the EPA's regulation, monitoring CO₂, N₂O, CH₄ and leakage and the GWP of any air conditioning refrigerant used. This option excludes the regulation of CH₄, air conditioning refrigerant leakage and GWP limits for the European market. The former is covered under EURO emission standard compliance testing, and air conditioning leakage from refrigeration systems is covered by Regulation 517/2014 (European Commission, 2014).⁵⁹ For this option N₂O is covered only under engine testing, as is the case in the US Phase 2 standards.

4.6.3.4 Metrics

As the US use the imperial system of measurement, their metrics include gallons and miles which are converted to litres and tonnes for the European market. This measure takes only the GHG (or 'CO₂ equivalent') component of the US regulations, hence fuel economy metrics are not considered.

For simulation outputs gCO₂eq/1,000 ton-mile becomes gCO₂eq/1,000 tonne-km. Depending on the vehicle's duty cycle, limits may also be specified in gCO₂eq/m³km or used in combination with the weight-based metric. For engines, gCO₂eq/bhp-hr becomes gCO₂eq/kWh.

4.6.3.5 Drive cycles and payload

The US' engine cycles, namely the FTP and SET, are not considerably different from European tests. For example, the discrete mode version of the SET is comparable to the EU's static ESC, and the FTP uses cold and hot cycle weightings, various loads and stop-start, urban and motorway sections, which are all similar practices in European HDV noxious emission testing. Drive cycles are one of the most bespoke parts of the testing procedure, however, and thus will need to be tailored to European conditions from any international market. Utilisation of the European bespoke cycles that have been developed in consultation with industry alongside the VECTO model are applied instead.

Similarly, EU-specific average payload assumptions should also be used in setting the standards.

4.6.3.6 Regulated entities

This option regulates HDV manufacturers. Both engines and whole vehicles would have to comply with their respective standards.

4.6.3.7 Testing and certification requirements

Engine compliance testing would be performed on engine dynamometers, using limits in gCO₂eq/kWh. Whole vehicle compliance would be assessed using the VECTO simulation model, under the same conditions as will be performed for HDV certification.

4.6.3.8 Secondary systems covered

The option retains Europe's current regulations on air conditioning leakage from transportation refrigeration units and thus does not cover secondary systems itself.

4.6.3.9 Main efficiency technologies targeted/incentivised by the measure

The US measures incentivise both engine and vehicle improvements in a flexible way, which is desired in any EU measure. Engine improvements are encouraged through the use of a separate engine standard; whole vehicle improvements are encouraged through simulation. In utilising the VECTO model, application in the EU would cover a slightly broader range of technical improvements than is currently the case for the GEM modelling requirements and the application of default values in the US Phase 2 regulations.

4.6.3.10 Flexibilities in compliance

The US standards apply as a corporate average fuel economy limit. This is consistent with the approach also currently taken in the EU for the LDV CO₂ regulations and is maintained under this option.

⁵⁹ Whether Regulation 517/2014 comprehensively covers air conditioning for HDV cabs remains to be investigated (further discussed in Section 4.5.3.1.1).

The averaging, banking and trading (ABT) scheme included in the US regulation has been identified as an important enabler of the success of the programme and hence also forms an important flexibility within this option. The feasibility of installing such a scheme in the EU and the exact form this would take should be explored in future studies.

This option also employs early adoption credits and advanced technology credits. These have multiple benefits. Firstly, they act to incentivise manufacturers and suppliers to develop and install technologies which have real-world benefits but are not sufficiently represented by VECTO. Secondly, they provide manufacturers a reason to make fundamental innovations such as the use of alternative powertrains. The methodology for distributing both types of credits could be influenced by the current eco-innovations credit system used in EU LDV CO₂ legislation.

4.6.4 Advantages and disadvantages

Table 4.8: Advantages and disadvantages of Policy option 3: US-based approach

Stakeholder	Advantages	Disadvantages
General	<ul style="list-style-type: none"> • Effective policy for guaranteeing reduced tailpipe emissions, as targeted by the standard. • Foresight: lessons learned from US implementation. • Separate engine standards work alongside EURO standards and whole vehicle standards to minimise the incentive for gaming between CO₂ and NO_x performance. They also signal to manufacturers the commitment of European authorities in addressing the remaining capacity of the diesel engine. Manufacturers will thus be encouraged to invest in R&D programmes. 	<ul style="list-style-type: none"> • Relatively complex/expensive legislation. • Whilst standards offer more predictable reductions than component standards, potential rebound effects including faster growth in road freight activity do not fully guarantee that CO₂ targets will be met. • VECTO cannot currently assess AFVs intrinsically. • Separate engine standards do not incentivise whole vehicle improvements, but rather add an engine improvement 'silo'.
European Commission	<ul style="list-style-type: none"> • Relatively small administration costs; standards would need to be developed and evaluated. • Familiar regulatory development process. • Makes use of the existing VECTO tool which is tailored to EU market. • Maintains categorisation, metrics and drive cycles in VECTO. 	<ul style="list-style-type: none"> • Requires further development of VECTO to include trailer certification. • ABT and credits programmes add considerable complexity; may be prohibitively difficult to implement for the EU. • Considerable data collection requirements to set limits; however, no more than for EU LDV standards.
Member State authorities	<ul style="list-style-type: none"> • Whole vehicle standards help Member States to more predictably 	<ul style="list-style-type: none"> • MS authorities are responsible for testing/certification.

Stakeholder	Advantages	Disadvantages
	<ul style="list-style-type: none"> meet their GHG targets than other regulatory instruments. 	<ul style="list-style-type: none"> Additional monitoring / enforcement required.
OEMs	<ul style="list-style-type: none"> Flexibility mechanisms help minimise cost of CO₂ reductions. Effective, novel technologies rewarded with credits. Testing is not overly burdensome. Limited benefits for EU OEMs from closer alignment of engine standards. Medium-term standards offer clarity on which to base investment decisions. 	<ul style="list-style-type: none"> Costs associated with meeting the standards. Increased testing and compliance activities. Allocation of credits to particular technologies may disrupt OEM strategy if not carefully implemented.
Supply chain	<ul style="list-style-type: none"> The market for certain CO₂ reduction products is guaranteed. Medium-term standards offer clarity on which to base investment decisions. 	<ul style="list-style-type: none"> The supply chain will incur a large proportion of the innovation costs, though with associated returns.
Fleet operators	<ul style="list-style-type: none"> Lower fuel costs. Increased clarity on vehicle performance during procurement. 	<ul style="list-style-type: none"> Potentially higher upfront vehicle costs.
Drivers / transport SMEs	<ul style="list-style-type: none"> Lower fuel costs. 	<ul style="list-style-type: none"> Potentially higher upfront vehicle costs.
Consumers / Non-transport SMEs	<ul style="list-style-type: none"> Potential for reduction in transport costs. 	<ul style="list-style-type: none"> Negligible impacts.

4.6.5 High level impact assessment

Table 4.9: High level impact assessment of a US-based approach in the EU context

Criterion	High level impact assessment
Cost-effectiveness and economic efficiency	Extensive studies result in high setup costs but facilitate choice of the most cost-effective trajectory - technology cost-effectiveness is a primary consideration upfront. The certification process, monitoring and enforcement procedures are in line with existing air quality standard procedures and so are added cost-effectively.
Effectiveness, particularly in delivering	Higher probability of reducing CO ₂ than with softer measures, though with potential rebound effects. Extensive flexibility measures

Criterion	High level impact assessment
GHG emissions reductions	<p>increase the likelihood of the European fleet as a whole meeting the standards. Separate engine standards ensure that both CO₂ and NO_x improvements are considered, and gives confidence to manufacturers to invest in diesel engine improvements.</p> <p>Some secondary systems are covered, leading to more representative real-world performance and representing greenhouse gases other than CO₂.</p>
Administrative costs, including monitoring and reporting	<p>Monitoring and reporting add material cost, though can occur through existing channels. Additional costs are expected relating to challenges in implementing the ABT flexibility mechanisms under the EU-MS framework.</p> <p>The European Commission’s role in developing a CFD model will demand further administrative costs, though this will act overall to save costs by reducing the impact on SME trailer manufacturers.</p>
Coherence with EU policy objectives	<p>The basis for setting standards is broadly technology neutral and flexible. The regulation is designed to ensure that emissions reductions delivered are consistent with those needed under a long-term trajectory – their success will depend on the stringency set.</p> <p>Inclusion of trailer standards is in line with the European ethos of requiring improvements across the whole vehicle and better distributes responsibility across the industry.</p> <p>Separate engine standards detract from a ‘whole vehicle’ approach and limit manufacturer options. As it is not currently possible to simulate alternative powertrains within VECTO, any imbalance of the credit system could affect technology neutrality.</p>
Other environmental and social impacts	<p>The standards will contribute to reduced air pollution. Other secondary benefits are marginal. Employment is unlikely to be significantly impacted, however certain aspects of the measure could result in additional employment for administrative purposes.</p>
EU added value	<p>It is important to have homogenous standards across the EU to protect the integrity of single market.</p>

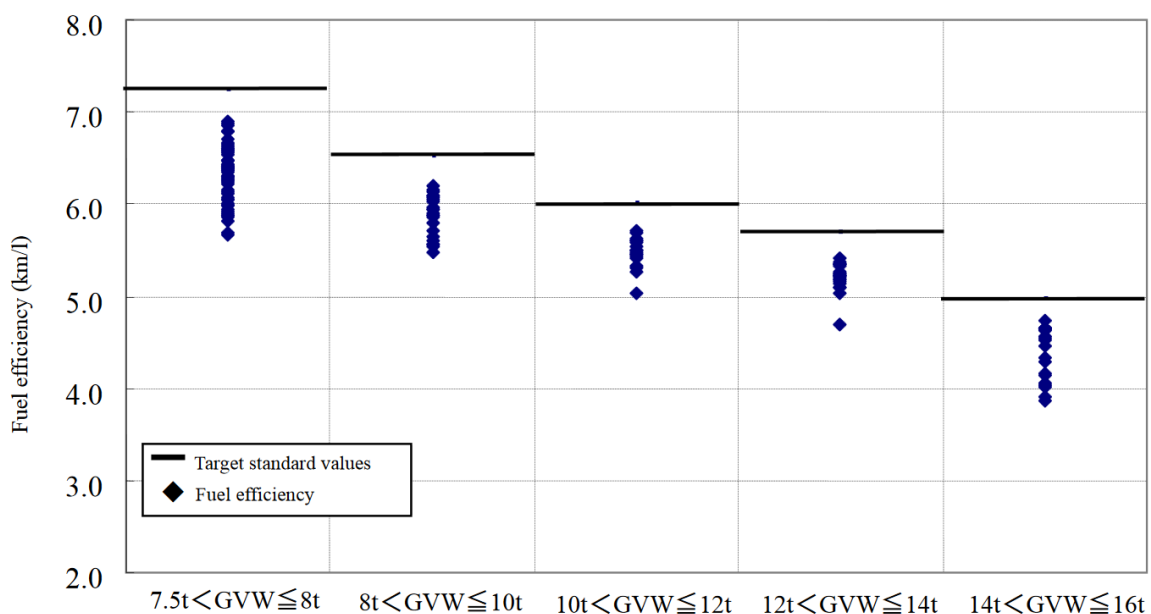
4.7 International approaches: Japanese-based measure

As discussed in Section 4.2.1, the Japanese measures are used as a base standard from which to construct an option formed of international experiences for the EU via the process described in Section 4.1.2. The following section describes some of the core elements of the Japanese approach and how those which are least replicable or suitable for the EU have been substituted.

4.7.1 Summary

A second option constructed from international approaches will draw on the Japanese ‘top-runner’ method, a method of standard-setting that, in addition to HDVs, has been widely applied to various different product categories by the Energy Efficiency Standards Subcommittee in Japan. The ‘top-runner’ approach works by measuring the energy requirements of all products of a given category in order to identify the best-in-class ‘top-runner’. The basic idea underlying the approach is that the energy performance of all products should converge towards that of the top-runner. Therefore, a standard for a future reference year, to be met by all manufacturers, is set slightly beyond the current top-runner’s performance, in order to allow for expected further improvements to the best-in-class product (which may change) over time. The level of the standard and the target year are defined in consultation with industry. Figure 4.2 provides an illustration of this approach.

Figure 4.2: Fuel efficiency in the base year 2002 and standard to be met for target year 2015 for Japanese freight vehicles (other than tractor (GVW 7.5 to 16 tonnes)) (HVFSE, 2005)



Engine testing is used to provide parameters for the simulation model; engines themselves are not required to meet minimum CO₂ performance standards. Similarly to the US-based measure, for the EU it would be more appropriate to utilise the VECTO model being developed by the Commission for certification purposes, which fulfils similar input-output objectives, but with a wider coverage of bespoke vehicle specifications.

4.7.2 Timeline

- 2018-2021: Data collection (focus on classes 1-5, 9-10) through certification and consultation
- 2021-2024: Data collection (other classes)
- 2023-2024: Potential implementation of top-runner standards (starting with classes 1-5, 9-10)

4.7.3 Design

4.7.3.1 Basis for setting standards

As described in the summary above, standards are set based on:

‘top-runner’ performance + x,

where ‘x’ reflects expected technical improvements between the base year and the target year (taking into account the range of available technical options for improving fuel efficiency, as well as balancing impacts, such as the introduction of more stringent air pollutant emissions standards).

In principle, a similar ‘top-runner’ approach could also be adopted in the EU, though it would first require the collection of suitable data to define the top runner. The planned HDV CO₂ certification and monitoring regulations will allow for this.

Given the large variation in HDV types, there are almost infinite possibilities as to how to define vehicle categories, and set out vehicle characteristics and duty cycles along which to define top runner vehicles. If a single top runner is specified amongst a fairly heterogeneous range of vehicles, e.g. rigid lorries <7.5t GVW, then there is a risk that the top runner’s performance is driven by the design requirements of its specific application and is not reflective of the emission reduction potential in other applications. This could result in little incentive to improve some vehicle applications, and impose too high a burden on others. If top runners are specified within very narrowly defined groups of vehicles (which adds complexity and results in a very large amount of different top runners) then there may be little incentive to optimise vehicle design to the application required, as improved designs may lead to falling into a more stringent top-runner category (e.g. artificially increasing lorry weight to require a lower overall CO₂ reduction). Moreover, narrowly specified criteria may be more vulnerable to gaming: vehicle designs could simply be modified without functional improvement, but simply to fulfil the criteria of a top-runner category with more lenient emission limits. Finally, having a narrowly defined group of vehicles and a large number of top runners could mean that becoming a top-runner would become fairly unchallenging, thereby removing top-runner certification as an option for manufacturers to effectively distinguish themselves from their competition.

Similarly to light-duty vehicle legislation, there is a case for setting a utility parameter – an indicator of the usefulness of the vehicle in proportion to which fuel consumption and CO₂ emissions are allowed to vary. For goods vehicles, a key utility parameter is payload, which is why the US standards for road tractors and trailers have been set in terms of gCO₂/tonne-mile. The US standards set further tacit utility parameters: smaller vehicle categories, and tractors with a sleeper cab reflect increases in utility for certain applications and are therefore allowed higher emissions per tonne mile. In the case of rigid lorries (‘vocational vehicles’) which cover a large variety of different applications including school buses and waste collection vehicles, simple, uniform standards have been set for each of three GVW categories. Under Phase 2, these have been further sub-divided into three different duty-cycles (Urban, Multi-purpose, and Regional) depending on where the vehicle is typically used.

Overall, it is probably not possible to create a categorisation that sets appropriate and proportionate standards for every single vehicle. It is therefore helpful to require manufacturers to meet a fleet average target as is done in Japan and the US, rather than require every single vehicle to meet a target, as done in China.

Given that thousands of different variants of HDVs are available, a key question relates to defining relevant groups in which each vehicle (and the group’s top runner) sits. This option proposes to divide each of the 18 European HDV categories into a number of GVW bins, then to set top runner standards within these bins by mission profile⁶⁰ / vehicle configuration (the 7 mission profiles/vehicle configuration are given in Table 7.1 of Appendix 1). Manufacturers would have to meet sales-weighted performance averages within these groups, based upon the performance of the top runner within the group.

⁶⁰ VECTO terminology for duty cycle.

Table 4.10: Summary of drive cycle and payload tests for a 12t delivery lorry in VECTO

	Urban	Regional	Long haul
Empty	✓	✓	✓
Reference weight	✓	✓	✓
Fully laden	✓	✓	✓

HDVs will be simulated over each mission profile and payload. In the case of a 12 tonne delivery lorry, for example, VECTO generates output for nine distinct mission profile and loading condition combinations, as illustrated in Table 4.10. The final result will be a weighted average between these cycles and payload averages, with weightings dependent on which of the 7 mission profile/vehicle configurations the HDV belongs to.

4.7.3.2 Vehicle categories

The commercial vehicle fleet composition in Japan is very different from that of the EU. Duty cycles are predominately urban in Japan, even for vehicles of over 20 tonnes, and rigid vehicles dominate. As such, the classification of vehicles used in Japan would not be suitable for any EU legislation. As described in Section 4.7.3.1, the categories to be used will follow those already defined/being utilised in the VECTO model.

4.7.3.3 Emissions covered

This option directly covers CO₂.

4.7.3.4 Metrics

Japan measures the fuel efficiency performance of HDVs in kilometres per litre, however this does not facilitate an easy comparison between powertrains due to the differing energy density of fuels. Instead, the European implementation would certify vehicles using a combination of gCO₂/tonne-km and gCO₂/m³km.

4.7.3.5 Drive cycles and payload

Generation of an engine map and periphery data for virtual simulation is familiar to EU regulators and appears to give a reasonable solution to take into account the complexity of HDV configurations. The cycles used in Japan's simulations are not representative of European duty cycles however, comprising the start-stop intensive JE05 'urban driving mode' and the 'interurban driving mode' cycle using a constant 80km/h speed and variable road gradients. The overall result is weighted between the cycles, as is often practiced in EU standards, though these skew towards the urban cycle in the Japanese procedure. The drive cycles used would therefore need to be updated or substituted for the European market; for the purpose of this option the cycles to be used would be those being developed for VECTO.

4.7.3.6 Regulated entities

This option places regulation on HDV manufacturers.

4.7.3.7 Testing and certification requirements

Testing is performed using the VECTO simulation model, as is performed for HDV certification.

4.7.3.8 Secondary systems covered

No secondary systems are regulated under this option.

4.7.3.9 Main efficiency technologies targeted/incentivised by the measure

Although no separate engine standards are included in this measure, it incentivises both engine and vehicle improvements due to the determination of simulation parameters from engine dynamometer testing. It does not target particular technologies.

As the original simulation model uses default figures for aerodynamics and tyre rolling resistance, these technologies are not necessarily incentivised in the Japanese market. Given that air and rolling resistance are a major component of European HDV fuel consumption (due to the higher average speeds), these would be taken into account for the European market using VECTO’s tuneable parameters.

4.7.3.10 Flexibilities in compliance

The top runner approach ensures that the required fuel efficiency improvements are technologically possible, and hence intrinsically includes a degree of flexibility. The standards are measured by corporate average product sales, allowing manufacturers to provide regulators with a weighted average value for compliance.

Advanced technology credits are used to incentivise manufacturers and suppliers to develop and install technologies which cannot be represented within VECTO. This also acts to mitigate the potential for gaming by timing technology releases to ensure the greatest chance of reaching top-runner status or to make the next iteration of standards easier to comply with.

Averaging, banking and trading is used to allow manufacturers a further degree of flexibility. How this operates across the HDV categories is not decided.

4.7.4 Advantages and disadvantages

Table 4.11: Advantages and disadvantages the top-runner approach

Stakeholder	Advantages	Disadvantages
General	<ul style="list-style-type: none"> • Ensures feasible targets and progressive improvement at a reasonable confidence of achievement. • ‘Top runner’ target is reasonably simple to set once data is available. • A short timeframe to implementation in principle, once the programme is running. • Foresight: lessons learned from Japanese implementation. • Top runner standards could expedite the introduction of fundamental vehicle improvements, such as those sourced from alternative powertrains: once a top-runner HDV is identified the standards will be governed by its performance. 	<ul style="list-style-type: none"> • Unlikely to drive technological innovation as much as US style approach, though ABT and advanced technology credit systems may partially combat this. May reduce incentive for blue-sky innovation. • The incentive for manufacturers to ‘time the market’ is not insignificant. ABT and advanced technology credit systems may partially combat this, also. • Whilst standards offer more predictable reductions than component standards, potential rebound effects including faster growth in road freight activity do not fully guarantee that CO₂ targets will be met. • VECTO cannot currently assess AFVs.
European Commission	<ul style="list-style-type: none"> • Makes use of the existing VECTO tool which is tailored to EU market. 	<ul style="list-style-type: none"> • Would require approval of the top runner approach in the European legal framework.

