CO_2 standards and labels for heavy duty vehicles

A comparative analysis of design options

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Summary

Transport is responsible for around a quarter of the EU greenhouse gas (GHG) emissions, and the road freight sector for almost 6% (EC, 2013). In the future, significant increases in total GHG emissions from Heavy Duty Vehicles (HDVs) are expected if no additional policies are implemented (ACEA, 2010). As a result, the European Commission is currently preparing a strategy to address the CO_2 emissions from HDVs and is developing a simulation tool to measure their CO_2 emissions in addition. It is therefore quite likely that the strategy will include a CO_2 standard or label for HDVs. However, due to the complexity of the HDV market, designing a standard (or label) would be highly complex as well and could be operationalised in many different ways (e.g. for the whole vehicle, for one or multiple components, etc.). To inform policy makers in the EU and abroad, this study explores the main advantages and disadvantages of different design options. The study is based on literature and on eleven in-depth interviews with experts, policy makers, manufacturers and NGOs.

This report focusses on five design options that have been implemented in other countries and/or are of particular interest to EU policy makers:
1. Engine standard & standard for the rest of the vehicle.
2. Engine + transmission standard.
3. Standard for the whole vehicle.
4. Multiple component-based standards.
5. Engine + transmission standard & standard for the rest of the vehicle.

Each design option was assessed on its effectiveness, market impacts, technical feasibility, and on its legislative impacts.

The results from this analysis show that there is no superior design option scoring highest on all above-mentioned criteria. A standard or label for the whole vehicle has the largest benefits in terms of the flexibility that is provided to integrated Original Equipment Manufacturers (OEMs): they can implement the technologies with the lowest marginal abatements costs, which in turn is argued to result in the lowest end-user costs. It has the potential to cover the full emission reduction potential of HDVs with an additional incentive to optimise the interactions between components (assuming that the simulation tool is well-designed).

However, the whole vehicle approach also has some drawbacks. It is expected to provide lower incentives for the relatively more expensive innovations. This may hamper innovations that have the potential to result in steep emission reductions (e.g. hybridisation), which may be undesirable from an environmental point of view. Furthermore, this design option is argued to result in an uneven level-playing field for component manufacturers, who have no clear indication of which components vehicle OEMs will choose to improve; this lowers their investment certainty. Finally, the simulation tool that is required for this standard design results in relatively few synergies with the existing legislative and test procedures for the HDV air pollution standards. It requires a lot of data from OEMs, which may be difficult to verify and monitor closely. Thereby, for some components it is not certain (i.e. enforceable) whether the targeted emission reductions will be obtained over the entire vehicle lifetime in the real-world. Some components have short lifetimes (e.g. tires) and may be replaced with less performing alternatives.

Implementing a separate engine standard and standard for the rest of the vehicle would eliminate some of the above-mentioned disadvantages. It would enable complete alignment with the test and legislative procedures of the HDV air pollution standards thus providing the opportunity for enforcement and minimising opportunities for gaming. Furthermore, it provides a specific incentive for innovations in the engine, while at the same time targeting the rest of the vehicle as well (i.e. with a well-designed simulation tool it covers the full emission reduction potential of the vehicle). Also investment certainty would be provided to both engine and vehicle manufacturers. However, this design also has some drawbacks. It reduces the flexibility of vehicle OEMs to only take the most cost-effective measures. In addition, this design option does not explicitly target the interaction between the engine and transmission. Although the standard or label for the rest of the vehicle also requires a simulation tool, and hence the need for monitoring and verifying OEMs' input data, costs are somewhat reduced as the engine part can make use of the air pollution tests. An engine + transmission standard that is combined with a standard for the rest of the vehicle would result in comparable advantages and disadvantages. However, interactions between the engine and transmission are targeted explicitly, providing an incentive for optimisation. The engine + transmission design aspect is likely to require upgrades in the test facilities and adjustments in air pollution test cycles (to enable simultaneous measurement and enforcement) though.

The latter-mentioned arguments for a specific engine + transmission standard would also apply if no separate standard for the rest of the vehicle would be implemented. Although this would eliminate the need for a simulation tool and thus result in a standard design that is easier to verify, this design would only cover part of the emission reduction potential of HDVs, severely limiting the effectiveness of this design.

Finally, implementing multiple component standards could in theory result in an almost full coverage of the reduction potential of HDVs, but would be much more complicated and costly to implement. For each component, and for each duty cycle, separate limits would have to be negotiated and a large number of entities would have to be regulated. Thereby, this standard design would completely ignore the interactions between the vehicle components and eliminates OEMs flexibility to implement the most cost-effective measures and to customise their trucks. This would result in the relatively highest end-user costs. On the positive side, implementing component-based standards ensures that innovations are stimulated in all regulated parts of the vehicle and provides investments certainty for both the vehicle and relevant component manufacturers.

An alternative approach to implementing a limit standard or a label would be to first mandate information disclosure of the simulation results to consumers, which would allow policy makers to test the complex simulation tools and underlying test procedures required for most designs. This would result in an enormous database of information on the HDV fleet, which in turn can be used to fine-tune the test procedures and to set appropriate limits with the standard(s) in a later stage. On the other hand, an approach that merely relies on information provisioning to customers (or labels) risks that emission reductions will not be as fast as required for meeting the long term GHG emission reduction targets.

1 Introduction

1.1 Background

Transport is responsible for around a quarter of the EU greenhouse gas (GHG) emissions, and the road freight sector for almost 6% (EC, 2013). While GHG emissions from other sectors have decreased by almost a quarter between 1990 and 2009, those from transport have increased by almost a third in the same period. Also, in the future, significant increases in total GHG emissions from transport – and in particular of Heavy Duty Vehicles (HDVs) – are expected if no additional policies are implemented (ACEA, 2010).

This explains why the European Commission is currently preparing a strategy to address the fuel consumption and CO_2 emissions from HDVs, which is expected to be launched in December 2013. The design of the CO_2 policy and regulatory instrument(s) have yet to be determined. A wide variety of policy design options can be thought of, such as the EU ETS, CO_2 labels, or CO_2 standards. One of the two latter-mentioned instruments is most likely to be implemented. This measure could be applied to the entire vehicle, to the engine, to the engine and driveline, or to separate components for example. However, at the moment, the EU is still working on a methodology to measure the CO_2 emissions of HDVs, which is a necessary first step for implementing a CO_2 standard or label at a later stage.

Although CO_2 standards for Light Duty Vehicles (LDVs) are widely deployed in a variety of countries, including in the EU, such a policy instruments is relatively novel for HDVs. Amongst other reasons, this may have resulted from the fact that the HDV market is much more complicated (e.g. a wider variety of vehicle designs) than that of LDVs, which makes the design of a CO_2 standard more complex as well. Despite the complexity of the HDV market, several non-EU countries (the US, Canada, Japan and China) have now implemented CO_2 standards for this market or will do so in the near future.

The design of these standards indicate that CO_2 standards (or labels) for HDVs could have a different coverage: engine standards vs. standards for the whole vehicle. Additionally, other options, like standards for the engine + driveline or standards for the different components of the vehicle, are possible. Obviously, differences in standard (or label) design will also result in differences in the impacts that can expected.

Considering that the EU still has to design a CO_2 standard (or label), CE Delft has explored the different impacts that may be expected for different standard (or label) design options. A structured analysis of the advantages and disadvantages of different designs of CO_2 standards/labels for HDVs is currently lacking. With this project, it is aimed for to close this gap.

1.2 Objective and scope of the study

The objective of the project is to compare various design options of CO_2 emission standards and CO_2 labels for HDVs in Europe. This comparison is based on relevant criteria and provides insight in the main advantages and disadvantages of the various options available.
In this project we consider both CO_2 standards and CO_2 labels, because the design of these policy options share many similarities. Additionally, since it is not clear yet which policy option will be implemented in the EU, it still makes sense to consider both types of instruments.

The analysis of both the CO_2 standards and CO_2 labels is focussed on their design. In the report, the arguments made for a particular standard design also apply in case a label would be implemented, except when stated explicitly.
A complete comparison between standards and labels (in terms of effectiveness, efficiency, etc.) is, however, out of the scope of this project.

The scope of the study is both Heavy Goods Vehicles (HGVs) and buses, with the main focus on HGVs.

1.3 Approach

The analysis in this study follows the following approach.

First a literature review was conducted to gather information on the relevant policy context, the characteristics of the European HDV market, and on the CO_2 standards for HDVs that have already been implemented outside Europe. Based on this review, a long list of design options for standards/labels was made. From this list, a selection was made with several criteria, such as whether the design option has been implemented in other countries.
In addition, a list of assessment criteria was developed to evaluate the selected options with.