Stakeholder	Advantages	Disadvantages
	<ul style="list-style-type: none"> • Maintains categorisation, metrics and drive cycles in VECTO. • Potential for increased interaction with industry. • Certification data will assist setting of baseline, however is not required to enact top-runner standards. 	<ul style="list-style-type: none"> • Studies to update stringency may be required more frequently than other options.
Member State authorities	<ul style="list-style-type: none"> • Enforcement can be performed as part of existing work. 	
OEMs	<ul style="list-style-type: none"> • Potential for increased involvement in regulatory process; closer to decision makers; aiding collaboration. • Flexibility: single sales-weighted average target across all HDVs, ABT and advanced technology credits. • Familiarity with the testing process, injecting experimentally determined engine parameters into simulation. • Less pressure for blue-sky innovation. 	<ul style="list-style-type: none"> • Periodic nature of top-runner means less clarity of future requirements on which to base investment timing. • Costs associated with meeting standards. • Increased testing and compliance activities.
Supply chain	<ul style="list-style-type: none"> • More certain market for some CO₂ reduction technologies. • Advanced technology credits system gives confidence to produce more innovative and costly solutions. 	<ul style="list-style-type: none"> • Periodic nature of top-runner means less clarity of future requirements on which to base investment timing. • Reliant on the credits system being representative, or investments in new technologies may not be as attractive.
Fleet operators	<ul style="list-style-type: none"> • May achieve lower fuel costs than without standards. 	<ul style="list-style-type: none"> • Potential for higher upfront vehicle costs.
Drivers / transport SMEs	<ul style="list-style-type: none"> • May achieve lower fuel costs than without standards. 	<ul style="list-style-type: none"> • Potential for higher upfront vehicle costs.
Consumers / non-transport SME	<ul style="list-style-type: none"> • Potential for lower freight costs. 	<ul style="list-style-type: none"> • Negligible impacts.

4.7.5 High level impact assessment

Table 4.12: High level impact assessment of the top-runner approach

Criterion	High level impact assessment
Cost-effectiveness and economic efficiency	<p>The cost-effectiveness of the approach is uncertain. There are moderate regulatory burden on OEMs, especially in setting the standards, but incremental changes are likely to focus on the most cost effective technologies.</p> <p>The top runner method has the potential to be less expensive than a fundamentally analytical, bottom-up approach as used in the EU LDV regulations.</p> <p>Given the intrinsic incentive for only gradual CO₂ reduction, the standard is less likely than a US-style approach to be as cost-effective in the long-term.</p>
Effectiveness, particularly in delivering GHG emissions reductions	<p>The effectiveness of the approach is uncertain. Smaller performance increments are likely to be more easily achieved by OEMs but no evaluation has yet been made available from Japanese regulators to understand whether this could be hastened.</p> <p>The basis for setting standards does not suitably encourage the most impactful innovations.</p>
Administrative costs, including monitoring and reporting	<p>Administrative costs are moderately high, principally due to the periodic nature of the top runner method. The extensive data collection activities are performed much more frequently than a traditional analytical approach which sets limits over a longer term. This would represent less of a burden in Europe, however, as the upcoming monitoring and reporting requirements deliver fleet performance information to legislators.</p>
Coherence with EU policy objectives	<p>The 'top runner' approach does not encourage large innovations and may not be fully coherent with achieving long-term EU CO₂ targets. Conversely, short term targets are realistic and the system permits a good evidence base for the chosen standard limits.</p>
Other environmental and social impacts	<p>The standard will also yield reduced air pollution, in line with general vehicle improvements. Employment is unlikely to be significantly impacted, however certain aspects of the measure could result in additional employment for administrative purposes.</p>
EU added value	<p>It is important to have homogenous standards across the EU; protecting the integrity of the single market.</p>

4.8 Stakeholder consultation: illustrative measure

The project team invited stakeholders to discuss and comment on initial policy options before making subtle modifications to result in those presented in the previous sections. An overview of the stakeholder comments is given in Section 5.2.2. Overall, the stakeholders were in agreement on many of the design features of a potential future regulation. For example:

- There was consensus that a mechanism to promote alternative fuel types and powertrains was a key aspect of any future measure, if the EU are to meet the CO₂ emissions reductions targets.
- Stakeholders recognised the benefits of flexibilities on compliance, such as through credit schemes, if implemented carefully and were satisfied if this was used to take into account alternative powertrains (in the short-term).
- Trailer certification was identified by almost all stakeholders as important for EU CO₂ regulation.
- Most stakeholders, including an end user organisation, were supportive of best practice where it enabled operators to track and benchmark their CO₂ performance against their competitors and to evaluate CO₂ reduction technologies anecdotally from real-world operations.
- All stakeholders were in favour of driver training improvements and periodic retesting to some degree, noting that some Member States (such as Germany) already have similar requirements in place.

Given that there exists broad stakeholder consensus on many elements of the policy options presented, a 'resulting measure' was constructed from the aggregated stakeholder perspectives. The measure is based predominately on the US standards given the stakeholders' views and shares its key design features, including trailer certification, separate engine standards and extensive flexibility mechanisms. The testing procedures use existing European HDV categorisations, test/drive cycles and metrics. Most stakeholders felt that elements of the options presented could be combined to create a more optimal standard, particularly when referring to elements of Policy Option 1. The measure is thus supported with softer measures such as enhanced CPC requirements and a centrally-organised best practice dissemination programme.

This resulting measure should be used for illustrative purposes: stakeholder opinion often remains divided (but skewed), where frequently the recommendation of the majority party has been taken. This may not necessarily be reflective of the optimal pathway or fully representative of industry's perspective as a whole. The timing of the regulations remains undecided in the illustrative measure as it is a fundamental consideration where two starkly different opinions emerged. Most stakeholders were in favour of the implementation of a less rigorous standard in the immediate future, followed by a broader and more stringent regulation once a baseline had been agreed. Manufacturers were among two stakeholders in favour of setting limits only after a baseline had been agreed on the basis of the certification data in 2018, then leaving sufficient lead time for their members. Timing of periphery elements was also contentious: one stakeholder considered trailer certification only after a CFD simulation had been verified and with a minimum of four years' lead time; NGOs amongst other stakeholders believed trailer certification could be put in place for the most common trailer types as soon as VECTO could handle them. One NGO suggested that the top runner standard could still be valuable in setting interim standards for the principal HDV categories whilst certification data is unavailable. These design choices remain optional in the illustrative measure.

4.8.1 Timeline

The timelines offered below are based upon stakeholder feedback regarding their temporal feasibility.

- 2017-2022: Certification data collection, technology cost-benefit analysis and lead-time
- 2018-2020: Best practice dissemination framework set up across Member States; minimum tyre performance standards increased; fuel efficient driver training module added to CPC requirements.
- Either:
 - 2021-2022: Implementation of limited standards
 - 2023+: Implementation of refined standards

Or:

- 2023-2024: Implementation of refined standards
- Either:
 - 2021-2022: Trailer certification introduced for 'regular' trailers
 - Post-CFD development (~2023): Trailer certification introduced for all trailers

Or:

- 2023-2024: Trailer certification introduced for all trailers

4.8.2 Design

4.8.2.1 Basis for setting standards

The European Commission sets standards for HDV engines, whole vehicles and trailers⁶¹ through a thorough assessment of current performance and anticipated future development, after consultation with industry and relevant stakeholders. Future limits are set through detailed cost and CO₂ reduction potential analysis, as is performed for EU LDV regulations. Separate engine standards are maintained to encourage investment into internal combustion-engine improvements, and to reduce the opportunity for gaming between NO_x and CO₂ certification. It should be noted that currently the draft certification procedure includes already a safeguard against such potential gaming behaviours, measuring and limiting the regulated pollutant emissions (including NO_x) during the engine certification procedure.

The first HDV standards can be introduced in one of two narratives:

- Europe could follow the US in setting an initial, less stringent, less encompassing regulation, shortly followed by a technology-forcing standard with a wider reach. This facilitates the swift introduction of standards and offers the market an understanding of the format of such regulation without necessarily being burdensome to satisfy. If development of a second regulation starts immediately after the implementation of the first, many stakeholders believe that long-term CO₂ targets will be easier to meet than through a single, refined standard later.
- Development of refined standard for enactment in the medium-term, perhaps built upon a baseline set following the first year of certification data.

In either scenario, it appears prudent to begin development of a standard as soon as possible, with measurement and analysis of HDV certification values in parallel to this activity.

4.8.2.2 Vehicle categories

The existing categories in the VECTO model are used to disaggregate European HDVs. Separate gasoline standards are not given: gasoline HDVs would be subject to the same requirements as their diesel counterparts. Specialist vehicles such as emergency vehicles are exempt.

HDVs with alternative powertrains do not require whole vehicle type approval but instead will be offered credits under the advanced technology credits scheme. If desired, manufacturers will be able to certify the whole vehicle using a chassis dynamometer. Note that alternative ICE powertrains which cannot be simulated in VECTO must still meet diesel engine standard limits. Nuances such as whether hybrid vehicles need to demonstrate that they do not emit more NO_x than their ICE equivalents in order to be rewarded with advanced technology credits (as proposed by CARB) remain to be decided.

As the trailer market consists primarily of cost-sensitive SME builders, trailer certification would use simulation to model a coefficient of drag parameter. Before the CFD simulation is available only regular box trailers will require certification. Once the CFD simulation has been validated the requirement will expand to cover all types of trailer, with exemptions for specialist equipment to be defined.

4.8.2.3 Emissions covered

The standards regulate CO₂ and, for engines, include N₂O.

⁶¹ 'Trailers' includes both semi-trailers and full-trailers.

4.8.2.4 Metrics

The standards offer limits in gCO₂/tonne-km. Depending on the vehicle's duty cycle, limits may also be specified in gCO₂/m³km or used in combination with the weight-based metric.

For engines, gCO₂/kWh and gN₂O/kWh are used.

4.8.2.5 Drive cycles and payload

The standard assesses whole vehicle performance over the duty cycles developed for VECTO, in consultation with industry. EU-specific average payload assumptions are used.

Engines are evaluated over the WHTC.

4.8.2.6 Regulated entities

This option regulates HDV manufacturers. Both engines and whole vehicles would have to comply with their respective standards.

4.8.2.7 Testing and certification requirements

Engine compliance testing would be performed on an engine dynamometer using the WHTC cycle. Whole vehicle compliance is assessed using the VECTO simulation model, under the same conditions as will be performed for HDV certification and using input data from steady-state engine tests.

Trailer certification is applied to trailer *families*, in a similar way to the US' separation of aero, partial-aero and non-aero types. Limits are adjusted depending on the length of the trailer (e.g. the US use 'long' and 'short' distinctions) and for refrigerated units.

Trailers are certified using the VECTO model with a generic-tractor, specific-trailer approach. The generic tractor characteristics remain to be defined. A validated CFD simulation – developed between the European Commission and industry in an analogous way to VECTO – is used to determine the trailer's coefficient of drag by cross-sectional area ($A_x C_d$) for input into VECTO. The CFD model takes a 3D model of the trailer as its input, and is able to extrude 2D diagrams to 3D models automatically should the organisation not have a 3D model available.

Where trailer certification is required before the CFD model is available, traditional testing methods are used to identify the $A_x C_d$ parameter. VECTO's capability is extended to include trailers as soon as possible, and will use the experimentally derived coefficient of drag parameter to certify trailers. The CFD model has been estimated to require up to five years to develop.

Specific-tractor, specific-trailer combinations are not possible in VECTO as part of this standard.

4.8.2.8 Secondary systems covered

No secondary systems are covered in the initial regulation. Auxiliary equipment, such as APUs, may be subject to standards in future iterations.

4.8.2.9 Main efficiency technologies targeted/incentivised by the measure

Both engine and vehicle improvements are incentivised through testing and simulation, respectively. The standard allow manufacturers to meet the limits in a flexible way and attempts to be technology neutral. The degree of technology neutrality depends on whether alternative powertrains can be modelled within VECTO, and the fairness and representativeness of the credit systems.

4.8.2.10 Flexibilities in compliance

The standards apply on a CAFE basis, as for the EU LDV CO₂ regulations. The regulation then offers two credit systems to aid flexibility:

- Averaging, banking and trading provisions are included, if administrative hurdles can be overcome. Manufacturers are able to enter a credit deficit for a given number of years without incurring penalties.

- Advanced technology credits are used to incentivise and help manufacturers to justify development of innovative technologies which may not be suitably represented in VECTO. Until such technologies are able to be simulated, credits enable technologies with real world benefits to be recognised. This includes alternative powertrains.

The methodology for distributing both types of credits shall be influenced by the current eco-innovations credit system used in EU LDV CO₂ legislation.

4.8.3 Complimentary measures

The standards would be accompanied by three further, complimentary measures:

- An increasingly stringent minimum performance standard for tyres, including re-treaded tyres.
- A dedicated and complete fuel efficient driver training module is added to the CPC requirement. A five-year periodic retesting is in place. This both acts to improve driver understanding and upskills the professional driving profession.
- Best practice dissemination has multiple facets:
 1. A portal enabling SMEs to access information to support procurement decisions based on their situation: e.g. typical duty cycles, location and anticipated period of ownership.
 2. A framework where operators are able to use online tools to track the CO₂ performance of their fleet. Operators can benchmark their performance against other companies (who may be anonymised). The framework will record the CO₂ reduction technologies used by the fleets in order to demonstrate the effect of certain technologies in real world use, educating fleet managers to their benefits and encouraging wider adoption.

The European Commission’s role is to support these activities which will be delivered at the Member State level, acting as a central point of contact and potentially providing access to funding.

In addition, if alternative powertrains and new technologies are to be modelled within VECTO, the Commission shall release and update an illustrative timeline for enhancements to VECTO. This provides more certainty to manufacturers and suppliers when timing their investments. If alternative powertrains and new technologies are handled outside of VECTO, this would not be performed.

4.8.4 Advantages and disadvantages

Table 4.13: Advantages and disadvantages of the illustrative policy option

Stakeholder	Advantages	Disadvantages
General	<ul style="list-style-type: none"> • Effective policy for guaranteeing reduced tailpipe emissions, as targeted by the standard. • Foresight: lessons learned from US implementation. • Separate engine standards minimise the incentive for CO₂ and NO_x gaming, and encourage manufacturers to invest in expensive R&D programmes. • Soft measures and trailer standards diversify improvements across all industry players. 	<ul style="list-style-type: none"> • Thorough legislation may be relatively complex/expensive. • Stakeholders are divided on timing, in particular. • Unknown rebound effects do not fully guarantee that CO₂ targets will be met. • VECTO cannot currently assess AFVs intrinsically. • Separate engine standards do not incentivise whole vehicle improvements, but rather add an engine improvement ‘silo’.

Stakeholder	Advantages	Disadvantages
European Commission	<ul style="list-style-type: none"> • Relatively small administration costs; standards would need to be developed and evaluated. • Familiar regulatory development process. • Makes use of the existing VECTO tool which is tailored to EU market. • Maintains categorisation, metrics and drive cycles in VECTO. 	<ul style="list-style-type: none"> • Requires further development of VECTO to include trailer certification. • Requires development of a CFD model. • ABT and credits programmes add considerable complexity. • Considerable data collection requirements to set limits; however, no more than for EU LDV standards.
Member State authorities	<ul style="list-style-type: none"> • Whole vehicle standards help Member States to more predictably meet their GHG targets than other regulatory instruments. • Soft measure implementation at MS-level ensures Member States can tailor programmes to their particular region and situation. • Soft measures may be possible through centralised funding. 	<ul style="list-style-type: none"> • MS authorities are responsible for testing/certification. • Additional responsibility in setting up best practice portals and driver training evaluation. • Additional monitoring / enforcement required.
OEMs	<ul style="list-style-type: none"> • Flexibility mechanisms help minimise cost of CO₂ reductions. • Effective, novel technologies rewarded with credits. Alternative powertrains are centrally considered, even if not modelled in VECTO. • OEMs are able to improve vehicle performance flexibly, with the exception needing to meet engine performance standards. • Testing is not overly burdensome. Simulation approach remains cost effective. • Limited benefits for EU OEMs from closer alignment of engine standards – engine technologies could become more applicable between US and EU markets, and use of component sharing could thus increase. 	<ul style="list-style-type: none"> • Costs associated with meeting the standards. • Increased testing and compliance activities. • Allocation of credits to particular technologies may disrupt OEM strategy if not carefully implemented. • Separate engine standards are not desired by OEMs, who prefer whole vehicle improvement opportunities. • No initial ability for joint ventures to certify their tractor-trailer combinations.

Stakeholder	Advantages	Disadvantages
	<ul style="list-style-type: none"> • Medium-term standards offer clarity on which to base investment decisions. • Measure shares responsibility for CO₂ emissions throughout industry. • CFD simulation created collaboratively with authorities in a similar way to VECTO. 	
Supply chain	<ul style="list-style-type: none"> • The market for certain CO₂ reduction products is guaranteed. • Medium-term standards offer clarity on which to base investment decisions. • Potential for increased revenue for tyre manufacturers. 	<ul style="list-style-type: none"> • The supply chain will incur a large proportion of the innovation costs, though with associated returns. • Increased R&D required from tyre manufacturers.
Fleet operators	<ul style="list-style-type: none"> • Lower fuel costs through cost-effective technology application. • Increased clarity on vehicle performance during procurement. 	<ul style="list-style-type: none"> • Potentially higher upfront vehicle costs.
Drivers / transport SMEs	<ul style="list-style-type: none"> • Lower fuel costs. 	<ul style="list-style-type: none"> • Potentially higher upfront vehicle costs.
Consumers / Non-transport SMEs	<ul style="list-style-type: none"> • Potential for reduction in transport costs. 	<ul style="list-style-type: none"> • Negligible impacts.

4.8.5 High level impact assessment

Table 4.14: High level impact assessment of the illustrative policy option

Criterion	High level impact assessment
Cost-effectiveness and economic efficiency	<p>Both the Regulation and its setup are likely to be cost-effective. Technology cost-effectiveness is a primary consideration upfront as improvement pathways are largely left to the market. Testing itself remains simulation-based, including the development of a CFD model to maintain minimal cost burden to SME trailer builders.</p> <p>‘Low-hanging fruit’ improvements which have proven effects but limited penetration have been leveraged where possible. These are hypothesised to exist mainly from imperfect distribution of information, and include increasing the minimum rolling resistance</p>

Criterion	High level impact assessment
	<p>performance of tyres and facilitating technology demonstrations via best-practice portals.</p> <p>The certification process, monitoring and enforcement procedures are in line with existing air quality standard procedures and so are added cost-effectively.</p>
<p>Effectiveness, particularly in delivering GHG emissions reductions</p>	<p>Effectiveness will be predominately determined by the stringency of any limits set. Extensive flexibility mechanisms and complimentary soft measures increase the likelihood of the European fleet as a whole meeting the standards.</p> <p>Separate engine standards ensure that both CO₂ and NO_x improvements are considered, and gives confidence to manufacturers to invest in diesel engine improvements.</p> <p>CO₂ is the primary consideration of this measure, and not greenhouse gases, so that regulatory complexity is limited in any initial regulation. This will limit the effectiveness to tackling CO₂ and engine-out N₂O.</p>
<p>Administrative costs, including monitoring and reporting</p>	<p>Monitoring and reporting add material cost, though can occur through existing channels. Additional costs are expected relating to challenges in implementing ABT flexibility mechanisms under the EU-MS framework.</p> <p>The European Commission's role in developing a CFD model will demand further administrative costs, though this will act overall to save costs by reducing the impact on SME trailer manufacturers.</p> <p>The use of simulation for compliance assessment reduces administrative costs at the expense of increased development and model validation costs.</p>
<p>Coherence with EU policy objectives</p>	<p>The basis for setting standards is broadly technology neutral and flexible. The regulation is designed to ensure that emissions reductions delivered are consistent with those needed under a long-term trajectory – their success will depend on the stringency set.</p> <p>Separate engine standards reduce manufacturer flexibility and are at odds with a 'whole vehicle' optimisation approach, however they also act to reduce the incentive for gaming and encourage diesel engine improvements.</p> <p>Inclusion of trailer standards is in line with the European ethos of requiring improvements across the whole vehicle and better distributes responsibility across the industry.</p> <p>As it is not currently possible to simulate alternative powertrains within VECTO, any imbalance of the credit system could affect technology neutrality.</p>
<p>Other environmental and social impacts</p>	<p>The standards will contribute to reduced air pollution. Safety may be positively or negatively impacted from tyre rolling resistance improvements; this would need to be considered in any limit set.</p> <p>Enhanced CPC requirements position professional driving as a more qualified job, potentially increasing its attractiveness as a career.</p>

Criterion	High level impact assessment
EU added value	<p>It is important to have homogenous standards across the EU to protect the integrity of single market.</p> <p>The EU is needed to facilitate a useful pan-European ABT scheme to help manufacturers to meet the limits.</p> <p>Best practice portals shall be influenced by centralised EU knowledge, and potentially be set up through centralised funding programmes. Benchmarking of operator fleet performance may require monitoring across the EU, rather than on a MS level, and so the EU can facilitate the sharing of Member State data.</p>

5 Task 4: Stakeholder consultation

Box 4: Key points for Task 4

Task outline:

1. Task 4.1: Initial outreach to key stakeholders
2. Task 4.2: Stakeholder questionnaire and interviews

Key outputs:

- Summary of initial views on international schemes and their applicability to the EU
- Questionnaire for bilateral consultations
- Write-up of discussions from bilateral consultations and revised priority measures for the EU

5.1 Overview of methodology for Task 4

Task 4 was used to assess, modify and refine the policy options developed through Tasks 1-3. It is important that the options are reviewed by relevant experts in the EU and that those who will be most affected by any such policy are given a platform to raise concerns specific to them which the project team may not have sufficient insight to identify. This was performed through a series of questionnaires and detailed, semi-structured interviews – a template for the questionnaire which formed the basis of the interviews can be found in Appendix A5.