The gathered data was supplemented with information obtained in interviews with experts, NGOs, policy makers, and manufacturers. However, the main focus of the interviews was on the disadvantages and advantages of the selected design options. The list of organisations and experts that were interviewed can be found in Annex A, together with the interview topics/questions. The assessment of the different design options was supplemented with literature sources where available.

In sum, two main sources of data were used (literature and interviews) to follow the following steps:
1. Description of the policy context and European HDV market.
2. Description of the standard designs implemented outside the EU.
3. Development of a long list of design options and assessment criteria.
4. Selection of design options to analyse in detail.
5. Analysis of the selected design options for each assessment criteria.

Based on the results of the steps outlined above, a synthesis was made on the main pros and cons of each standard and the implication of these findings for the EU policy process.

1.4 Outline of this report

First in Chapter 2 background information is given on the HDV market and climate policy in Europe. It includes a brief comparison of the main policies at EU level targeting vehicle technology of HDVs (i.e. CO_2 standards, information provisioning, fuel taxes and emission trading). Next in Chapter 0, the various design options for CO_2 standards/labels for HDVs are identified. This includes an overview of standards outside the EU, a long list of design options and the selection of options for the short list. In Chapter 4 the assessment criteria are summarised and the selected design options are assessed on each of the defined criteria. Other design features (e.g. metric) are also discussed. Finally, Chapter 0 concludes on the main pros and cons of the different standard designs and elaborates on the implications for the EU. This chapter also provides some recommendations for further research.

2 HDV market and climate policies in Europe

2.1 Introduction

This chapter provides some background on the structure of the European freight transport market (Section 2.2) and hereafter elaborates on the wide range of possible CO_2 policies that could be implemented to incentivise the freight transport sector to reduce its emissions (Section 2.3).

2.2 European HDV market and freight transport industry

Within the EU, there are seven large original equipment manufacturers (OEMs)[1], which deliver approximately 93% of the new EU HDV registrations (AEA & Ricardo, 2011). In contrast to the LDV market, OEMs are usually only responsible for the powertrain, chassis and cabin; the final vehicle configurations (additional auxiliaries, bodies, etc.) are accomplished by one (or more) body builders, especially for rigid trucks. The demand for specific configurations varies significantly between customers.

In 2012, new HDV registrations in the EU equalled 317,890, of which 285,809 (90%) involved trucks and 32,081 (10%) involved buses or coaches (ACEA, 2013). These numbers also provide good estimations of the distribution in the total EU HDV fleet. Although the existing HDV fleet in the EU is rather difficult to estimate due to the fact that Eurostat does not distinguish heavy duty rigid trucks from Light Duty Vehicles (LDVs) (only the category 'lorries' is reported, which includes both LDVs with a GVW < 3.5 t and heavy rigid trucks > 3.5 t). AEA & Ricardo (2011) have combined this dataset with data from ACEA on their respective shares and have estimated that the total EU truck fleet had little over 6,500,000 vehicles in 2008. The bus and coach fleet is much smaller; Steer Davies Gleave (2009, cited in AEA & Ricardo) have estimated that this fleet comprises of 679,066 vehicles. The composition of the total HDV fleet is summarised in Table 1.

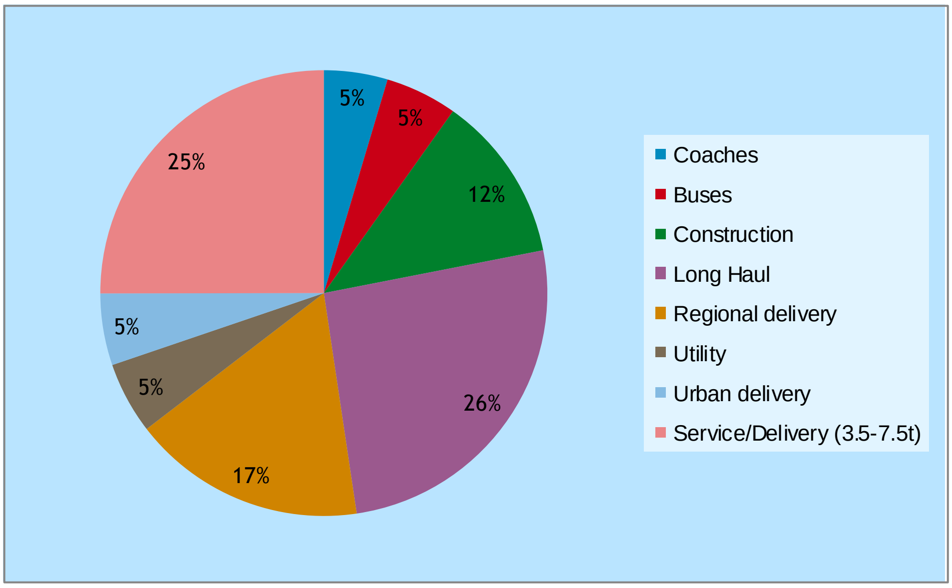
Table 1 Estimated composition of the entire HDV fleet in the EU

Vehicle category	Estimated number of vehicles	Share in total EU fleet
Trucks	6,500,000	90%
Buses and coaches	679,066	10%
Total	7,179,066	100%

The mission profile of this entire HDV fleet is shown in Figure 1.

[1] It concerns: DAF Trucks, Daimler AG, M.A.N., Renault Trucks, Scania, Volvo Trucks and Iveco.

Figure 1 Utility cycles of the EU HDV fleet in 2010



Source: AEA and Ricardo, 2011.

As can be seen, most vehicles in the HDV fleet are used for long haul or service deliveries, followed by regional deliveries and construction purposes. Only a small part of the HDV fleet is used for urban deliveries, utilities, buses, and coaches, which each have a share of 5% in the total HDV fleet.

Whereas the HDV market is highly concentrated with only seven major OEMs, the trailer manufacturer market comprises of thousands of companies and has a much more local focus (AEA and Ricardo, 2011). The seven largest suppliers have delivered approximately 53% of the new EU trailer registrations (ibid.).

According to CLEAR (2010, cited in AEA and Ricardo, 2011), 250,000 new EU trailer registrations were made in 2008. No data was found for 2011, however, considering that the number of new truck registrations has decreased significantly after 2008 (a rough estimation results in a decrease of 30%), it seems likely that the number of new trailer registrations will have decreased with about the same magnitude as well.

The total trailer fleet is difficult to estimate, as Eurostat also includes trailers operated by light duty vehicles. When only including trailers > 10 t, the total trailer fleet can be estimated on 3.2 million units, which is further elaborated on later in this section.

The remainder of this section describes the HDV market in more detail for the truck fleet, trailer fleet and for the bus and coach fleet, respectively.

2.2.1 EU Truck fleet

AEA and Ricardo (2011) have estimated the total EU truck fleet to comprise of approximately 6,500,000 vehicles.

AEA and Ricardo (2011) have estimated the respective shares of two main truck types, rigid trucks and road tractors, and their mission profiles. These shares and the resulting vehicle fleet composition is summarised in Table 2.

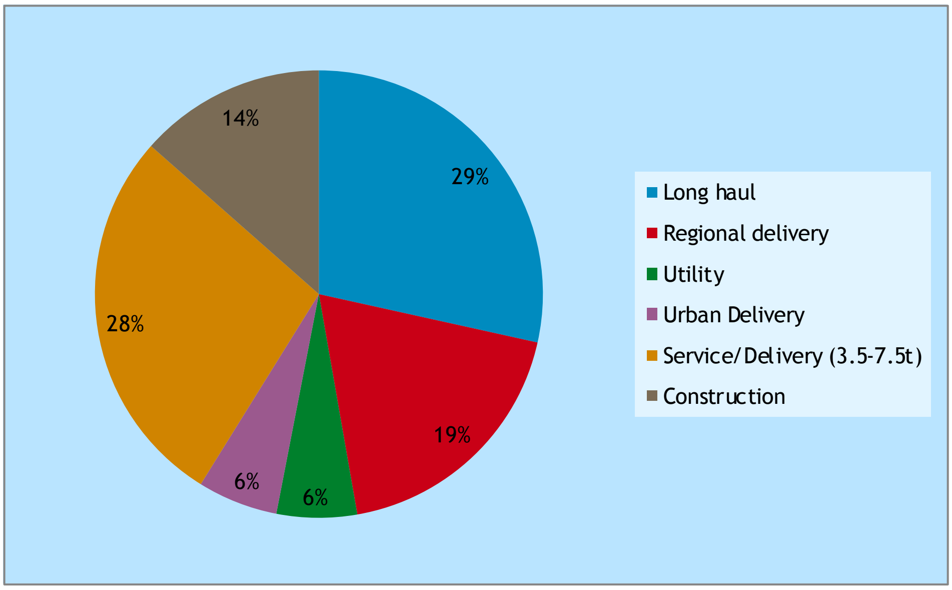
Table 2 **Estimated composition of the EU Truck fleet in 2008**

Type of truck	Estimated number of trucks	Share in total truck fleet
Rigid trucks	**4,803,500**	**74%**
Long haul	749,346	12%
Regional delivery	600,438	9%
Utility	422,708	7%
Urban Delivery	417,905	6%
Service/Delivery (3.5-7.5 t)	2,012,667	31%
Construction	605,241	9%
Road tractors	**1,696,500**	**26%**
Long haul	911,021	14%
Regional delivery	527,612	8%
Construction	257,868	4%
Total	**6,500,000**	**100%**

Source: AEA and Ricardo, 2011, adjusted by CE Delft.