A broad range of industry organisations were invited to comment, representing a comprehensive array of perspectives. The consultation targeted those experienced in EU policymaking, such as HDV and component manufacturers, NGOs, transport operators and logistics associations. The result of this stakeholder consultation is a more finely tuned set of recommendations on the most appropriate options for improving HDV efficiency. The aggregated perspectives are documented in Section 5.2.2.

5.2 Outcome of stakeholder consultation

5.2.1 List of participants

In total, seven organisations contributed their perspective of the options developed in Task 3. The organisations and their method of input are displayed in Table 5.1.

Table 5.1: Stakeholders involved in the stakeholder consultation in Subtask 4.2

#	Organisation	Group	Response
1	ACEA – The European vehicle manufacturers association	Industry association	Interview
2	CLEPA – The association of European automotive suppliers	Industry association	Interview
3	CLCCR – International association of the body and trailer building industry	Industry association	Interview
4	IRU – The international road transport union	Industry association	Written response only
5	T&E – Transport and Environment	Non-governmental organisation	Interview

6	ICCT – International Council on Clean Transportation	Non-governmental organisation	Interview
7	DPDHL – A large fleet operator	Hauliers and operators	Interview

5.2.2 Stakeholder consultation conclusions and resulting modifications to the options

This section provides a high-level overview of stakeholder perspectives on key elements of each proposed policy option. The policy options in Section 4 have been modified where indicated in the text below.

5.2.2.1 Policy option 1: Technology requirements and soft measures

Overall, the stakeholders consulted expressed the least support for policy Option 1 (technology requirements and soft measures). The stakeholders agreed that while several specific measures could be helpful, this measure would not achieve the level of GHG emissions reductions required by the European Commission by 2030 and was not consistent with other long-term goals, such as the Paris Agreement. The majority of stakeholders agreed that elements of Option 1 should be used as complementary measures to support a GHG standards-based regulation. Respondents were also aware that to achieve significant GHG emissions reductions there must be a move to alternative fuels, which the stakeholders felt this option did little to encourage.

Minimum performance standards for certain technologies were considered by many to be a less than optimal approach, although some stakeholders believed they could be valuable if used in addition to setting standards. Specifically, a more stringent minimum performance standard for tyres (and re-treaded tyres) was supported by most stakeholders. One stakeholder pointed out that many operators have concerns about the lifetime of low rolling resistance tyres and instead select tyres with known durability benefits for hard-wearing axle applications, hence the removal of the worst performing tyres would reduce the effect of this. Another noted that despite the introduction of a labelling programme and standards, tyre classes have not notably changed, and hence the effectiveness of this depends heavily on the limits set. Otherwise, some stakeholders felt that minimum performance standards for refrigeration APUs and insulation performance for temperature controlled trailers focused on too small a component of the overall HDV emissions and would have a relatively limited effect. It was decided to maintain these elements in the option, however, given the identified potential of fuel cell and liquid-air APUs which have the potential to remove the point-source emissions of traditional diesel APUs entirely, and which work in tandem with already available trailer insulation improvement options (such as vacuum insulation panels). Using figures given in Section 4.5.3.1.1 it can be estimated that 0.5% of current total HDV CO₂ emissions are attributed to refrigeration APUs, which the project team considered suitably significant to maintain.

Mandating the application of certain technologies was the least supported element within the measure, principally as most stakeholders agreed that regulations should encourage improvements over the whole vehicle as opposed to optimising within component silos. Further, most stakeholders indicated that they believe any regulation should maintain technology neutrality. It was suggested by NGOs and manufacturers alike that adaptive and predictive cruise control, driver aids and aerodynamic features already have a high or increasing uptake due to market pressures, leaving little benefit to mandatory implementation. Gear shift indicators are also purported to have minimal effect due to the wide use of AMTs in Europe. Aerodynamic features were recognised by many stakeholders as a 'key lever' in reducing CO₂ emissions, but stakeholder concerns surrounded difficulty in ensuring the suitability of their application to the drive cycle of the vehicle. In particular, several stakeholders were concerned about the applicability of aerodynamic features for side-loading or intermodal transport due to the reduction in access and load space, even in light of the revised Weights and Measures Directive. Strategies such as requiring the fitment of a defined number of aerodynamic technologies from a selection were suggested to mitigate this, however most stakeholders agreed that better informed buyers would enable the market to achieve this organically and more efficiently. Overall, it was suggested that mandatory technology application had the potential to be useful in the event of exclusion of certain vehicle categories from a VECTO-based standard, but that otherwise this should be left to

the market. The only exception to this was to require OEMs to fit tyres with a performance some level greater than the required minimum. If a minimum tyre *class* was mandated, most stakeholders other than manufacturers agreed this could be effective. The option was not modified given that mandatory technology application was one of its key design features.

Best practice dissemination and driver training were widely considered to be significantly beneficial by the stakeholders consulted but principally as a complementary measure, and it was noted that in many cases these already exist within Member States. Stakeholders agreed that the benefits realised from driver training, in particular, are significant but difficult to quantify and rely on the driver adopting the practices continually. Periodic re-testing was thus supported, and the link between driver training and driver assistance technologies was reinforced with stakeholder support. Stakeholders commonly thought that the European Commission's role in best practice dissemination was to support Member States in setting up such programmes, but not to regulate. In terms of the content of best practice programmes, four of seven stakeholders were advocates of a framework whereby operators could record and benchmark their fleet fuel economy performance on a leader-board and could access information on the cost and real-world of technologies relevant to the duty cycle of their fleet (analogously to the US' SmartWay programme, or an expansion of The Netherlands' Lean and Green program). The remainder were in support of best-practice dissemination, but were unsure how this should be done. The option was updated to include this best practice content.

Trailer certification was considered to be an important part of the measure by all of the stakeholders; most believed trailers should be subject to standards. The main barrier raised was the cost of certification given that trailers are typically manufactured in small, bespoke batches by small-medium enterprises. Several stakeholders identified CFD as the most cost-effective way to certify trailers and considered real-world or wind tunnel testing to be too expensive for SME trailer manufacturers. It was highlighted that some SME trailer builders still used 2-dimensional models and would need further software to extrude these into three-dimensional models for any CFD simulation. Developing and validating such a simulation was estimated to take up to 5 years, and as such it was urged that development should be started as soon as possible. One stakeholder also suggested certification of trailer families, as opposed to individual designs, in order to reduce the burden on trailer manufacturers. This is partially done for the US regulations which separate trailers into aero box trailers, partial-aero box trailers and non-aero box trailers (refrigerated, long/short). The standards are then applied using a CAFE framework. The option was modified to clarify that trailers would need to meet standards and not only certify over VECTO drive cycles, to include trailer family certification and impose a CAFE structure.

T&E suggested that trailer certification requirements could be introduced more swiftly (i.e. preceding the development of a CFD model) given broad exemptions for trailer manufacturers producing less than a given number of trailers per year. The project team decided against modifying the option to include this as it is understood that even large trailer manufacturers typically create many, small production volume products. Alternatively, it was proposed that an initial introduction of trailer certification could focus only on 'standard' box trailers and make use of multiple default parameters, including for the coefficient of drag.

Stakeholders were unified in support of a generic-tractor, specific-trailer approach to trailer certification in VECTO, as is done in the US simulation. Whether specific-trailer, specific-tractor modelling was appropriate in the certification of whole combinations was contested with disagreement among stakeholders. Those in support suggested that it allowed OEM-trailer builder collaborations, though saw this as secondary to trailer certification with a generic tractor. Those against were concerned that this could benefit only the largest trailer manufacturers who worked with OEMs and may disrupt the market.

The timeline proposed for this option was not contested by or was coherent with the stakeholders' perspective, and thus was not modified.

It was suggested by the ICCT that the overall cost of this option could potentially exceed that of the standards-based options due to the intensive administrative demands of the soft measures.

5.2.2.2 Policy option 2: US-based measure

The US-based measure was the most well received of the options. The vast majority of the stakeholders thought that this option was the most effective approach to achieving CO₂ emissions reductions in

Europe. This measure was considered to be a technology neutral approach that incentivises improvements to the whole vehicle, other than its non-intrinsic encapsulation of alternative powertrains.

The stakeholders were split regarding the timeline for implementation of a US-based measure. The NGOs were among three organisations which were supportive of a two-phase approach (emulating the US implementation) so that standards could be introduced to the market as soon as possible. These stakeholders believed that delaying the measures would make achieving the long-term EU CO₂ reduction targets considerably more difficult and thus desired a swifter implementation of less stringent and less encompassing regulations before a second, technology forcing and detailed regulation. The ICCT stressed that the EU already has more data available and a more detailed model than the US had when implementing their Phase 1 standard and hence this approach could be worked on immediately. The remaining stakeholders (except one, who did not state a position) were less supportive of any 'fast' implementation and stressed the need for a robust measure that has been sufficiently tested for real world gains, in order to prevent perverse incentives or negative effects on the industry. Manufacturers, in particular, sought for limit values to be considered only after a robust baseline had been developed from 2018 certification data. The indicative timeline indicated in the option was not changed and represents an average of these perspectives.

The vehicle categories proposed were supported as stakeholders were content with the categories used in VECTO. Two stakeholders advised that CO₂ should be the emission of focus; one of these suggested only CO₂ should be considered as not to add complexity. It was decided that N₂O limits would be maintained due to agreement from the majority of stakeholders, assuming that issues surrounding the measurement of N₂O did not delay any eventual measure.

All stakeholders supported the use of drive cycles and metrics already in VECTO. Two stakeholders suggested use of volume-based metrics (e.g. gCO₂/m³km) in the standard, however were not yet able to detail when to apply either (or both) of a weight-based (gCO₂/tkm) or volume based metric. In general, they suggested, it would be more representative to use a volume-based metric when the duty cycle of the vehicle was frequently limited by volume available ('cube-out') rather than weight permissible ('gross-out'). The option has not been modified as the study is not addressing the standard in this level of detail.

Most stakeholders were supportive of separate engine standards and argued that engine improvements are a key lever for CO₂ emissions reductions. Conversely, manufacturers suggested that separate engine standards should not be duplicated from the US approach as the engine building market is vastly different (dominated by large players in the EU rather than many small manufacturers as in the US) and it does not optimise improvements over the whole vehicle. Objectively, there are a variety of advantages and disadvantages to this set-up⁶². Some of the participant's most prevalent arguments for maintaining separate engine standards include:

- Engine standards maintain a link between standards for criteria pollutants and those for CO₂. Without engine CO₂ standards gaming strategies are made easier - for example, engines could be tuned to minimise NO_x emissions during EURO standard engine testing while having high CO₂ emissions, but the opposite during vehicle CO₂ testing and in-use operations.
- Engine CO₂ standards follow existing test procedures and their use aligns with the current market structure. The industry is already familiar with the engine duty cycles (used for testing for criteria pollutants) and therefore minimises the additional testing burden. Engines are currently sold into many different vehicle platforms, and certifying engines allows the market to maintain this structure.
- Engine standards drive improvements in both engine and vehicle technologies, the former of which are often expensive. This is important as improvements in engine technology are considered a major lever for potential fuel efficiency gains. Standards would help provide engine technology investment clarity for both independent engine manufacturers and vertically integrated vehicle manufacturers.

⁶² These are explored in detail in (ICCT, 2014).

- T&E further suggested that having a powertrain standard rather than an engine standard could encourage OEMs to invest in alternative technologies rather than focusing on conventional powertrains.

However, as highlighted by manufacturers, separate engine standards also have several drawbacks, including:

- Engine standards detach engine requirements from vehicle design, which can lead to the promotion of non-optimal powertrain design.
- Having engine standards also reduces the flexibility of compliance for OEMs and may prevent them from pursuing the most cost-effective compliance pathway.
- Furthermore, the test cycles used for engines have been criticised for poor representation of in-use driving, and therefore maintaining standards based on these cycles perpetuates inappropriate engine optimisation. This can result in engine efficiency improvements that do not necessarily translate into real-world fuel savings.

Certainly, whether separate engine standards are to be kept should be further explored, however could not be considered in this project due to limited time. In summary, no changes were made to the option.

Most stakeholders felt that to achieve the long-term emissions reduction targets, any measure must include alternative fuels and powertrains. It was broadly desired that alternatively-fuelled vehicles would be included intrinsically in the VECTO model, and most stakeholders stressed the importance of having a mechanism to incentivise research and development in these areas. Several stakeholders were concerned that the cost and length of time required to include alternative powertrains in VECTO would be too great for the first implementation of standards. Instead, most stakeholders were satisfied with the implementation of a fair and representative credit system as exists in the US measures. No stakeholders disagreed with the use of advanced technology credits. ABT provisions were supported by manufacturers, in particular, if implemented carefully. None of the stakeholders had an aversion to a US CAFE style regulation.

5.2.2.3 Policy option 3: Japanese-based measure

This option was commonly considered by stakeholders to be less effective than a US-based measure, but more effective than the technology requirements and soft measures. The stakeholders agreed that the Japanese measures were domestically successful but to a lesser degree than the US approach, even considering the lesser stringency of the Japanese limits. The stakeholders generally considered this option to be less technology forcing than the US approach as manufacturers are potentially disincentivised to innovate: innovation is likely to increase the stringency of the next iteration of the standards so manufacturers may seek only incremental improvements. Further, it was identified by multiple stakeholders that manufacturers may consider delaying the introduction of innovations to the market if they believed they were not likely to achieve the top runner in a certain period, but rather wait for the next iteration. Without a credit system, perverse incentives could be difficult to mitigate.

The second most common view of the top runner standard was that it does not give the market sufficient clarity of upcoming requirements. Setting targets every year, or every few years, results in a moving target for manufacturers and suppliers who would find it difficult to know when to time investments and upscaling operations. It was felt that this short-term cycle could slow the introduction of new technologies into the marketplace through dis-incentivising OEMs and suppliers from investing in fundamental advances which carry increased risk.

One method of combatting the lack of intrinsic incentive for innovation in the top runner approach is to add a fair credit system. Stakeholders raised support for incentivising advanced powertrains (if not included in the VECTO simulation) and flexibilities via a credit system. Manufacturers were in favour of maintaining ABT provisions if implemented well. Given the ability of a credit system to reduce perverse incentives (through potential 'timing the market' by manufacturers introducing new technologies) and counteract the hindrance to advanced technology development it was decided to add both ABT and advanced technology credits to the option. The large number of vehicle bins in the top runner could make any ABT scheme more susceptible to gaming if it is possible to trade credits too liberally, however, so careful implementation would be required.

Stakeholders agreed with the proposed system of disaggregation, using HDV category (as defined in VECTO), duty-cycle and GVW, but warned of the large number of limit values required and associated complexity. It was highlighted that unless limits were set very carefully, gaming between the many categories could result through mild adjustments in vehicle size. The ICCT suggested mitigation via the use of a linear function instead of a stepped approach to set limits. Overall, as this disaggregation is a necessary characteristic of the top runner approach, no change was made to the option.

Proposing to start with HDV categories 4, 5, 9 and 10 was supported. Most stakeholders reiterated the need for volume-based metrics to support the proposed weight-based metrics and were comfortable with those already used in VECTO. The option was modified to certify vehicles using $\text{gCO}_2/\text{m}^3\text{km}$ in addition to gCO_2/tkm , though how this would work in practice has not been discussed. Given the large number of bins in which limits must be set, the addition of another metric will need to be carefully implemented – perhaps only for specific HDV categories which more commonly ‘cube-out’.

Stakeholders were not particularly concerned that the option did not place requirements on secondary systems. The option has not been modified to include them.

Again, stakeholders were consistently divided on whether separate engine (or powertrain) standards should feature in the measure, weighted in favour of including them. The option was not modified, to maintain diversity with Policy Option 2.

Overall, support for the top runner approach was mediocre. One NGO conjectured that this method for setting standard could be used initially to define a baseline vehicle and bring in a first phase of standards before certification data is available, but then to revert to a US-style approach when more data was available to set a robust baseline.

5.2.2.4 Other

A timeline for expansion of VECTO’s capabilities was requested by one stakeholder, in order to enable new technologies to be brought to market smoothly. It was suggested that such a timeline would allow companies to better time their investments into new technologies and enable the resultant benefits to be realised within certification immediately.

Three stakeholders supported further flexibility in the Weights and Dimensions Directive, especially considering length and weight. It was argued that not only could this improve the efficiency of the freight industry as a whole, but it could be adapted to incentivise new technologies. For example, one stakeholder suggested a one-tonne exemption for alternatively-fuelled tractor-trailer vehicles, as is currently allowed for rigid vehicles. Manufacturers and the IRU stated that adoption of the European Modular System (EMS) for longer and heavier vehicles could dramatically increase efficiency.

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7 Appendices

Appendix 1: Review of the VECTO simulation tool

Appendix 2: Summary of the Draft Certification Procedure

Appendix 3: Contents of the Technical annex to the Draft Certification Procedure

Appendix 4: EU HDV Fleet Composition

Appendix 5: Stakeholder consultation questionnaire template

A1 Appendix 1: Review of the VECTO simulation tool

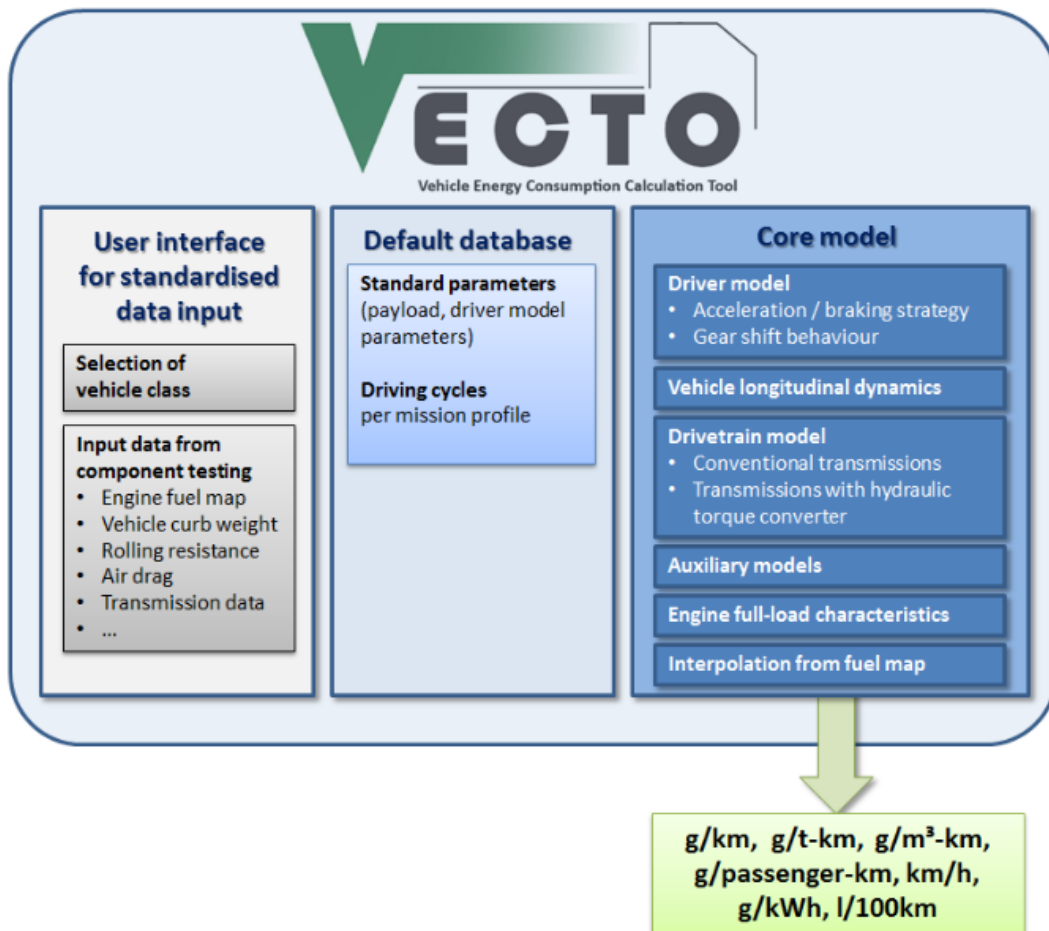
The Vehicle Energy Consumption Calculation Tool, referred to as VECTO, is a simulation tool that is being developed by the European Commission as the backbone of a certification methodology for heavy duty vehicles (HDVs). Its principal purpose is to quantify CO₂ emissions from new heavy duty vehicles. It achieves this by modelling the key components of a heavy-duty vehicle and simulates a virtual drive on representative routes. The goal is to provide a standardised way of calculating the energy consumption (fuel consumption) and corresponding CO₂ emissions.