As can be seen in Table 2 the main share of trucks in the EU HDV fleet are rigid trucks, while a quarter of the vehicles are road tractors. The mission profiles of the whole EU truck fleet (i.e. both rigid trucks and road tractors) are depicted in Figure 2. As was the case for the entire HDV fleet, long haul and regional delivery have the largest share.

Figure 2 **Mission profiles of the EU truck fleet in 2010**



Note: The shares shown in the figure are the same as those shown in Figure 1 but without heavy duty passenger transport. The shares are based on vehicle numbers, not on tonne or vehicle kilometres. In these latter cases, the shares of those mission profiles that have lower annual driving cycles (e.g. urban, regional) would become even smaller, while the share of long haul would increase significantly.

Source: AEA and Ricardo, 2011.

There are no datasets available that show more detail on the type of vehicles within the fleet and for the different mission profiles. Two datasets provide some information on this though. Firstly, AEA and Ricardo (2011) have made an estimation of the most commonly used mission profiles for each EU truck type. Their results are summarised in Table 3.

Table 3 Common mission profiles for different truck types

Axle/chassis configuration			GVW	Urban	Utility	Regional	Long haul	One day trip	Light construction	Heavy construction
2 axles	4x2	R	7.5-16 t	30%	20%	30%		20%		
	4x2	R	≥16 t	20%	20%	20%	20%	20%		
	4x2	T	≥16 t			35%	25%	25%	15%	
	4x4	R	7.5-16 t		20%				80%	
	4x4	R	≥16 t		20%				80%	
	4x4	T	≥16 t						100%	
3 axles	6x2/2	R	all			33%	33%	33%		
	6x2/2	T	40 t					100%		
	6x2/4	R	all		100%					
	6x2/4	T	40 t				100%			
	6x4	R	all					20%	40%	40%
	6x4	T	40 t				30%	30%	20%	20%
	6x6	R	all							100%
	6x6	T	40 t							100%
4 axles	8x2	R	all		25%	75%				
	8x4	R	all						50%	50%
	8x6	R	all							100%
	8x8	R	all							100%

Note: R = rigid truck, T = Tractor.
Source: AEA and Ricardo, 2011.

Additionally, the number of deliveries of the seven major OEMs per truck type are known. These are shown in Table 4 for the years 2000 up to and including 2009. These numbers are expected to provide a good estimation of the truck types that are most common in the EU truck Fleet.

Table 4 **Truck deliveries from the seven major OEMs from 2000-2009**

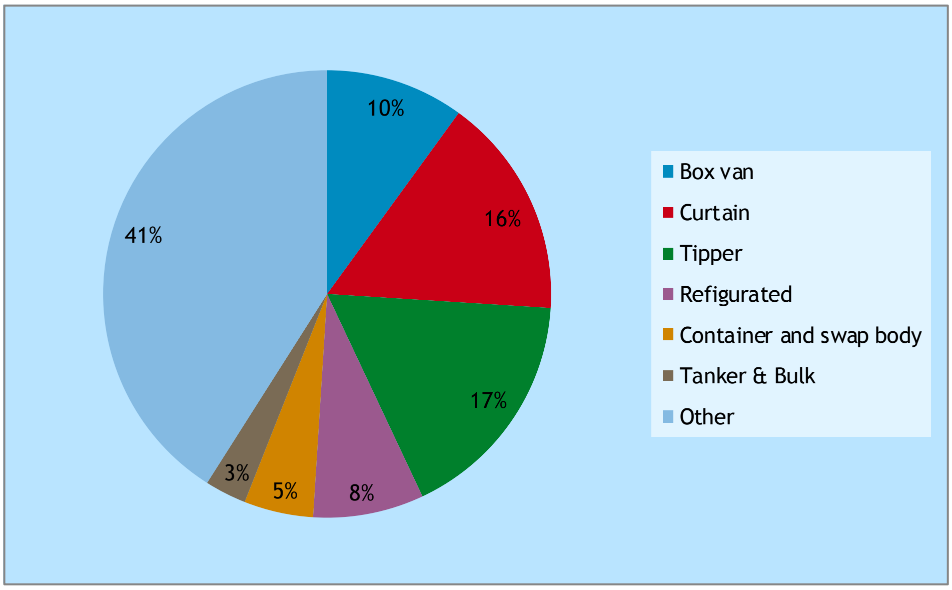
Axle/chassis configuration			GVW	Number of vehicles	%
2 axles	4x2	Rigid	7.5-16 t	653,841	20,3%
	4x2	Rigid	≥16 t	356,636	11,1%
	4x2	Tractor	≥16 t	1,247,813	38,8%
	4x4	Rigid	7.5-16 t	25,852	0,8%
	4x4	Rigid	≥16 t	28,030	0,9%
	4x4	Tractor	≥16 t	12,290	0,4%
3 axles	6x2/2	Rigid	all	289,636	9,0%
	6x2/2	Tractor	40 t	150,149	4,7%
	6x2/4	Rigid	all	55,140	1,7%
	6x2/4	Tractor	40 t	1,354	0,0%
	6x4	Rigid	all	130,048	4,0%
	6x4	Tractor	40 t	31,556	1,0%
	6x6	Rigid	all	28,072	0,9%
	6x6	Tractor	40 t	2,762	0,1%
4 axles	8x2	Rigid	all	9,298	0,3%
	8x4	Rigid	all	180,797	5,6%
	8x6	Rigid	all	7,910	0,2%
	8x8	Rigid	all	7,341	0,2%
Total				3,218,525	100,0%

Source: ACEA, 2010, cited in AEA and Ricardo, 2011.

2.2.2 New truck registrations in the EU

For newly registered trucks the shares of different truck types are known (Figure 3 for rigid trucks), which may also provide some knowledge about the share of these types in the total EU fleet.

Figure 3 **New registrations of different rigid truck types of VDA members in 2009**



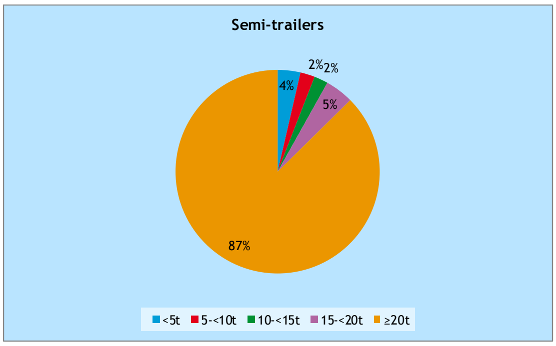
Source: VDA, 2010, cited in AEA and Ricardo, 2011.

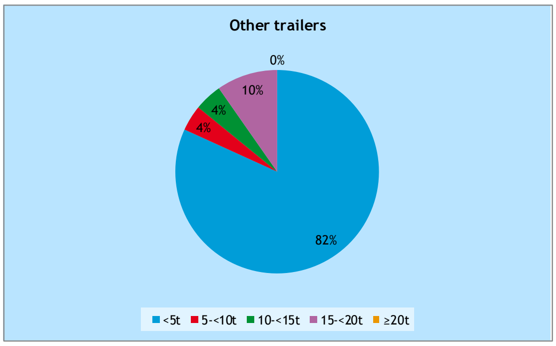
2.2.3 EU trailer fleet

There is significantly less information available on the use of trailers in the EU road freight transport market as there is on trucks. Eurostat does provide data on the total trailer fleet of the EU. However, these numbers also include trailers < 10 t, which according to TU Graz et al. (2012) are not used in HDV transport.

Figure 4 shows the shares of different trailer weights for the entire trailer fleet of the EU. As can be seen, the main share of semi-trailers (87%) has a load capacity of over 20 t (and hence is mostly used for HDV transport), while the main share of other trailers (82%) has a load capacity of only 5 t or less (and is mostly used by LDVs therefore).

Figure 4 Distribution of weight classes of trailers in the total EU fleet





Source: Eurostat, 2013, adapted by CE Delft.

The total number of semi-trailers (trailer without a front axle, mainly driven by road tractors, see Figure 5) in the EU fleet is estimated at approximately 2.2 million units. Other, mainly drawbar, trailers (trailers *hauled* by road motor vehicles, see Figure 5) were approximately 6.8 million units in 2008 on the other hand (Eurostat, 2010). When only taking into account other trailers of > 10 t (14% of 6.8 million), 952,000 units result. The total HDV trailer fleet can therefore roughly be estimated at 3.2 million units.