The VECTO model is a *downloadable executable file* and not a model that runs using a proprietary application, e.g. a Microsoft Excel model.

A1.1 VECTO overview

VECTO takes the results from the testing, or measurement, of key relevant components of the HDV as inputs, and calculates the fuel efficiency and CO₂ emissions of their use together (i.e. for the whole vehicle) driven over vehicle-class specific mission profiles. VECTO is written in Visual Basic.NET, to create executable code which can be run without proprietary software. This programming approach makes the model free to use, and more widely accessible. An overview of the model's methodology is given in Figure 7.1 below:

Figure 7.1: Diagrammatic overview of VECTO⁶³



A1.2 VECTO history

VECTO has been developed by the Commission (DG CLIMA and JRC) with contractor support (principally the Technical University of Graz, also with development by Ricardo of a more advanced bus/coach auxiliaries module) since 2011. DG CLIMA is the lead organisation for this project and further developments of the model are expected to occur in the future.

As the model has been developed, stakeholders such as ACEA, OEMs and component manufacturers have also been involved. They have both provided key input and test vehicles and reviewed the model as it has been developed.

A1.3 Detailed description of the VECTO model

A1.3.1 Scope

The need for the VECTO tool arises because, unlike light-duty vehicles, for which it is relatively straight forward to define “vehicle types” and to test on a chassis dynamometer to quantify their CO₂ emissions, HDVs are more complicated. The variety of vehicle types (rigid, semitrailer, tractor, bus, coach, etc), cabs and bodies, axle configurations, wheels and tyres fitted, engines and gearbox options means there

⁶³ Figure taken from JRC presentation, see http://www.theicct.org/sites/default/files/Fontaras%20ICCT_presentation.pdf

are millions of possible types. As such, VECTO has been designed to simulate across these options as described below.

A1.3.1.1 Operating modes

VECTO can operate in one of two modes:

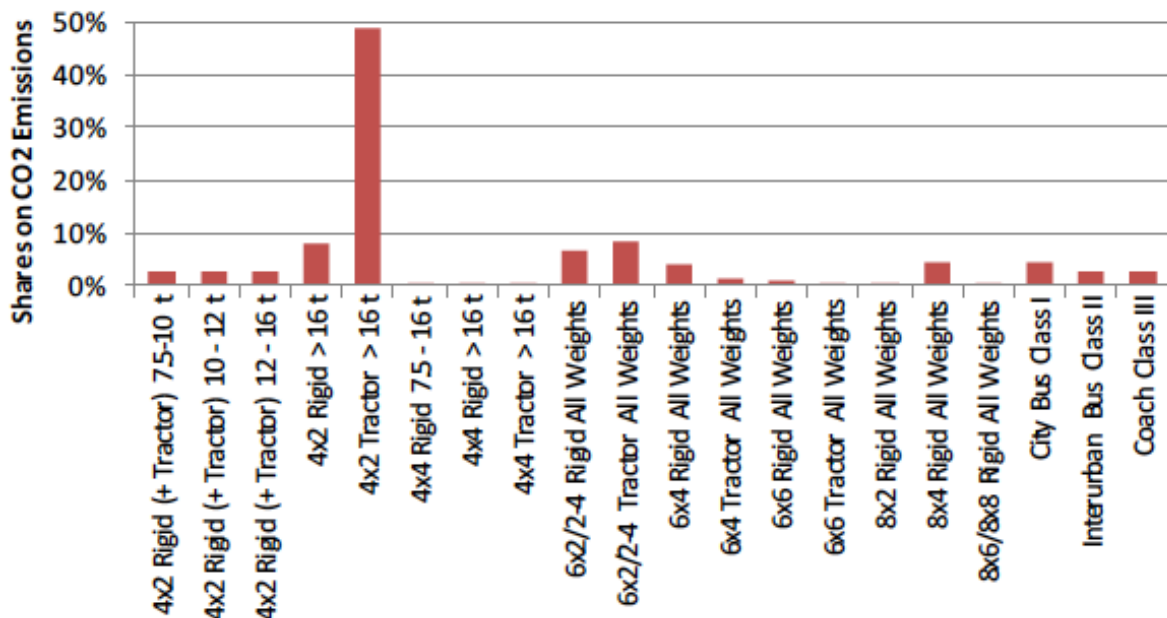
- A *declaration mode*, where all generic data and the test cycle are allocated automatically as soon as the *vehicle class* is defined.
- An *engineering mode* is also offered, where the user can select and change all input data to allow recalculation of test data e.g. for experimenting and model validation purposes.

The engineering mode allows the model to be used with a wide variety of “vehicle non-standard” conditions, which include both engineering aspects, and operational aspects, i.e. enabling bespoke driving patterns to be simulated. In addition, it allows the model to be used to calculate the fuel consumption based on an engine load cycle (engine speed and torque, rather than a vehicle driving cycle). This would enable VECTO to calculate the fuel consumption from, for example, the regulatory engine WHTC, so that the VECTO calculated fuel consumption can be directly compared with that obtained from the engine certification test on a transient engine dynamometer. This would validate the engine (.veng) map used.

A1.3.1.2 Vehicle types covered

The modular structure of VECTO allows the number of vehicle types that are defined to be extended, relatively easily. To date the development of VECTO has principally focussed on two somewhat generic vehicles, a 12-tonne GVW rigid, two axle box-truck, and a tractor unit, with a generic trailer, which comprise a 40-tonne GVW articulated vehicle. (A 24-tonne coach is also defined for use within the Engineering Mode.) However, the full segment structure is presented in Table 7.1 and Table 7.2 below, with the focus of attention on the categories responsible for the greatest emissions (see Figure 7.2). A range of internal testing has also been conducted by industry organisations providing support to the VECTO development process.

Figure 7.2: Estimated share of total CO₂ emissions from different HDV categories



Source: Chart from (TU Graz et al, 2012) based on analysis of data provided by ACEA in (AEA/Ricardo, 2011), accounting for typical mileage and fuel consumption. Prioritisation based on discussions with the Commission.

Table 7.1: Classification of the N category vehicles

Identification of vehicle class				Allocation of mission profile and vehicle configuration							
Axle configuration	Chassis configuration	Maximum GVW	Vehicle Class	Long haul	Long haul (EMS)	Regional delivery	Regional delivery (EMS)	Urban delivery	Municipal utility	Construction	Standard body allocation
4x2	Rigid	>3.5 – 7.5	(0)								
	Rigid (or tractor)*	7.5 - 10	1			R		R			B1
	Rigid (or tractor)*	>10 - 12	2	R+T1		R		R			B2
	Rigid (or tractor)*	>12 - 16	3			R		R			B3
	Rigid	>16	4	R+T2		R			R		B4
	Tractor	>16	5	T+ST	T+ST+T2	T+ST	T+ST+T2				
4x4	Rigid	7.5 - 16	(6)								
	Rigid	>16	(7)								
	Tractor	all weights	(8)								
6x2	Rigid	all weights	9	R+T2	R+D+ST	R	R+D+ST		R		B5
	Tractor	all weights	10	T+ST	T+ST+T2	T+ST	T+ST+T2				
6x4	Rigid	all weights	11	R+T2	R+D+ST	R	R+D+ST		R	R	B5
	Tractor	all weights	12	T+ST	T+ST+T2	T+ST	T+ST+T2			R	
6x6	Rigid	all weights	(13)								
	Tractor	all weights	(14)								
8x2	Rigid	all weights	(15)								
8x4	Rigid	all weights	16								
8x6 8x8	Rigid	all weights	(17)								

Notes: * in these vehicle classes tractors are treated as rigid vehicles but with specific curb weights of tractor.

R = Rigid & standard body
T1, T2 = Standard trailers
ST = Standard semitrailer
D = Standard dolly

- Categories 4, 5, 9 and 10 are expected to be covered by the upcoming certification regulation, with certification of CO₂ emissions and fuel consumption of new vehicles likely in 2019.
- Categories 1, 2, 3 may be covered in the future for certification likely one year later compared to the previous categories.
- Categories 11, 12 and 16 may be covered at a later stage.

Table 7.2: Classification of the M category vehicles

Bus class	First approach: EU registration classification 2001/85/EU (I, II,III)	Second approach: if vehicle is registered as two different classes		Cycle allocation
		Class I or II	Class II or III	
City	Class I	Low floor, low entry*, double decker**		Heavy urban, Urban, Suburban
Interurban	Class II	Luggage compartment	Floor height ≤ 900 mm	Interurban
Coach	Class III		Floor height > 900 mm double decker	Coach

A1.3.1.3 Powertrain types covered

Currently VECTO only simulates conventional internal combustion engines (principally compression ignition, diesel fuelled engines, although All reference fuels described in the Euro VI regulation can be simulated with VECTO, see section A1.3.1.5), and it does not cover hybrids, electric, or fuel cell vehicles.

A1.3.1.4 Driving cycles covered

The description of driving cycles for HDVs is fundamentally different to those specified for LDVs. Most LDVs follow a specified time–speed profile, however this is impractical for HDVs as their time–speed profile is markedly affected by the load they are carrying. Therefore, VECTO specifies *mission profiles* rather than driving cycles. Mission profiles define the distance to be travelled and the target speed and road gradient for each metre of the route. Some mission profiles exceed 100km in length.

The effect of this is illustrated by the use of an example. If, during a long haul cycle, a truck passes a roundabout leading onto a dual carriageway, then its target speed goes from stationary to, for example, 90kph in a metre. For an empty articulated truck, its engine’s peak power and the vehicle’s low weight, enables it to accelerate moderately swiftly to this target speed. However, for the same truck when fully laden, the same engine peak power acting on, for example, over twice the vehicle mass, means that its rate of acceleration is under half that of the empty truck. Consequently, for this same truck with these two different loads, the mission profiles assessed would be the same, but the time it would take for the vehicles to travel the total distance would vary, it being longer for the heavier vehicle.

At present there are ten different mission profiles specified in VECTO. These, and the types of vehicle that might be assessed using them are tabulated in Table.7.3.

Table.7.3: Types of HDV and their associated mission profiles in VECTO

Mission profile for freight HDVs	Broad vehicle category	Mission profile for passenger HDVs	Broad vehicle category
Urban delivery	Rigid truck	City-bus heavy urban	Bus
Regional delivery	Rigid and articulated truck	City-bus urban	Bus
Long haul	Rigid and articulated truck	City-bus suburban	Bus

Mission profile for freight HDVs	Broad vehicle category	Mission profile for passenger HDVs	Broad vehicle category
Construction	Rigid truck	Interurban bus	Bus
Municipal utility	Refuse collection truck	Coach	Coach

A1.3.1.5 Fuels covered

Currently VECTO is configured to provide the fuel consumption and CO₂ emissions from heavy duty vehicles fuelled with diesel reference fuel (B7, meeting the fuel specification given in Annex IX of Regulation 582/2011). It is planned that in the future this will be expanded so that VECTO will cover all five reference fuels included in the Euro VI regulation (B7, Ethanol for dedicated CI engines (i.e. ED95), and the three grades of (bio)methane fuel G_R, G₂₃ and G₂₅.)

A1.3.2 Inputs

VECTO is still being developed, and consequently the information provided in this section is appropriate to the latest version at the time of writing (2016_07_19-VECTO-3.0.4.565). Many of the linked files were created in June or July 2016.

An excellent summary of the details required as inputs to VECTO, and their specifications, is given in the Technical Annex to the Draft Certification Procedure. The versions available on DG CLIMA's website are dated 15.05.2014⁶⁴. Notwithstanding, the key information they contain remains relevant to the July 2016 VECTO (version 3.0.4.565) except for some minor changes which are updated in this document.

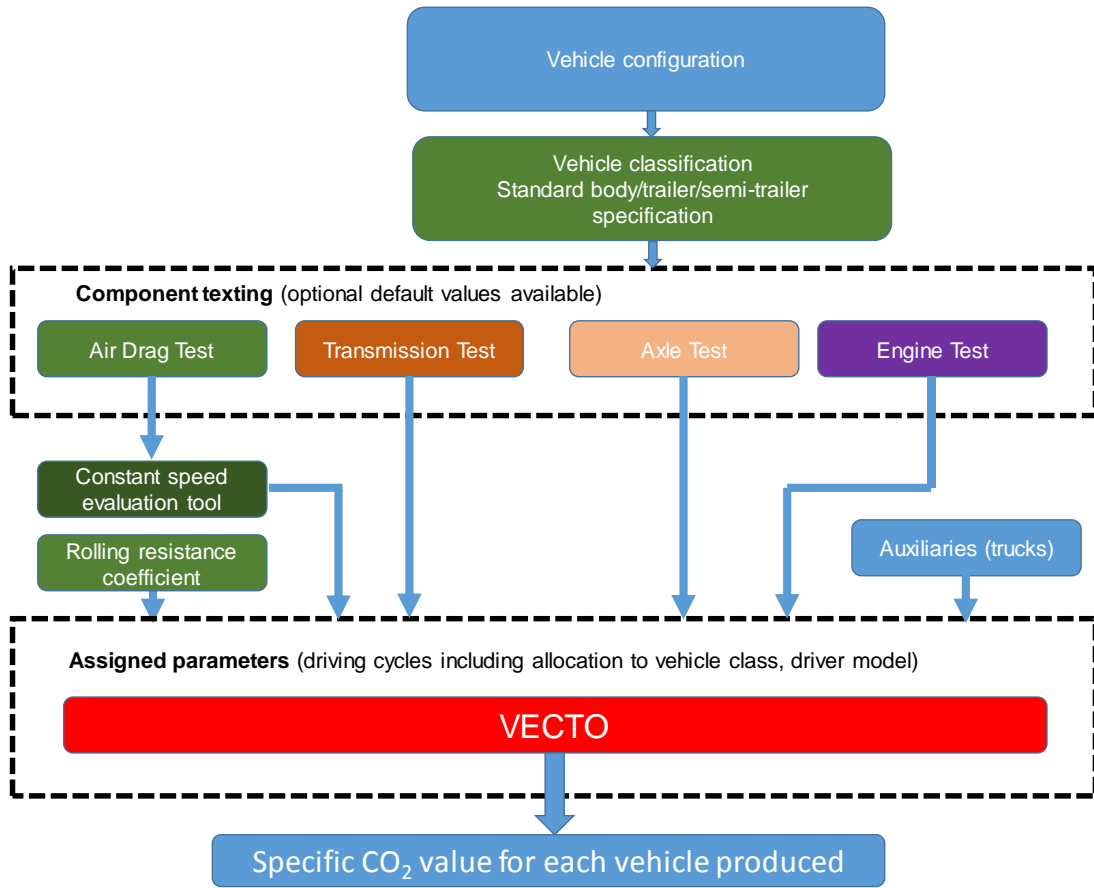
An overview of the VECTO process scheme is summarised in Chapter 3 of the Technical Annex, entitled: "Technical Approach". This is shown in Figure 7.3, which provides more detail than the higher level overview shown in Figure 7.1.

Figure 7.3 is a redrawn version of Figure 3-1 of the technical annex, but with many of the components in the process scheme being coloured in this version. The colour coding indicates the associated VECTO file that contains the general or component testing information described and shows the flow of information, e.g. from component testing, into the VECTO model. The principle exception is the air drag test, where data is to be collected according to Section 5.1.2 of the draft test procedure using constant speed testing. These data are then fed into a constant speed evaluation tool, which processes them, to generate a mean drag force, which is the parameter fed into VECTO.

The details of a whole vehicle simulation run (or 'job') are held in the corresponding ".vecto" file. The pathway to this file is identified in the job file when the VECTO application is run – see Figure 7.4. The interface for each VECTO file is displayed in Figure 7.5.

⁶⁴ Technical Annex for VECTO is available from http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/technical_annex_en.pdf

Figure 7.3: VECTO process scheme (from EC Technical Annex⁶⁵)



Key

	Data input via .vecto job file
	Data input via .vveh file
	Data input via .vgbx file and via (ln)direct. vtlm file
	Data input via Axle. vtlm file
	Data input via .veng , with full load curve via .vfld file and with fuel consumption map via .vmap file
	Data input from drag test into “Constant speed evaluation tool” and then into VECTO

⁶⁵ Technical Annex for VECTO is available from http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/technical_annex_en.pdf

Figure 7.4: Graphic User Interface for VECTO that appears on starting the application

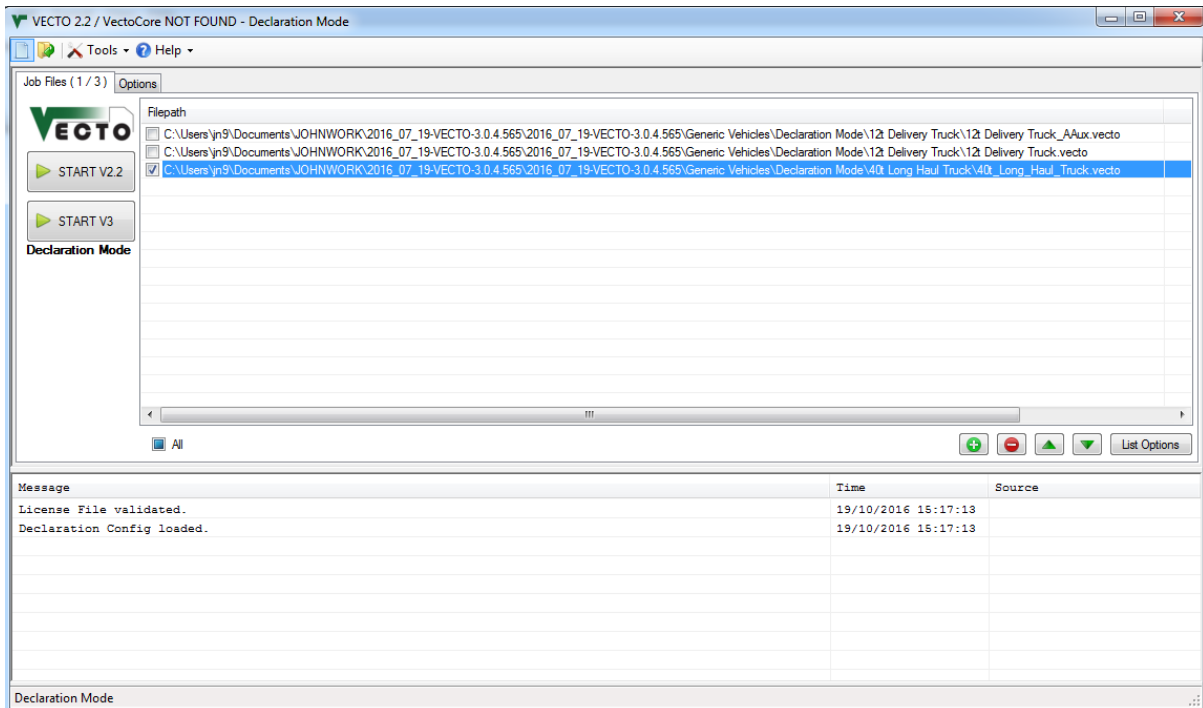
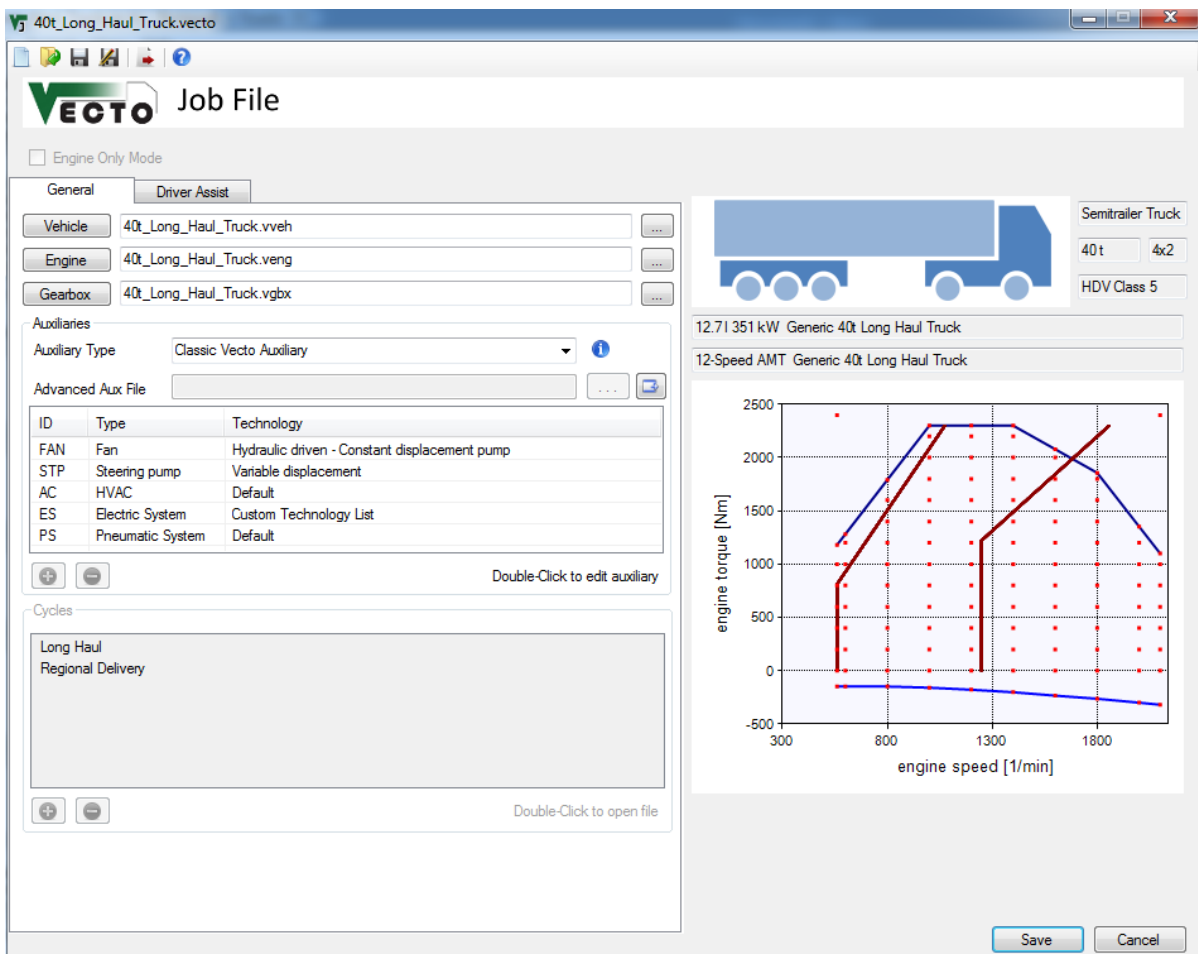


Figure 7.5: Illustrative VECTO job (.vecto) file



There are 45 inputs specified in Chapter 3 of the Technical Annex (Table 3-1 of the draft Technical Annex, published by the Commission on 15th May 2014). The only difference noted between these inputs and those required when running VECTO version 3.0.4.565 (discussed throughout this document) is that instead of two inputs 11 & 12, or 13 & 14, these have been combined into a single variable, “drag factor” which is the product of the drag coefficient and the vehicle’s frontal (cross sectional) area.

Column 2 of the list of input parameters tabulated in the Technical Annex indicates when inputs are arrays rather than single values, and when a string refers to a file path. Column 3 of the list of input parameters tabulated in the Technical Annex indicates the variable types: strings, Boolean variables, decimal numbers or to be selected from a drop-down list.

In summary there are seven types of files, which contain input parameters, as summarised below:

- .vecto - the controlling job file.
- .vveh - specifies the vehicle classification, its weight characteristics and some key retarding coefficients.
- .veng - specifies information about the vehicle’s engine, including its displacement, idling speed, inertia, and the paths to its "Full Load Curves" and its "FuelMap".
- .vflc - file specifies the engine’s full load power curve.
- .vmap - file specifies the engine’s fuel consumption characteristics.
- .vgbx - file specifies the gear ratios for each gear, and for the final drive.

.vtlm - files specify vehicle torque loss maps with different files for the direct and indirect gears, and for the axle.

Further information on these seven different data file types are given in Table 3-1 of the draft Technical Annex, published by the Commission on 15th May 2014.

A1.3.3 Outputs

This section covers the general outputs from VECTO, the format and level of detail of information about a vehicle's CO₂ emissions and fuel consumption that VECTO generates.

When VECTO is run in *Declaration Mode*, a number of output files are created for each ".vecto" file. For the 12-tonne rigid truck a standard declaration mode run generates output for nine different drive-cycle / loading conditions, as tabulated in Table.7.4, below, although the empty run may not be included in the declaration mode at the end.

Table.7.4: Summary of drive cycle and payload for all the .vmod files created for 12t delivery truck using the Declaration Mode simulation

	Urban	Regional	Long haul
Empty	✓	✓	✓
Reference weight	✓	✓	✓
Fully laden	✓	✓	✓

A file (.vmod) is generated for each of these, whose generic name is of the form: "12t Delivery Truck_drive cycleLoading.vmod". In addition a further four files are written:

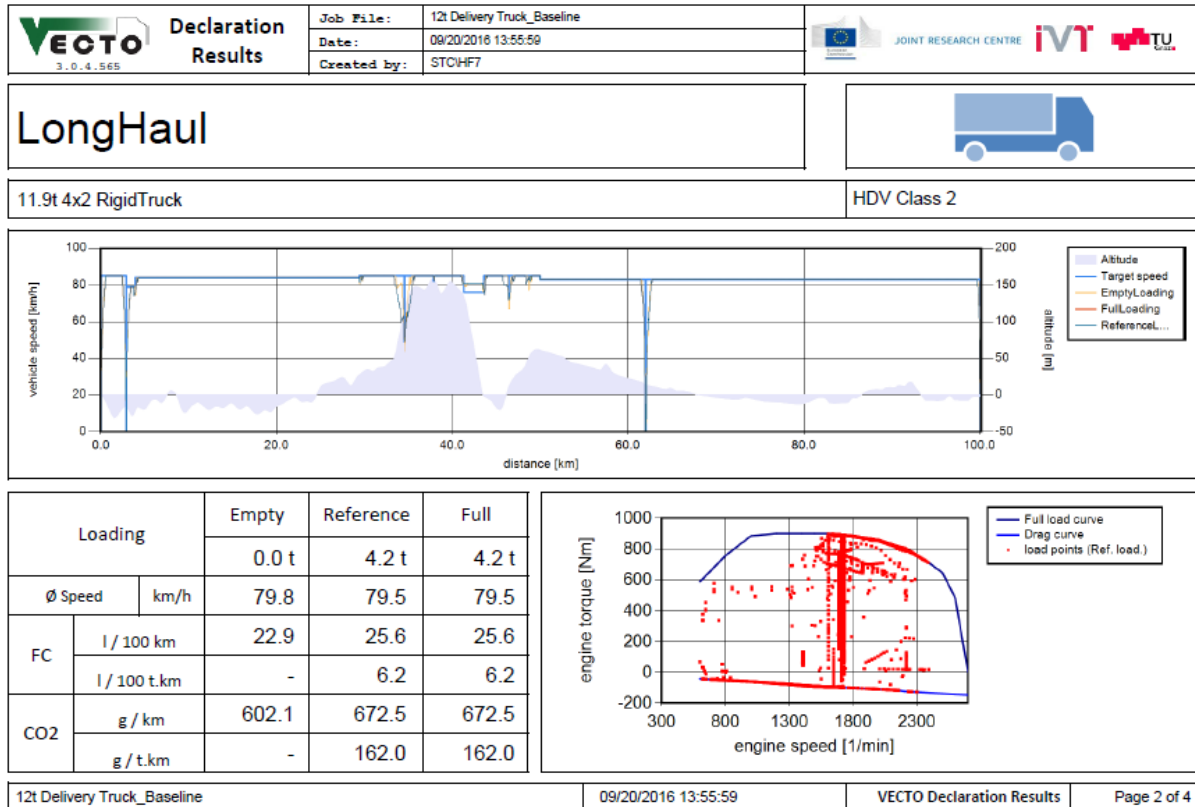
- 12t Delivery truck.vecto
- 12t Delivery truck.vveh
- 12t Delivery truck.PDF
- 12t Delivery truck.vsum

The .vecto and .vveh files are key input files and were discussed in the previous section. However, it might be that some file inputs/parameters of the originally loaded input file are edited within VECTO immediately prior to running the simulation. Therefore VECTO rewrites the input files with the parameter values *actually used* in the simulation at the same time as it writes the output files. The information content of these two file types is unaltered from that previously discussed.

The PDF file contains a summary of the fuel consumption and CO₂ emissions calculated from the whole run. It gives the outputs for each drive cycle/mission separately and summarises, numerically, the fuel consumption (fuel consumption) in both units of litres fuel per 100km and referenced to each tonne of payload, i.e. litres of fuel per 100 *tonne*-km. It also gives CO₂ emissions expressed in g/km and g/tkm using some standard, default, fuel characteristics to convert litres of fuel into gCO₂ emitted. It does these for three loading states: empty, full and at the reference weight for the drive cycle. The PDF file also shows, graphically, a plot of the vehicle speed against distance travelled and its altitude. (The latter is from integrating the area under the distance-gradient specified in the mission profile). A smaller graph gives the engine torque against engine speed for the full power load curve, the engine drag curve (i.e. the retarding torque of the engine when motoring) and the load points specified in the simulation for the run at the reference load each plotted as torque against engine speed.

The ".vsum" file contains a considerable quantity of summarised (whole cycle) numerical "intermediate calculation" data. This is in fact a CSV file, comprised of a column of parameter labels and a column containing the parameters' sum over the cycle for each of the nine mission profiles / load weights runs summarised in Table.7.4. The file contains 51 columns of data, as summarised in Table.7.5.

Figure 7.6: Illustrative output page within PDF file from a VECTO run using the 12t rigid truck, over the long haul drive cycle



The “.vmod” file contains 46 columns of data, as summarised in Table.7.6.

The data in the “.vmod” file is calculated from the individual second by second modal “.vmod” files. These contain a matrix of 46 columns of data, with the first two being the time since the start of the run, and the time interval since the last row of data. The simulation is generally undertaken at 0.50 second intervals, but this is not constant. In particular, when the vehicle is stationary the power consumed during the whole stationary period is summed and output as a single row of data. Consequently, for the 12t delivery truck over the regional delivery cycle, the overall time taken was 1,590 seconds, and the simulation generated 2,953 rows of data.

Table.7.5: Information tabulated in the “.vsum” output file

Information content	No of data columns
Key input parameters like input file, cycle, vehicle mass and load	6 columns
Whole run time, distance, speed, change in altitude	4 columns
Fuel consumption information	12 columns
CO ₂ for whole cycle (g/km & g/tkm)	2 columns
Powers	4 columns
Energies (kWh) for engine out, and the energy used by key auxiliaries, overcoming aerodynamic losses, rolling resistance and changes in altitude.	16 columns
Overall average accelerations, mean positive & negative accelerations	3 columns

Information content	No of data columns
Times spent accelerating, decelerating, cruising and stopped	4 columns

Table.7.6: Information tabulated in the “.vmod” output file

Information content	No of data columns
Time & time increment since last row of data	2 columns
Total distance travelled	1 column
Actual & target speeds	2 columns
Acceleration, gradient, gear selected	3 columns
Engine speed & load	2 columns
Vehicle torques	2 columns
Power values at a whole range of points in the vehicle simulation from a range of retarding forces, and auxiliaries	29 columns
Instantaneous fuel consumption values	5 columns

A1.4 Legislative framework

The current approval of HDVs is according to the directive 2007/46/EC, and its amendments, entitled: “Establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles”⁶⁶. In terms of themes/major areas, type approval of whole vehicles involves:

- Environmental systems;
- Active safety systems;
- Passive safety systems;
- Lighting equipment; and,
- Other requirements.

Type Approval legislation is the responsibility of DG GROW, who would oversee the preparation of any certification legislation that was within this regulation. The type approval of HDV types is granted by the Technical Services/Type Approval Authorities of the Member States, organisations agreed between the Commission and Member States. The current environmental legislative framework (covering exhaust emissions) are specified in Regulation EC 595/2009 and implementing regulations EC 582/2011 and 64/2012. These are known colloquially as Euro VI and apply to all *engines* to be used in HDVs. They currently contain:

- Exhaust emissions standards
- Conformity of production requirements;
- Durability of pollution control devices; and,
- In-service conformity (using PEMS testing).

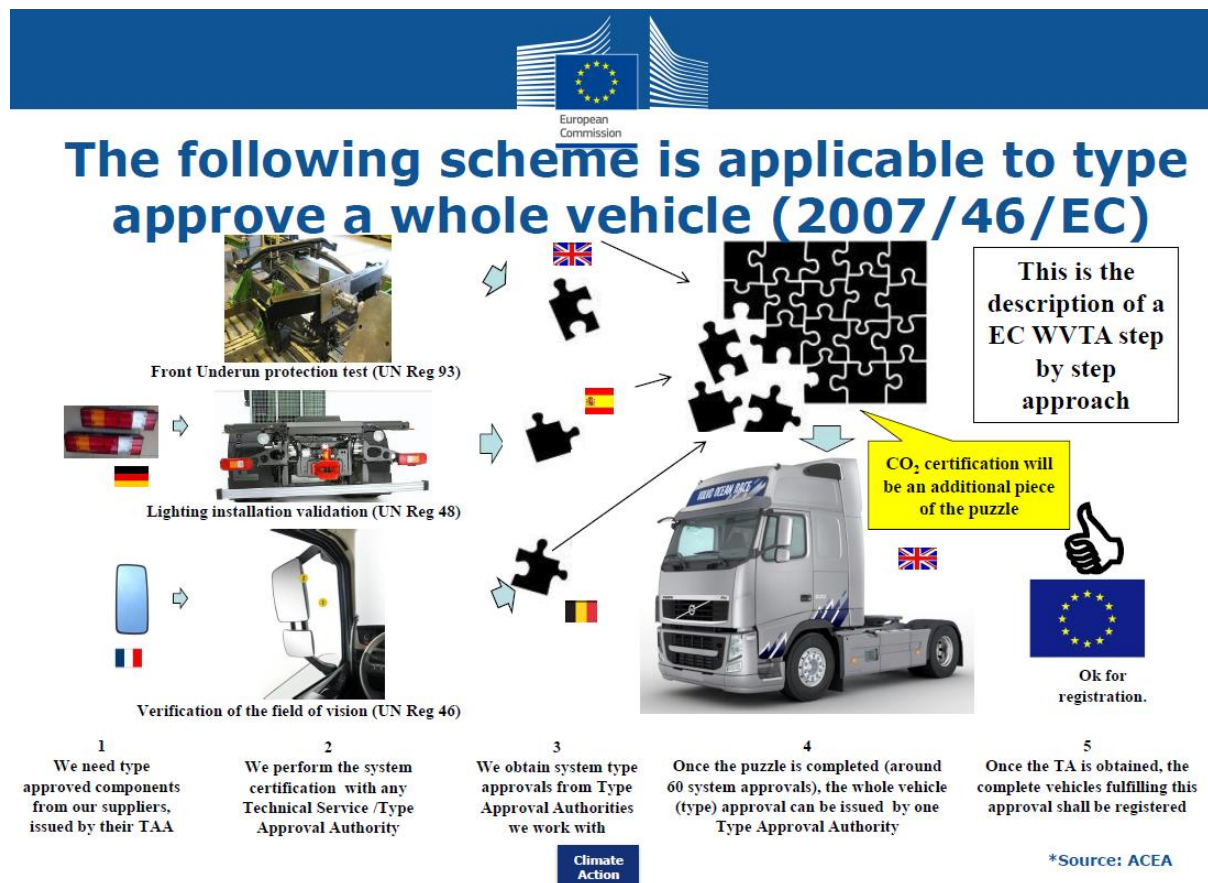
The exhaust emissions standards cover pollutant emissions. They specify the maximum emissions of a list of species per kWh of engine output. The species regulated are: carbon monoxide (CO), total hydrocarbons (HC) - or non-methane hydrocarbons (NMHC) and methane (CH₄) for PI engines - oxides

⁶⁶ This is an enabling directive, and can be viewed as a living document - since its publication it has had 25 amendments to 3rd February 2015.

of nitrogen (NO_x), particulate matter mass (PM) and particulate matter number (PN). They currently do not include carbon dioxide (CO₂) the key output parameter from VECTO.

It is understood that the CO₂ certification process will become an additional aspect of whole vehicle type approval, as is illustrated in Figure 7.7.

Figure 7.7: Overview of HDV type approval for whole vehicles, and where CO₂ certification is expected to be added.⁶⁷



A1.5 Practical implementation

A1.5.1 Technologies currently captured by VECTO

As described in the previous chapters, VECTO already acts to promote a range of technologies/eco-innovation opportunities that are currently captured in the most recently released version. Further options may also be captured in the future as the software is further developed, or may need a different procedure for being taken into account in the certification. It is assumed that VECTO-based certification occurs using the *Declaration Mode*, rather than the engineering mode. The additional flexibility within the engineering mode would allow some eco-innovation opportunities, listed in Section A.4.2, to be included.

An important aspect of including innovative technologies is to have certification, and ex-post verification procedures agreed, so that the impact of the technology can be accurately, consistently, and demonstrably included. For many areas where an eco-innovation is possible in principle, industry

⁶⁷ This graphic was presented by DG CLIMA in a presentation entitled: "Heavy duty vehicles' CO₂ legislation in Europe & VECTO simulation tool" at the 8th Forum on Energy Efficiency in Transport: "Energy Efficiency Regulation for Heavy-Duty (HD) Vehicles" in September 2015, in Mexico.

accepted certification and ex-post verification procedures are not agreed and different manufacturers and suppliers characterise their products in different non-standard ways. This is a barrier to enabling like-for-like consistent comparison. This lack of agreed procedures includes the characterisation of standard components, for example, alternators, or compressors for the vehicle’s pneumatic systems. The Commission is consulting with ACEA on work already underway by ACEA members to develop and agree suitable procedures for some systems such as alternators and compressors (i.e. as referenced in recent work on bus auxiliary systems by Ricardo for DG CLIMA).

A range of example technologies where developments are expected to reduce CO₂ emissions and fuel consumption are summarised in Table.7.7 (each of these are included in the current version of VECTO).