These numbers indicate that for each road tractor, approximately 1.3 semi-trailers are in operation. This is significantly lower than is the case in the US, where approximately 3 or more semi-trailers are in operation per tractor.

Figure 5 Difference between a semi-trailer and drawbar trailer

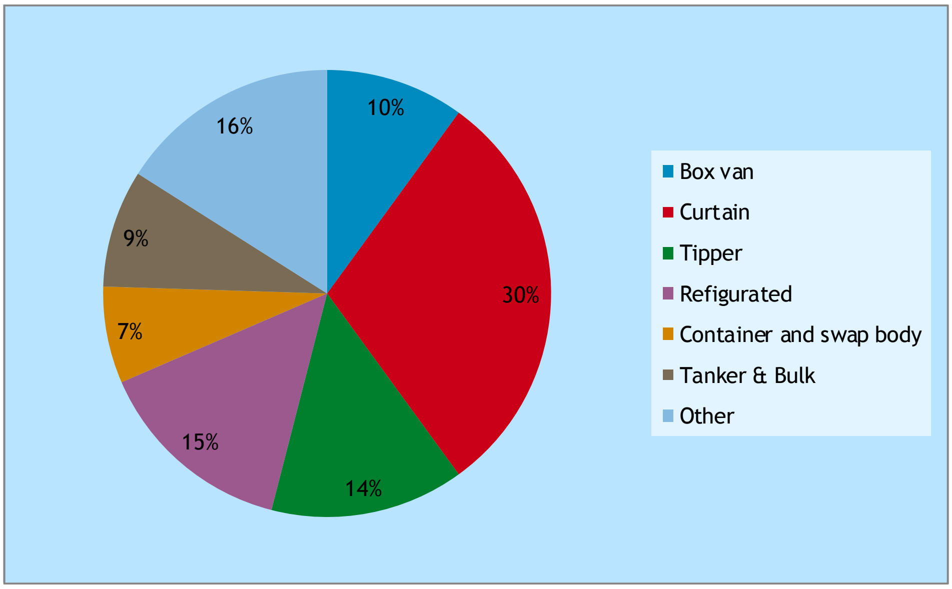
a) Semi-trailer (curtain)

b) Drawbar trailer (curtain)

2.2.4 New trailer registrations in the EU

In 2008, 80% of the new trailer registrations were for semi-trailers (200,000). The remainder (20%) were drawbar trailers (50,000) (CLEAR, 2010, cited in AEA & Ricardo, 2011). The types of trailers are shown in Figure 6 and Figure 7, and may provide an indication of the total EU truck-trailer fleet for which no data is available.

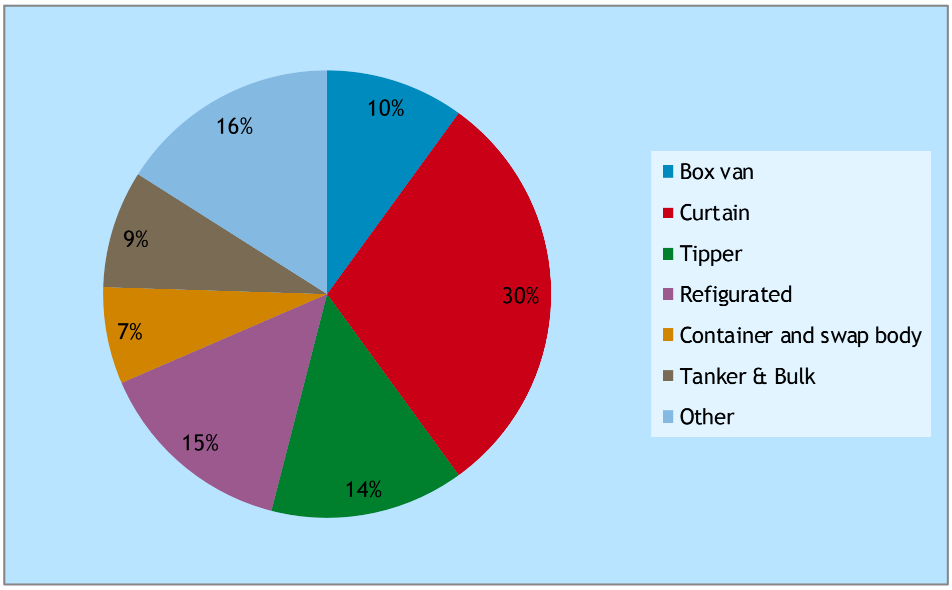
Figure 6 Shares of different semi-trailer types (of new registrations in 2009)



Note: Percentages are the averages of two datasets; CLEAR (2010) and VDA (2010),which are both cited in AEA and Ricardo (2011). These datasets are relatively comparable to each other.