Table.7.7: Technologies that are considered in the current version of VECTO

VECTO input	Technologies	How it is the innovation promoted
Real engine maps	Improvements in engine efficiency	Any technology that improves engine efficiency leads to reduced fuel consumption in the engine map, and directly influences VECTO’s calculated CO ₂ emissions and fuel consumption.
Real gear-box maps	Improvements in transmission efficiency	Technologies that improves transmission efficiency directly influences VECTO’s calculated CO ₂ emissions and fuel consumption.
Engine start/stop	Use of engine start/stop	If this is fitted VECTO, when informed, takes it into account when calculating CO ₂ emissions and fuel consumption.
Torque loss map	Reductions in transmission torque losses	Technologies that improves transmission efficiency directly influences VECTO’s calculated CO ₂ emissions and fuel consumption.
Smart auxiliaries	Auxiliaries like alternators or compressors that harvest energy on deceleration save overall fuel consumption	This is especially important for buses and coaches, and the next release of VECTO will probably recognise then smart alternators or pneumatic systems are fitted reducing the calculated CO ₂ emissions and fuel consumption.
Vehicle kerb weight	Light-weighting	Any measure that reduces the vehicle’s kerb weight leads to less energy being required to accelerate the vehicle, and reduces VECTO’s calculated CO ₂ emissions and fuel consumption.
Tyre rolling resistance	Low rolling resistance tyres	Lower rolling resistances lead to less energy being required when the vehicle is driven, and reduces VECTO’s calculated CO ₂ emissions and fuel consumption.
Drag coefficient	Improved aerodynamics	Lower aerodynamic drag leads to less energy being required when the vehicle is driven, particularly at higher speeds, and reduces VECTO’s calculated CO ₂ emissions and fuel consumption.

Some eco-innovations are characterised simply, e.g. light-weighting, which reduces the vehicle’s curb weight and is straightforwardly quantified by weighing the vehicle. Others require more complex but well established procedures, e.g. for characterising the engine, gearbox or torque maps. Low rolling resistance tyres are characterised according to EC regulations, and the key input parameter into VECTO (retarding force per tyre per tonne load) forms part of the tyre labelling regulations. Other eco-innovations are more difficult to quantify, e.g. improved aerodynamics, although VECTO provides scope for improvements in aerodynamics to be included. Figure 7.3 shows how data from *air drag testing*

feeds into the *Constant speed evaluation tool*, which gives appropriate parameterisation of the aerodynamics added for input into VECTO.

The potential significance of each of the identified technologies, in terms of their CO₂ reduction potential, is considered at the end of the next sub-section.

A1.5.2 Technologies that cannot currently be captured by VECTO

Whilst VECTO does promote many areas of technologies/eco-innovation resulting in improved fuel consumption and reduced emissions, there are other technologies that the current version of VECTO does not, or cannot, account for either at all, or only partially. Evidently, in the absence of HDV CO₂ emissions regulations, economic factors are important and are influential: if there is a technology that cost effectively reduces the vehicle’s fuel bill, then commercial pull may lead to its introduction.

A range of example technologies where the current version of VECTO is unable to calculate reduced CO₂ emissions or fuel consumption, despite the technologies delivering improvements in the real world, are summarised in Table.7.8. Ways to capture the effectiveness of these options in the future is also under investigation, however.

Table.7.8: Technologies that the current version of VECTO is unable to capture

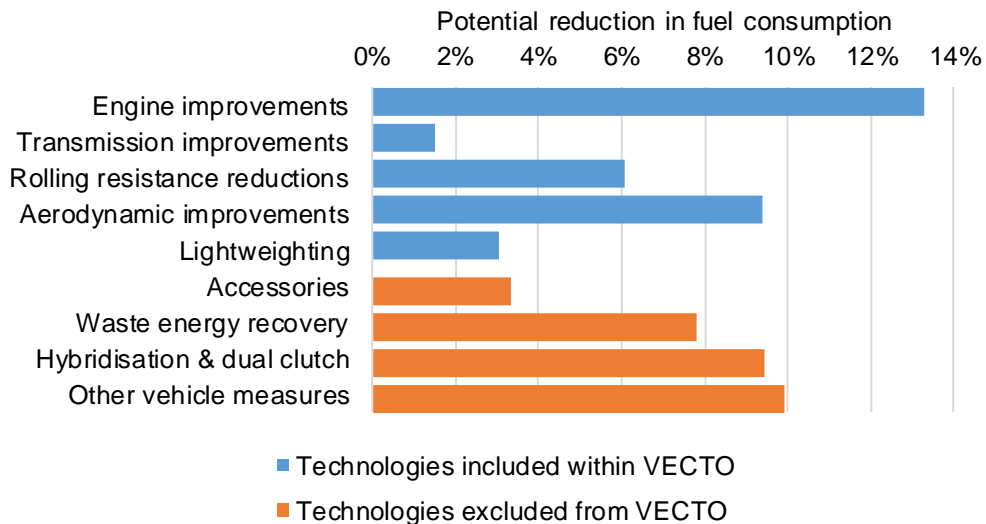
Technologies	Why VECTO currently does not account for this technology
Auxiliaries used on trucks	For lorries the “ <i>Classic VECTO Auxiliary</i> ” mode has default air conditioning, pneumatic systems and alternator characteristics, although it does contain a customised list of components that use electric power.
Auxiliary power used by trailers or cargo volume	VECTO currently does not include power drains from trailers and rigid truck systems. So refrigerated trailers or box-lorries which draw power from their tractor unit are not fully covered, and would emit more CO ₂ than the generic default vehicle. As such, approaches to reducing this, e.g. using a liquid nitrogen fuelled Dearman engine, would not be captured.
Waste heat recovery, or turbo compounding	VECTO does not currently allow for the fitting of these energy recovery technologies.
Alternative powertrain configurations	VECTO assumes a standard ICE powertrain. It does not currently include options for any scale of hybridisation. (<i>Note: These are currently under investigation, it may be that these are addressed outside of the model in the future.</i>)
Predictive cruise control	VECTO does not currently allow for predictive cruise control, which has been estimated to save 3% to 5% savings for inter-urban HGVs assuming moderate hilliness and relatively straight roads. Savings would be lower (or indeed negligible) at slow speeds (e.g. in urban areas) or on flat terrain.
Platooning	VECTO does not currently allow for platooning, where vehicles are in electronic communication with each other, sharing data about speed, relative position and drivers’ intentions to enable vehicles to travel very close behind one another safely, gaining aerodynamic benefit.

This potential importance of different technologies for the EU fleet for tractor-trailer combinations (undertaking long haul delivery) has been explored in a recent study from the ICCT (2016)⁶⁸. This study illustrated the potential percentage CO₂ savings which would be captured for a range of technologies by the version of the VECTO model at the time. The analysis, summarised in Figure 7.8, provides an approximate assessment on the potential significance of each of the ‘eco-innovation’ areas in terms of

⁶⁸ “Road to efficiency: New Study on Technology potential for tractor-trailers”, presented by ICCT at a workshop in Brussels in June 2016.

potential percentage savings that might be achieved by technologies applied to tractor-trailers, and an assessment on to what degree this potential is currently captured by VECTO. (Note: Figures for the lighter vehicles - especially when undertaking urban delivery cycles - would have some similarities, but the savings potential from improved aerodynamics and from waste energy recovery would be lesser and the savings potential from hybridisation would be larger, relative to those for a tractor-trailer combination.)

Figure 7.8: Fuel consumption reduction potential of different technology groups for tractor-trailer combinations undertaking long haul delivery, and their inclusion in the current version of VECTO



As indicated earlier, the VECTO software is still under development and discussions concerning future expansion to include various technologies are on-going. Further, some technologies, such as hybridisation, may be dealt with separately to the main VECTO simulation within the still developing certification procedures.

A2 Appendix 2: Summary of the Draft Certification Procedure

This appendix provides a brief summary of the draft Regulation on certification of the CO₂ emissions and fuel consumption of heavy-duty vehicles (based on draft version of September 2016⁶⁹).

According to the draft version, certification would be required for HDV classes (according to the HDV CO₂ scheme) 4, 5, 9 and 10 in 2018, 1, 2 and 3 in 2019, and 11, 12 and 16 at a later date in the future. Classes 6, 7, 8, 13, 14, 15, 17 are exempt. So are military, police and fire vehicles as well as special purpose and off-road vehicles.

The certification legislation sets out the steps HDV manufacturers are required to undertake in order to obtain a whole vehicle estimate of the distance-specific energy consumption and CO₂ emissions of each vehicle newly registered. Having this estimation procedure in place will be a requirement for obtaining vehicle type approval.

In a first step, manufacturers are required to obtain the fuel consumption and CO₂ emission-related properties of the relevant components that affect overall vehicle energy consumption used in the vehicle. For this purpose, the legislation sets out separate certification procedures for the following vehicle components: engines, transmissions, retarders, torque converters, axles, auxiliaries, tyres. Moreover, an air drag test of a vehicle within a family of similar vehicles is required, using a standard body, trailer or semi-trailer, in order to determine drag coefficient by cross sectional area. Alternatively, manufactures may use a default value drag coefficient by cross sectional area. One default value for each vehicle class is provided in the legislation. Separate annexes set out the procedures required to determine the energy and CO₂ emission-related properties of the components as well as the air drag testing procedure.

In a second step, manufacturers are required to use the VECTO tool in order to determine whole vehicle energy and CO₂ emissions. For each vehicle configuration sold, they are required to use the appropriate component performance data determined in the first step along with relevant data on the whole vehicle, including curb weight and HDV class according the HDV CO₂ scheme.

In order to obtain type approval, manufacturers need to submit a description to the relevant approval authority detailing the procedures for collection, storage and management of the input data, as well as handling of the software and the outputs it generates. The approval authority needs to audit the procedure. This includes the manufacturer demonstrating to the authority that their procedure correctly determines energy consumption and CO₂ emissions of their vehicles by calculating the CO₂ emissions of one vehicle from the vehicle class following the procedures they have set out.

⁶⁹ Draft legislation and annexes available at: https://circabc.europa.eu/webdav/CircaBC/GROW/automotive/Library/comitology_committees/technical_committee/60th%20meeting%20on%2015%20September%202016

A3 Appendix 3: Contents of the Technical annex to the Draft Certification Procedure (September 2016)

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A4 Appendix 4: EU HDV Fleet Composition

A4.1 Background

For the purpose of assessing the suitability of various international policy elements to the EU fleet, typical European HDV characteristics are considered. The structure of this section is identical to that used when describing the fleet composition in other countries.

A4.2 Types and dimensions

European HDVs are those vehicles exceeding a gross vehicle weight (GVW) of 3.5 tonnes, of which there are approximately 6.3 million in the European fleet (Anfac, 2015). A wide variety of vehicles come under this description, ranging from small city delivery vehicles which are just above the 3.5 tonne lower limit to 44-tonne lorries (permissible in some parts of the EU). Buses and coaches too are HDVs but are not considered further here as this assessment is limited to lorries. Table 7.11 of Appendix 1 illustrates the break-down for the category of heavy duty vehicles in Europe in 18 'classes'. This project focuses on four of these categories, listed in Table 7.9, which guides the following text.

Table 7.9: HDV categories of focus in this study

Axle configuration	Chassis configuration	Maximum GVW	Vehicle Category	Relevant vehicle mission cycles
4x2	Rigid	>16 tonnes	4	Long haul, regional delivery, municipality utility
	Tractor	7.5 – 16 tonnes	5	Long haul, long haul European Modular System (EMS), regional delivery, regional delivery (EMS)
6x2	Rigid	All	9	Long haul, long haul (EMS), regional delivery, regional delivery (EMS), municipality utility
	Tractor	All	10	Long haul, long haul (EMS), regional delivery, regional delivery (EMS)

Disaggregated data are published by a number of sources, including ACEA⁷⁰ and ICCT⁷¹. These use 16 tonnes GVW as a category boundary. When the lorries' fleet fractions of heavier and lighter than 16 tonnes (GVW) from the ACEA publication are combined with the rigid/tractor fractions from the ICCT analysis, the share of new registrations by GVW and lorry type (the four categories given in Table 7.9) are estimated. This is shown in Figure 7.9.

The size of the European fleet was estimated, and given in the Lot 1 report to the EC (AEA/Ricardo, 2011) for 1995 and 2008. Eurostat fleet statistics categorise vehicles into passenger cars and commercial vehicles. The latter category includes both light- and heavy-duty commercial vehicles. The former comprise around 90% of the commercial vehicle market, and consequently these statistics are not suitable for this analysis. The ACEA web-site refers to a report by Anfac on the European Vehicle Parc for 2014 (Anfac, 2015), which includes statistics for both medium- and heavy-commercial vehicles. The data contains some gaps, but after these are compensated for, a fleet profile for 2014 was obtained. This, together with the profiles for 1995 and 2008 (from (AEA/Ricardo, 2011)) are provided in Figure 7.9, below.

⁷⁰ Data on registrations in 2016 taken from ACEA, (ACEA, 2017).

⁷¹ ICCT publish annually market statistics, most recently for 2015-16, (ICCT, 2015-a). Whilst focussing on LDV they do provide profiles of the rigid/articulated lorry fractions.

Figure 7.9: Sales of new lorries in 2016 disaggregated by the four categories given in Table 1

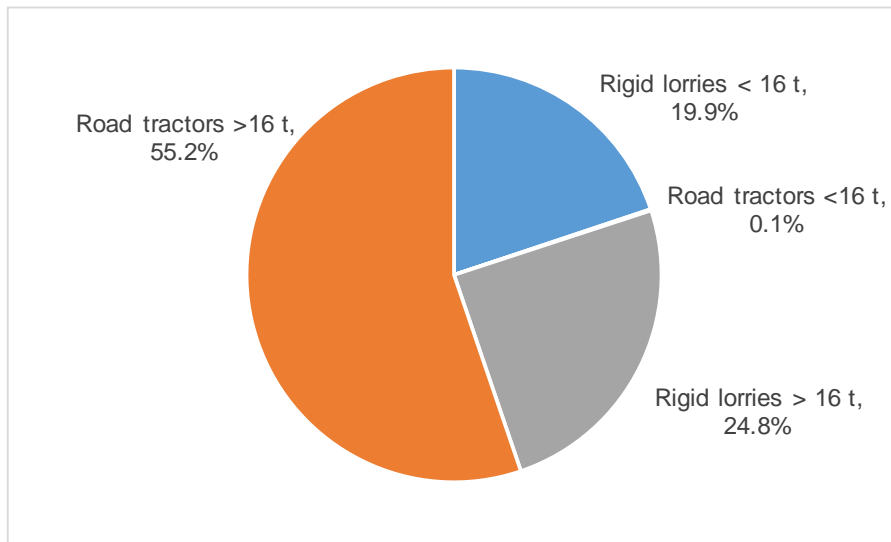
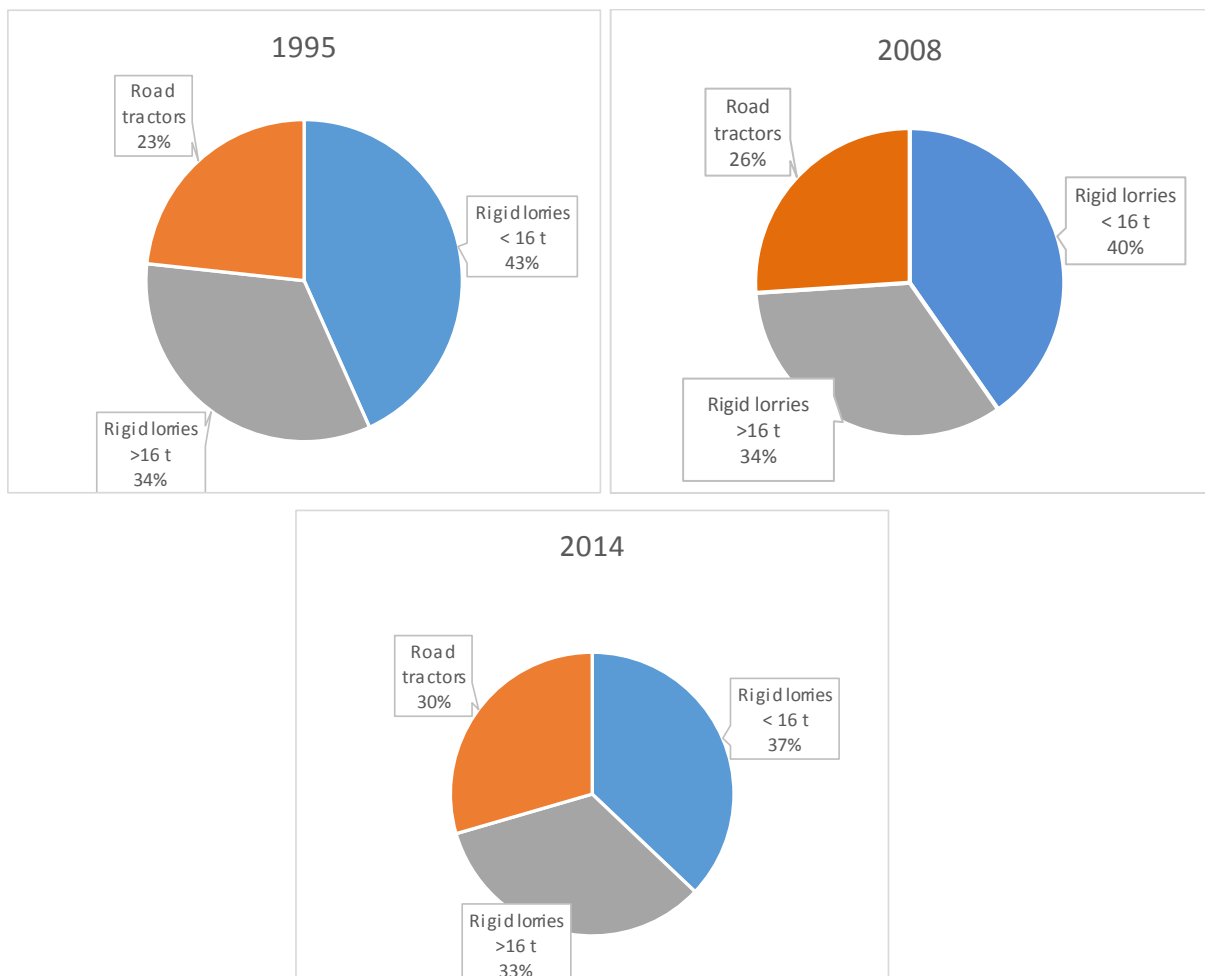


Figure 7.10: EU27 split of vehicle parc of rigid lorries and road tractors in 1995, 2008 and 2014



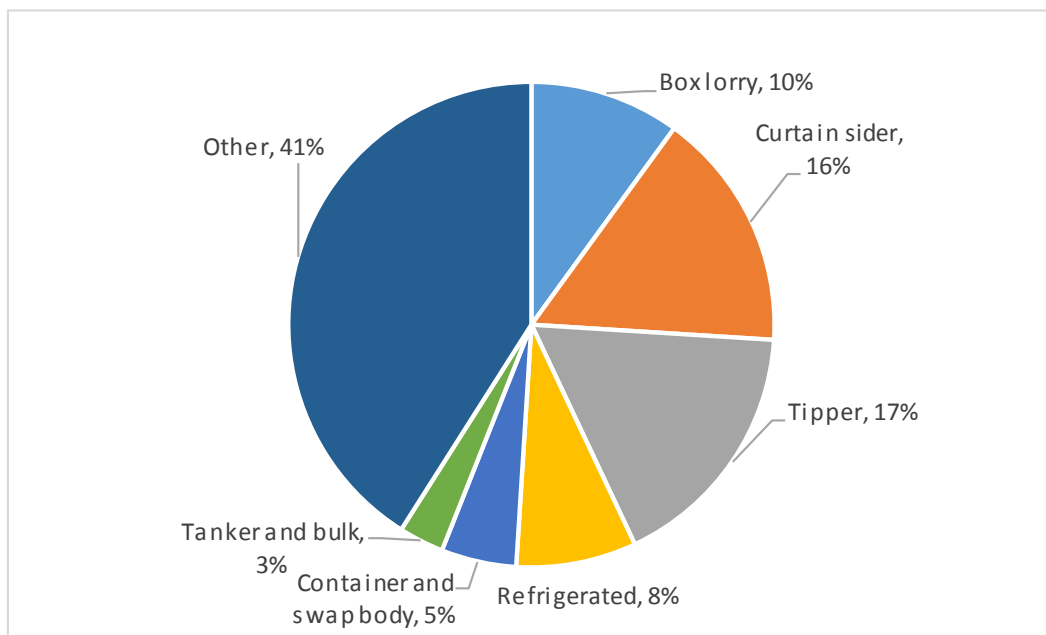
One immediately apparent difference exists between the new registrations data (Figure 7.9) and the parc data for 2014 (Figure 7.10): This is the relatively smaller fleet fraction of road tractors in the fleet (30%) relative to the fraction of new registrations (55%). This arises because road tractors cover much

longer average annual distances, and consequently have shorter lives than rigid HGV. In addition, Figure 7.10 also shows that the parc of road tractors has been increasing over time as higher shares of these vehicles are added to the fleet. From the vehicle age profiles used in the UK road transport inventory model, based on government UK fleet data, the average age of rigid lorries is 7.4 years, whilst for road tractors is 4.3 years.

The relative proportion of articulated vehicles in the fleet has been increasing over time because of higher average loading and longer journey distances, as also illustrated in Figure 7.10.

For rigid lorries there are a wide variety of different body types possible. For those lighter than 24 tonnes, the vast majority of rigid lorries in Europe, the most populous body types are box, curtain or tipper variants. A breakdown of the proportion of different body types is given in Figure 7.11⁷².

Figure 7.11: New registrations of rigid lorries by body type for 2009



The most common articulated lorries are of 34-40 tonnes with separate tractors and trailers. Approximately half are curtain-sider trailers. The default axle configuration for both types of HDV is either 4x2 or 6x2; larger HDVs with more axles are available but are less common.

European lorries are subject to maximum authorised dimensions according to Directive 96/53/EC. This gives height restrictions for **international traffic** (of 4.0 metres⁷³; and a maximum total vehicle length of 16.5 metres). This maximum length contributes to the cab-over-engine design used in Europe. Whilst this frontal shape is less aerodynamically efficient than the 'nosed' design of US lorries, the reduced tractor-trailer gap in Europe relative to US lorries is more aerodynamically efficient. The height and length restrictions are potential barriers to fitting aerodynamic trailers due to the associated reduction in payload space). However, for national traffic the 4.0 m height limit does not apply. For example, the UK currently has no height limit, merely a recommendation that vehicle heights should not exceed 4.95 metres⁷⁴. The use of high capacity vehicles (25.25m, 60t and higher) under EMS (European Modular System) has been much debated in Europe for several years. Some countries have used these vehicles for several decades, and whilst other countries have had successful trials with these longer, heavier vehicles (LHVs).

Recently, changes to the Weights and Dimensions Directive (EU) 2015/719 (which amends Directive 96/53/EC) granted derogations on the maximal lengths to make heavy goods vehicles greener by improving their aerodynamic performance. This also provides the opportunity to make them safer by

⁷² Data taken from VDA, 2010 and cited in (AEA/Ricardo, 2011) and in CE Delft, 2013.

⁷³ https://ec.europa.eu/transport/modes/road/weights-and-dimensions_en

⁷⁴ UK House of Commons summary of UK lorry sizes and weights, <http://researchbriefings.files.parliament.uk/documents/SN00654/SN00654.pdf>

including new features in the extra space. Derogations on weight are also allowed for vehicles powered by alternative fuels.

A4.3 Typical journeys / duty cycles

Approximately 89% of the HDVs in use are for the carriage of goods or work as utility vehicles (construction vehicles, specialised vehicles, etc), i.e. are HGVs, and the remainder (buses and coaches) are designed for the carriage of passengers.

The European fleet performs high annual mileages. Rigid lorries typically perform between 25,000 (for municipal utility vehicles) and 60,000 kilometres per annum (for regional delivery activities) (AEA/Ricardo, 2011), (TIAX, 2011). In a recent, currently unpublished study, Ricardo estimated that rigid box lorries undertaking regional delivery activities travelled on average 88,000 km a year. Both the TIAX study and the recent, currently unpublished Ricardo study, estimated the average annual distance travelled by articulated tractor trailer combinations, principally undertaking long haul deliveries, is 130,000 km.

Duty cycles are very varied, according to the type of vehicle, and its operational requirements. The VECTO model specifies five different lorry cycles, reflecting these:

- Urban delivery;
- Regional delivery;
- Long haul;
- Service utility, and
- Construction.

The current speed limit for HDVs exceeding 7.5 tonnes is fixed at 90kph on European motorways; though in some countries the limit is set lower, at 80kph. This is slower than the US, where the limit is state dependent and ranges between 104 and 128kph (65 – 80 mpg).

A4.4 Overview of operating costs and typical ownership profiles

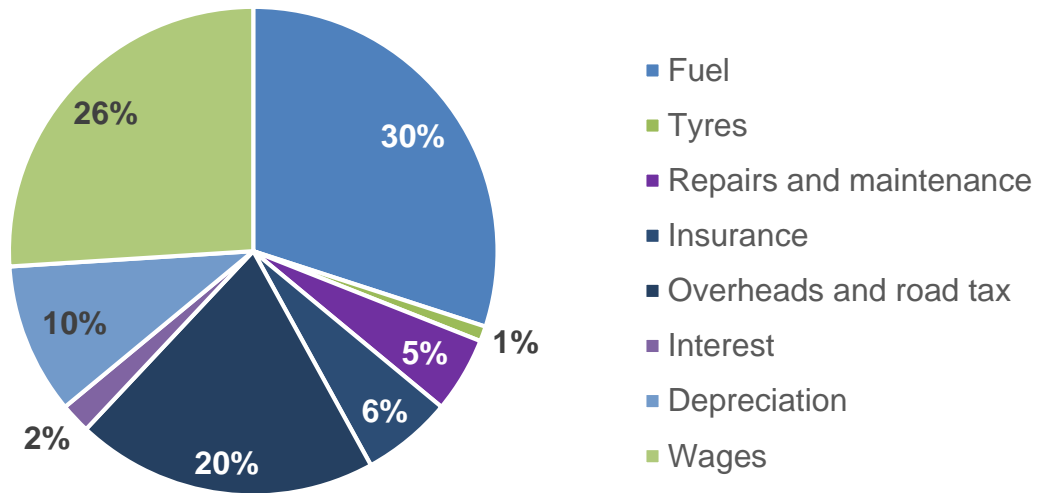
In Europe total cost of ownership is considered much more important than initial purchase price. Consequently, the average European HDV can be more expensive than in most other markets, provided the vehicle is competitively priced and has low/ competitive operational costs.

The vast majority of European HDVs are owned, however leasing strategies are likely to gain in popularity over the next few years. Indeed, the German consultancy firm Oliver Wyman estimated in 2011 that by 2020, as a conservative figure, 20% of lorries in the market are likely to be rented rather than owned (Oliver Wyman, 2011).

As for other advanced markets, driver wages and fuel dominate the typical operating costs. A breakdown of costs, provided by ACEA, is given in Figure 7.12⁷⁵.

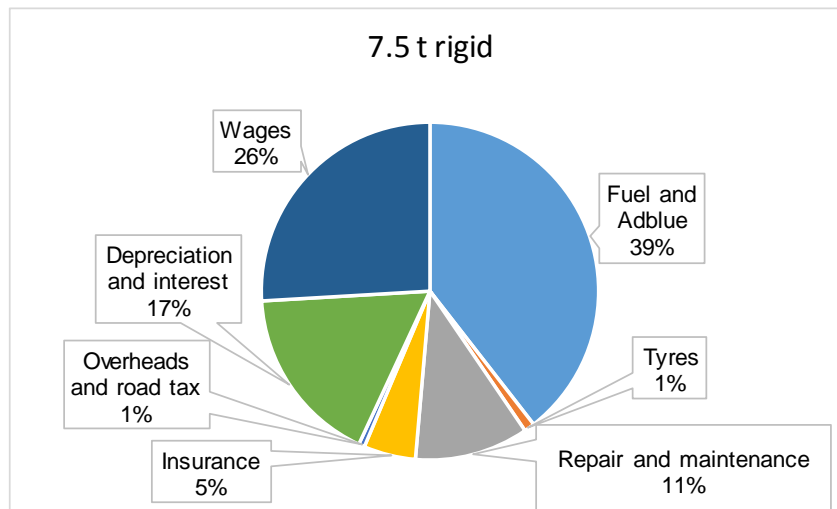
⁷⁵ Data taken from ACEA 2017, which originated from: <http://www.iea.org/workshop/work/hdv/larsson.pdf>

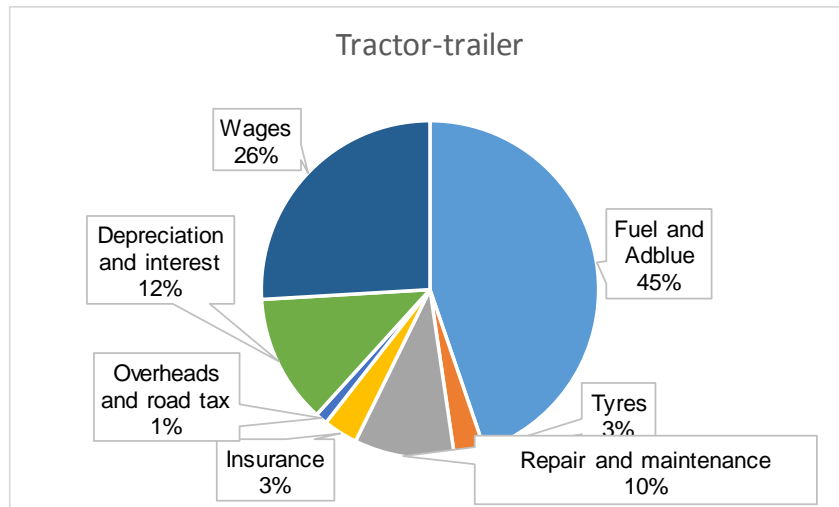
Figure 7.12: Breakdown of costs associated with commercial vehicles



It might be anticipated that the operating costs are considerably affected by the type of vehicle, and its usage pattern. However, analysis of the cost components from the FTA Manager’s Guide to distribution costs for different types of vehicle show the breakdown is relatively constant, e.g. when comparing a 7.5t rigid box lorry, driving around 61,600km p.a. with a 40t tractor-trailer combination driving 136,000km p.a. see figure below.

Figure 7.13: Breakdown of costs associated with 7.5 t rigid and 40 t tractor-trailer commercial vehicles





There are some systematic differences between the FTA data and the ACEA data, most notably in the “Overheads and road tax” segment.

Total operating cost includes both fuel and AdBlue (urea solution). There is a trade-off between these because an engine can be calibrated to have an advantageous fuel economy but at the penalty of higher engine-out NO_x emissions. (Abatement of the engine out NO_x emissions requires additional AdBlue consumption.) Alternatively, the engine can be calibrated to have a poorer fuel economy but lower engine-out NO_x emissions, therefore requiring less AdBlue. Europe has a low AdBlue to fuel price, so many lorries are often calibrated to have the advantageous fuel economy but require higher AdBlue consumption. This is not the case in other regions of the world where the AdBlue to fuel price ratio is more comparable.

The requirement to have a relatively high consumption of urea (necessary to maintain fuel efficiency whilst meeting NO_x limits) might become a concern because a lack of urea will render a European lorry effectively inoperable. This concern overlaps with reliability considerations which remain a very high priority of European buyers: low maintenance requirements and specifically infrequent service intervals are sought-after. Other factors of consumer demand in Europe include the HDV’s level of performance and driveability.

A4.5 Fuel efficiency technology uptake and effectiveness

All HDVs sold since 1st January 2014 have been required to be fitted with engines that meet the Euro VI emissions standard.

A typical 12 tonne rigid box lorry⁷⁶ uses a 6.5 – 8 litre displacement 6 cylinder in-line diesel engine with 4 valves per cylinder, developing around 200 kW at around 2,350 rpm. It uses a common rail injection with two stage turbo-charging and intercooling at higher power levels. It delivers the power to its rear axle through a 6-speed manual transmission gearbox, and is fitted with exhaust gas recirculation (EGR), a diesel oxidation catalyst (DOC), diesel particulate filter (DPF) and uses selective catalytic reduction (SCR) with an ammonia slip catalyst (ASC) to comply with the Euro VI NO_x emissions regulations. Such a “baseline” lorry when modelled using the EC VECTO model with a 72% loading (3,000 kg) has a fuel consumption of 24.9 litres diesel /100 km (or 8.3 litres /100 t-km) over the “Regional delivery” driving cycle.

An assessment of the potential of different technologies to reduce fuel consumption identifies:

- Improvements in engine efficiency from a whole series of measures reducing friction, and improving auxiliaries’ efficiencies,
- Improvements in aerodynamics,

⁷⁶ Reference to unpublished Ricardo study, u

- Replacing the manual gearbox with an automated manual transmission to optimise gear changing to the driving requirement and the engine's fuel efficiency;
- Use of lower rolling resistance tyres;
- Mild hybridisation and
- Light-weighting.

All these different technologies have the potential to reduce fuel consumption below that of the average current baseline engine.

A typical 40 tonne tractor-trailer combination ⁷⁷ uses an 11 – 13 litre displacement 6 cylinder in-line diesel engine with 4 valves per cylinder, developing around 325 kW at around 1,870 rpm. It uses a common rail injection with a waste-gated turbo-charger. It delivers the power to its drive axle through a 12 speed automated manual transmission (AMT) gearbox, and is fitted with exhaust gas recirculation (EGR), a diesel oxidation catalyst (DOC), diesel particulate filter (DPF) and uses selective catalytic reduction (SCR) with an ammonia slip catalyst (ASC) to comply with the Euro VI NO_x emissions regulations. Such a "baseline" tractor-trailer combination when modelled using the EC VECTO model with a 76% loading (19,300 kg) has a fuel consumption of 35.7 litres diesel /100 km (or 1.85 litres /100 t-km) over the "long haul" driving cycle.

An assessment of the potential of different technologies to reduce fuel consumption identifies:

- Improvements in aerodynamics;
- Improvements in engine efficiency from a whole series of measures reducing friction, and improving auxiliaries' efficiencies;
- Use of lower rolling resistance tyres;
- Waste heat recovery; and
- Light-weighting.

All these different technologies have the potential to reduce fuel consumption below that of the average current baseline engine. The assessment emphasises the difference between the **potential** to reduce fuel consumption, and what is **commercially realisable** given the required implementation timeline.

In the last few years, aerodynamic improvements have become increasingly applied to new HDVs and include integrated air dams, cab side edge turning vanes, roof deflectors and side deflectors. There has been some increased use of trailer skirts, but aerodynamic trailer shaping (such as the characteristic 'tear-drop' shape) is not prevalent. It is anticipated that the implementation of Directive (EU) 2015/719 which, according to Article 2, is to be brought into force by Member States by 7th May 2017, will further encourage the uptake of aerodynamic improvements.

Additional technologies that are anticipated include using gear shift control strategies which are optimised using GPS with tomography data and intelligent adaptive cruise control. Also, inter-vehicle communications offer the prospect of vehicle platooning as another way of reducing aerodynamic losses for groups of vehicles travelling at speed on motorways⁷⁸.

Aggressive light-weighting technologies are not common in the HDV sector, even in more weight-sensitive operations. The potential for light-weighting technologies to improve fuel economy in the European fleet was explored in a recent European Commission report (Ricardo-AEA, Millbrook, TEPR, TRT, 2015). This report explains that there is a linear relationship between weight reduction and fuel consumption, allowing lorries to move the same quantity of goods with less fuel. The average 'long haul'⁷⁹ lorry was estimated to be able to achieve a cost-effective⁸⁰ fuel consumption improvement of 8.0% between 2015 and 2030 through light-weighting; the figure for 'urban delivery'⁸¹ lorries reached

⁷⁷ Reference to unpublished Ricardo study, u

⁷⁸ This has recently been researched in the Safe Road Trains for the Environment project, funded by the European Commission under the Framework 7 programme. This project aims to develop strategies and technologies to allow vehicle platoons to operate on normal public highways with significant environmental, safety and comfort benefits. See <http://www.sartre-project.eu/en/Sidor/default.aspx>

⁷⁹ In the light-weighting study, 'long haul' lorries consisted of >16 tonne rigid lorries and >16 tonne articulated lorries, so direct comparison with the vehicle categories in this report should use caution.

⁸⁰ Net zero cost over the lifetime of the vehicle.

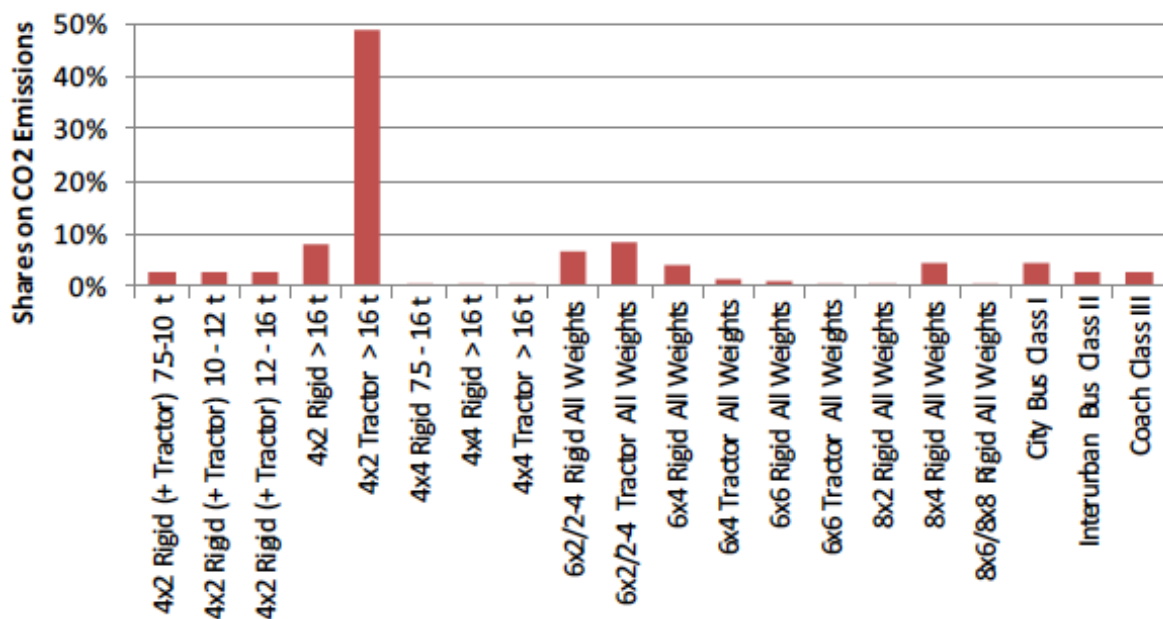
⁸¹ In the light-weighting study, 'regional delivery' lorries consisted of 7.5-32 tonne rigid lorries and some articulated vehicles, so direct comparison with the vehicle categories in this report should use caution.

10.3%. It will thus be important for any European CO₂ reduction measures to be able to take these technologies into account in the methodology as not to hinder its uptake. However, it is worth noting that (TIAX, 2011) analysed various CO₂ reduction technologies for the EU fleet and considered material substitution for light-weighting to be less cost-effective than other technology options such as predictive cruise control and low rolling-resistance tyres.

The use of alternative fuels to diesel (and biodiesel) by European HDVs is very limited, with the exception of Sweden, Poland, the Czech Republic and Austria who have sizable natural gas lorry fleets and sporadic electrically-powered trolley-bus systems (AEA/Ricardo, 2011). Whilst alternative fuel use is not widespread, numerous incentives exist to purchase clean heavy duty vehicles and restrict the movement of more polluting HDVs. For example, the pan-European Clean Vehicles Directive (European Commission, 2014) assists public authorities and fleet operators with the procurement or loading of clean and energy efficient vehicles and includes HDVs. In addition, low-emission zones have gained prevalence in Europe in recent years (BUND/EEB, 2015). It is anticipated that the initial impact will occur most for buses and smaller commercial vehicles which operate in areas with poorer air quality, and use smaller amounts of fuel than lorries undertaking long haul operations.

The Commission have worked with its contractors to classify and prioritise HDVs. Based on the analysis of data provided by ACEA in (AEA/Ricardo, 2011), which accounted for typical mileage and fuel consumption, TU Graz have estimated share of total CO₂ emissions from different HDV categories (TU Graz et al, 2012); this is shown in Figure 7.14.

Figure 7.14: Estimated share of total CO₂ emissions from different HDV categories



Source: Chart from (TU Graz et al, 2012).

The vehicles fall into two major groups, 18 freight carrying categories, the N category vehicles, and three passenger carrying categories, the M category vehicles. Table 7.10 and Table 7.11 give details of the classification of the M, and N, category vehicles, respectively.

Table 7.10: Classification of the M category vehicles

Bus class	First approach:	Second approach:		Cycle allocation
	EU registration classification 2001/85/EU (I, II,III)	if vehicle is registered as two different classes		
		Class I or II	Class II or III	
City	Class I	Low floor, low entry*, double decker**		Heavy urban, Urban, Suburban
Interurban	Class II	Luggage compartment	Floor height ≤ 900 mm	Interurban
Coach	Class III		Floor height > 900 mm double decker	Coach

Table 7.11: Classification of the N category vehicles

Identification of vehicle class				Allocation of mission profile and vehicle configuration							
Axle configuration	Chassis configuration	Maximum GVW	Vehicle Class	Long haul	Long haul (EMS)	Regional delivery	Regional delivery (EMS)	Urban delivery	Municipal utility	Construction	Standard body allocation
4x2	Rigid	>3.5 – 7.5	(0)								
	Rigid tractor)* (or	7.5 - 10	1			R		R			B1
	Rigid tractor)* (or	>10 - 12	2	R+T1		R		R			B2
	Rigid tractor)* (or	>12 - 16	3			R		R			B3
	Rigid	>16	4	R+T2		R			R		B4
	Tractor	7.5 - 16	5	T+ST	T+ST+T2	T+ST	T+ST+T2				
4x4	Rigid	>16	(6)								
	Rigid	>16	(7)								
	Tractor	all weights	(8)								
6x2	Rigid	all weights	9	R+T2	R+D+ST	R	R+D+ST		R		B5
	Tractor	all weights	10	T+ST	T+ST+T2	T+ST	T+ST+T2				
6x4	Rigid	all weights	11	R+T2	R+D+ST	R	R+D+ST		R	R	B5
	Tractor	all weights	12	T+ST	T+ST+T2	T+ST	T+ST+T2			R	
6x6	Rigid	all weights	(13)								
	Tractor	all weights	(14)								
8x2	Rigid	all weights	(15)								
8x4	Rigid	all weights	16								
8x6 8x8	Rigid	all weights	(17)								

Notes: * in these vehicle classes tractors are treated as rigid vehicles but with specific curb weights of tractor.

R = Rigid & standard body
T1, T2 = Standard trailers
ST = Standard semitrailer
D = Standard dolly

- Categories 4, 5, 9 and 10 are expected to be covered by the upcoming certification regulation, with certification of CO₂ emissions and fuel consumption of new vehicles likely in 2018.
- Categories 1, 2, 3 may be covered in the future for certification likely one year later compared to the previous categories.
- Categories 11, 12 and 16 may be covered at a later stage.

A4.6 References

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A5 Appendix 5: Stakeholder consultation questionnaire template

Analysis of fuel economy and GHG emission reduction measures for Heavy Duty Vehicles in other countries and options for the EU

Questionnaire – March 2017

Introduction to the questionnaire

Ricardo Energy and Environment are currently leading a project for the European Commission to develop a shortlist of policy options aimed at reducing CO₂ emissions from heavy duty vehicles (HDVs), in cooperation with our project partners TEPR and Ricardo UK. This document forms part of the first stakeholder consultation regarding the policy options developed in the project, and should be used in conjunction with the Stakeholder Information Pack (March 2017) circulated with it. Please review the Stakeholder Information Pack document(s) before proceeding with this questionnaire.

This questionnaire is designed to assist the interview process by capturing your opinions in relation to the various policy options and their constituent elements, in order to inform the further development and refinement of these options. The policy options presented are illustrative of how the European Commission could act to reduce HDV CO₂ emissions and will be further scrutinised in a later study. The feedback requested in this consultation is thus broadly qualitative and indicative, rather than quantitative.

Your responses will be used to help us assess the effectiveness, possible impacts and feasibility of the policy options being considered. It is therefore important that you complete this questionnaire as fully as possible. While this study focuses on trucks, we are also interested in your input regarding buses and coaches.

Use of your input

The study team will keep detailed notes of the discussion and will make use of your contribution (information/data provided) only for the needs of this study. Please indicate how you would like us to present the information provided during our discussion and any other information or data you provide to us:

- Publication of your contribution indicating the name of the organisation;
- Anonymised publication of statements made (without the name/ name of the organization);
- No publication but use of the contribution for statistical and analytical purposes

If you have any queries, please contact the project manager at ben.white@ricardo.com.

Contact information

Please provide the contact details of the organisation(s) contributing to this response.

a. Name of organisation(s): (please indicate the name of all contributing organisations)	Click here to enter text
b. Member State (if applicable) / EU-wide:	Click here to enter text
c. Contact person name(s):	Click here to enter text

d. Email address(es):	Click here to enter text
e. Telephone number(s):	Click here to enter text

Proposed policy options

The illustrative policy options have been constructed through both expert engagement and consideration of international experiences with HDV fuel economy and GHG emissions reduction measures. They have been developed under the European Commission's Better Regulation Guidelines and as such contain a wide range of methods, scopes and levels of regulation for the purpose of better surveying all possible routes to improvement. In total, five options (BAU + four policy options) have been developed and are fully explained in your stakeholder information pack. Through the following structured questions, we invite you to comment on these policy options.

Each option contains four sections of questions on:

1. Effectiveness and costs
2. Concerns and barriers regarding implementation
3. Opportunities
4. Other questions

Please read the stakeholder information pack before answering the questionnaire. A short introduction to each measure is contained in the grey boxes below for your convenience.

You are welcome to use bullet point answers for expansion during the upcoming interview. Please note that, regretfully, we are unable to review additional material unless it has been specifically requested by us. You are welcome to refer us to specific tables or figures in other literature but any text you wish to use must be transposed into this questionnaire.

Option 1: Technology requirements and performance requirements with soft measures

This option mandates minimum performance (efficiency) standards for specific technologies and imposes certain technology requirements (see stakeholder pack). It is proposed as an alternative to whole vehicle regulations. This option could help accelerate improvements in components which are either not currently regulated or are commercially available but underexploited.

Further, a package of softer measures (see stakeholder pack) is included to ensure a holistic approach to reducing HDV CO₂ emissions, helping buyers, drivers and logistical planners to better exploit the full potential of the vehicle. Whilst this measure is unlikely to achieve the same CO₂ reduction as vehicle limit values, it is likely to yield a faster reduction than the BAU scenario.

Effectiveness and costs

2. Please indicate your overall support for this policy option, considering all elements (CO₂ reduction potential, cost potential, barriers and opportunities, etc).

	Very supportive	Somewhat supportive	Somewhat unsupportive	Very unsupportive	Do not know
Overall policy option	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3. How effective do you think each policy element will be at reducing CO₂ emissions from HDVs (excluding cost considerations)? Please explain your reasons for the effectiveness indicated.

	Very effective	Somewhat effective	Slightly effective	Not effective	Do not know	Justification
Minimum technology performance standards (refrigeration APUs, insulation performance, tyre rolling resistance)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Mandatory application of certain technology classes (tyre rolling resistance (OEM fit), driver aids, aerodynamic features, advanced cruise control)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Facilitation of best practice dissemination	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Enhanced CPC requirements: fuel efficient driver training	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Trailer CO ₂ certification	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Overall policy option	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

4. **[A]** What do you see as the advantages or disadvantages of the specific technologies considered for this option? Please consider characteristics such as the relevance of the technologies to vehicle activities and cost implications.
[B, C, D] With regards to the specific technologies considered for this option, how will they affect your organisation, or organisations you represent? Please consider characteristics such as the relevance of the technologies to your activities and cost implications. Roughly quantify these where possible.

Level of support for inclusion of technology	
Minimum efficiency/performance standards	
Refrigeration auxiliary power units (APUs)	Click here to enter text
Insulation performance for temperature controlled vehicle bodies and trailers	Click here to enter text
Tyre rolling resistance	Click here to enter text
Mandatory implementation of certain technology classes	
Tyre rolling resistance (OEM fit)	Click here to enter text
Driver aids, including TPMS, fuel consumption and gear shift indicators	Click here to enter text
Aerodynamic features	Click here to enter text
Advanced cruise control	Click here to enter text

5. **[A]** Roughly, what do you expect the cost implications of each element of the policy option to be?
[B] Roughly, what are the cost implications of implementing each element of the policy option to your organisation or those you represent?

Policy element	Very expensive to implement	Some costs required to implement	Minimal or no costs required to implement	Implementation would ultimately save costs	Do not know	Clarification or quantification
Technology requirements and minimum performance standards	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Facilitation of best practice dissemination	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

Enhanced CPC requirements: fuel efficient driver training	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Trailer CO ₂ certification	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Overall policy option	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

[C, D] Roughly, what are the cost implications (to your organisation or those you represent) of developing and implementing the technologies required by the policy option?

Technology or policy element	Very expensive to implement	Some costs required to implement	Minimal or no costs required to implement	Implementation would ultimately save costs	Do not know	Clarification or quantification
Trailer CO ₂ certification	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Minimum efficiency/performance standards						
Refrigeration auxiliary power units (APUs)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Insulation performance for temperature controlled vehicle bodies and trailers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Tyre rolling resistance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Mandatory implementation of certain technology classes						
Driver aids, including TPMS, fuel consumption and gear shift indicators	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Aerodynamic features	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Advanced cruise control	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Other measures						
Trailer CO ₂ certification	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Overall policy option	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

Concerns and barriers to implementation

6. Please describe any concerns you may have regarding each of the policy elements given below. This includes considerations which could be **problematic** for you or the organisations you represent if not implemented carefully, and **prohibitive difficulties** arising from technological innovation, costs, or legal issues, for example. Where identified, please suggest how you believe the potential problems for your organisation can be mitigated.

Policy element	Concerns regarding implementation
Vehicle categories covered	Click here to enter text
Emissions covered	Click here to enter text
Metrics used	Click here to enter text
Drive cycles used (trailer certification)	Click here to enter text
Testing and certification	Click here to enter text
Secondary systems	Click here to enter text
Deadlines for compliance	Click here to enter text
Flexibilities on compliance	Click here to enter text
Implementation: minimum technology performance standards	Click here to enter text
Implementation: mandatory application of certain technology classes	Click here to enter text
Implementation: facilitation of best practice dissemination	Click here to enter text
Implementation: enhanced CPC requirements - fuel efficient driver training	Click here to enter text
Implementation: trailer CO ₂ certification	Click here to enter text

7. Do you have any concerns regarding elements of the policy other than those covered above? If so, please suggest how they can be mitigated.

Click here to enter text

Opportunities

8. What are the main opportunities you envision from the implementation of this policy option for your organisation or those you represent? This could include increased product value, greater interest from other markets or improved environmental credentials for example.

Click here to enter text

Other

9. **[B]** Please describe how the enhanced CPC requirement (an additional fuel efficiency training module for drivers) will affect your business, including considerations of where the initial capital would be sourced (drivers, employers, government schemes, etc).

Click here to enter text

10. **[A, C, D]** Air conditioning leakage from European lorry cabs is assumed to be circa 10-15% of the system total per year in the UK's National Atmospheric Emissions Inventory models, though such emissions are not currently regulated. Please indicate how effective and expensive you believe standards for HDV cab refrigerant leakage have the potential to be for your organisation, assuming that testing and certification requirements and stringency are similar to that used in the US Phase 2 regulations.

Technology or policy element	Very expensive to implement	Some costs required to implement	Minimal or no costs required to implement	Implementation would ultimately save costs	Do not know	Clarification or quantification
Inclusion of HDV cab refrigerant gas leakage in HDV CO ₂ certification	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Technology or policy element	Very effective	Somewhat effective	Slightly effective	Not effective	Do not know	Clarification or quantification
Inclusion of HDV cab refrigerant gas leakage in HDV CO ₂ certification	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

- a. Please offer brief comments regarding the advantages and disadvantages of implementing such standards.

Click here to enter text

11. Do you believe the option could encourage unintentional changes to HDVs which do not improve, or worsen, real-world CO₂ performance, or could introduce other perverse incentives?

[Click here to enter text](#)

12. Do you believe the effort required as a result of this option is fairly distributed between organisations in your industry? If not, please describe any issues identified.

[Click here to enter text](#)

13. **[B, C]** Do you believe the option could positively or negatively affect competition between manufacturers / hauliers in your industry and general competitiveness of the market?

[Click here to enter text](#)

The technology-related measures include minimum efficiency/performance standards for refrigeration APUs, insulation and tyre rolling resistance, and mandatory implementation of TPMS, fuel and gear shift indicators, aerodynamic features and advanced cruise control.

14. Do you believe any other technologies should be included, or any specific technologies should be excluded? Why?

[Click here to enter text](#)

15. Which aerodynamic features should be covered under this option? Please consider cost-effectiveness, feasibility and applicability to the vehicle classes considered in the measure when making your choice. Please outline any concerns you may have in the comments field.

Aerodynamic feature	Feature should be covered	Feature should not be covered	Comments
Cab deflectors / fairing	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Cab air dams	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Cab collars	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

Aerodynamic feature	Feature should be covered	Feature should not be covered	Comments
Cab and trailer side skirts	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Trailer rear quarter panels	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Trailer tapered shape	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Trailer front fairings	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Trailer tail extensions	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Spray-reduction mud flaps	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text
Active aerodynamics	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

16. Do you agree with the requirement for HDV manufacturers to fit low rolling resistance tyres (of a performance *better* than the minimum) on first delivery to the customer? Please explain.

Click here to enter text

The soft measures include the development of free logistical planning tools, best-practice dissemination and driver training.

17. Are there any other soft measures that you think should be considered, or any specific soft measures that should be excluded? Why?

Click here to enter text

18. Do you believe a tractor and trailer labelling scheme (not included) would be effective in reducing CO₂ emissions?

Click here to enter text

19. Do you believe that best practice dissemination will help to reduce CO₂ emissions? Please comment on the expected effectiveness of this element.

Click here to enter text

20. Please provide any other comments on this option, or highlight particular topics you would like to cover during the follow-up interview.

Click here to enter text

Option 2: International approaches: US-based measure

This option will use a standard inspired by the US example on which to construct a measure for the EU. This system uses a combination of engine testing and simulation (via the VECTO model, in place of the US GEM) to calculate/certify the emissions performance of regulated vehicle categories.

Effectiveness and costs

21. Please indicate your overall support for this policy option, considering all elements (CO₂ reduction potential, cost potential, barriers and opportunities, etc).

	Very supportive	Somewhat supportive	Somewhat unsupportive	Very unsupportive	Do not know
Overall policy option	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

22. How effective do you think a US-style policy option will be at reducing CO₂ emissions from HDVs (excluding cost considerations)? Please explain your reasons for the effectiveness indicated.

	Very effective	Somewhat effective	Slightly effective	Not effective	Do not know	Justification
Overall policy option	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

Concerns and barriers to implementation

23. Please describe any concerns you may have regarding each of the policy elements given below. This includes considerations which could be **problematic** for you or the organisations you represent if not implemented carefully, and **prohibitive difficulties** arising from technological innovation, costs, or legal issues, for example. Where identified, please suggest how you believe the potential problems for your organisation can be mitigated.

Policy element	Concerns regarding implementation
Basis for setting standards	Click here to enter text
Vehicle categories covered	Click here to enter text
Emissions covered	Click here to enter text
Metrics used	Click here to enter text
Drive cycles used (incl. trailer certification)	Click here to enter text

Policy element	Concerns regarding implementation
Testing and certification	Click here to enter text
Secondary systems	Click here to enter text
Main efficiency technologies targeted	Click here to enter text
Deadlines for compliance	Click here to enter text
Flexibilities on compliance	Click here to enter text
Overall policy option	Click here to enter text

24. Do you have any concerns regarding elements of the policy other than those covered above? If so, please suggest how they can be mitigated.

Click here to enter text

Opportunities

25. What are the main opportunities you envision from the implementation of this policy option for your organisation or those you represent? This could include increased product value, greater interest from other markets or improved environmental credentials for example.

Click here to enter text

Other

26. The US measures have been successful in delivering emissions reductions and cost savings for operators. Can you think of any situational differences between the US and EU market which would **prevent** such measures also being successful in the EU? Where possible, please explain the magnitude of any potential effect, and any mitigation strategies you have identified.

Click here to enter text

27. [A, C, D] Do you support standards for both engines and whole vehicles? Please explain.

Click here to enter text

28. Do you believe the effort required as a result of this option is fairly distributed between organisations in your industry? If not, please describe any issues identified.

Click here to enter text

29. **[B, C]** Do you believe the option could positively or negatively affect competition between manufacturers / hauliers in your industry and general competitiveness of the market?

Click here to enter text

30. Do you believe the option could encourage unintentional changes to HDVs which do not improve, or worsen, real-world CO₂ performance, or could introduce other perverse incentives?

Click here to enter text

31. Please provide any other comments on this option, or highlight particular topics you would like to cover during the follow-up interview.

Click here to enter text

Option 3: International approaches: Japan-based measure

This option will use the structure and basis of setting standards from the Japanese standard on which to construct a measure for the EU. The Japanese system uses engine tests in combination with a simulation approach, with a combination of specific vehicle parameters and standardised values. To determine the limit values, the top runner approach is used. Again, it would be more appropriate for the EU to utilise the VECTO model being developed by the Commission for certification purposes, which fulfils similar input-output objectives, but with a wider coverage of bespoke vehicle specifications.

Effectiveness and costs

32. Please indicate your overall support for this policy option, considering all elements (CO₂ reduction potential, cost potential, barriers and opportunities, etc).

	Very supportive	Somewhat supportive	Somewhat unsupportive	Very unsupportive	Do not know
Overall policy option	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

33. How effective do you think a top runner approach will be at reducing CO₂ emissions from HDVs (excluding cost considerations)? Please explain your reasons for the effectiveness indicated.

	Very effective	Somewhat effective	Slightly effective	Not effective	Do not know	Justification
Overall policy option	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Click here to enter text

Concerns and barriers to implementation

34. Please describe any concerns you may have regarding each of the policy elements given below. This includes considerations which could be **problematic** for you or the organisations you represent if not implemented carefully, and **prohibitive difficulties** arising from technological innovation, costs, or legal issues, for example. Where identified, please suggest how you believe the potential problems for your organisation can be mitigated.

Policy element	Concerns regarding implementation
Basis for setting standards	Click here to enter text
Vehicle categories covered	Click here to enter text
Emissions covered	Click here to enter text
Metrics used	Click here to enter text

Policy element	Concerns regarding implementation
Drive cycles used (trailer certification)	Click here to enter text
Testing and certification	Click here to enter text
Secondary systems	Click here to enter text
Main efficiency technologies targeted	Click here to enter text
Deadlines for compliance	Click here to enter text
Flexibilities on compliance	Click here to enter text
Overall policy option	Click here to enter text

35. Do you have any concerns regarding elements of the policy other than those covered above? If so, please suggest how they can be mitigated.

[Click here to enter text](#)

Opportunities

36. What are the main opportunities you envision from the implementation of this policy option for your organisation or those you represent? This could include increased product value, greater interest from other markets or improved environmental credentials for example.

[Click here to enter text](#)

Other

37. Do you think the Top Runner approach used in the Japanese standards is applicable to the EU automotive industry? Please explain your reasoning.

[Click here to enter text](#)

38. Do you believe the method of separating HDVs into groups by HDV category, GVW and mission profile (for the purpose of applying limits) is reasonable? Please explain your reasoning.

[Click here to enter text](#)

39. Do you believe the effort required as a result of this option is fairly distributed between organisations in your industry? If not, please describe any issues identified.

[Click here to enter text](#)

40. **[B, C]** Do you believe the option could positively or negatively affect competition between manufacturers / hauliers in your industry and general competitiveness of the market?

[Click here to enter text](#)

41. Do you believe the option could encourage unintentional changes to HDVs which do not improve, or worsen, real-world CO₂ performance, or could introduce other perverse incentives?

[Click here to enter text](#)

42. Please provide any other comments on this option, or highlight particular topics you would like to cover during the follow-up interview.

[Click here to enter text](#)

Summary and other comments

43. Please rate the options in your order of preference (1 = most preferable, 3 = least preferable), offering a **brief** shortlist of the most favourable and unfavourable points for each approach.

Policy option	Order of preference	Favourable points	Unfavourable points
Option 1: Technology performance requirements and soft measures	0	Click here to enter text	Click here to enter text
Option 2: US-based measure	0	Click here to enter text	Click here to enter text
Option 3: Japan-based measure	0	Click here to enter text	Click here to enter text

44. The project team have decided to exclude the Chinese and Indian standards as basis for the development of a European option in this study. The rationale for this decision is explained in Section 5 of the Stakeholder Information Pack. Please indicate your support or disagreement for this decision, and briefly explain your rationale.

Click here to enter text

45. Please provide a shortlist of any other issues you feel are relevant to the reduction of CO₂ from HDVs, which you would like to discuss in the upcoming interview.

Click here to enter text

Thank you for your participation. Please note that we may contact you for clarifications or additional information in relation to any of the issues raised.



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