Source: AEA and Ricardo, 2011, adjusted by CE Delft.

Figure 7 Shares of different drawbar trailer types (of new registrations in 2009)



Note: Percentages are the averages of two datasets; CLEAR (2010) and VDA (2010),which are both cited in AEA and Ricardo (2011). These datasets are relatively comparable to each other.

Source: AEA and Ricardo, 2011, adjusted by CE Delft.

Figure 8 shows these trailer types graphically.

Figure 8 Examples of common trailer types in Europe

a) Semi-trailer (swap body/container)

b) Drawbar trailer (box)

c) Semi-trailer (refrigerated)

d) Drawbar trailer (tipper)

e) Semi-trailer (curtain)

f) Semi-trailer (tanker)

2.2.5 EU Bus and coach fleet

The bus market in the EU is mostly a mix of privately and publicly owned fleets. Private companies with bus fleets usually have public contracts (AEA and Ricardo, 2011). The EU fleet of coaches on the other hand is operated mainly by private companies (ibid.). SDG (2009, cited in AEA and Ricardo, 2011) has characterised the bus and coach fleet of the EU, their results have been summarised in Table 5. As can be seen in the table, the EU bus fleet is significantly larger than the EU coach fleet, which results from larger fleets per company. In total, the EU has a bus and coach fleet of 679,066 vehicles, of which 63% are buses and 37% coaches.

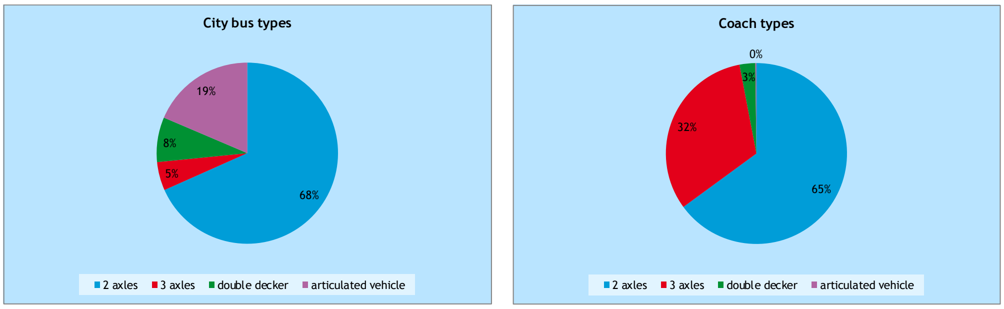
Table 5 Characteristics of the EU bus and coach market

	Bus	Coach	Total
Number of EU companies	13,997	29,221	43,218
Average EU fleet size per company	31	9	16
Total EU fleet size	**430,187**	**248,879**	**679,066**

Source: SDG, 2009, cited in AEA and Ricardo, 2011.

According to ACEA (2010, cited in AEA and Ricardo, 2011), 40% of the 2009 new bus registrations in the EU are for buses and coaches with a GVW of 7.5-16 t, while 60% has a GVW of >16 t. There are no estimates for the total existing fleet, but these numbers may provide a good indication of the weight distribution in the EU bus and coach fleet. Likewise, the bus and coach types of new registrations (2007-2009) are available (ibid.), but not for the whole existing bus and coach fleet. The respective shares of different bus and coach types are shown in Figure 9.

Figure 9 **City bus and coach types of new registrations (2007-2009)**



Source: ACEA, cited in AEA and Ricardo, 2011.

As becomes evident from Figure 9, 2 axle vehicles are the dominant type for both city buses and coaches. However, while for city buses articulated vehicles play a significant role as well, this is not the case for coaches, where 3 axle vehicles are an important share of the fleet.

Table 6 shows that the EU bus and coach fleet operates 522,500 million passenger kilometres per year, which roughly equals 31,623 million vehicle kilometres. Passenger kilometres are equally divided over the bus and coach fleet, but due to a lower occupancy factor, the bus fleet travels twice more vehicle kilometres than the coach fleet.

Table 6 **Driven kilometres of EU bus and coach fleet**

	Million passenger kilometres	Average occupancy factor	Million vehicle kilometres
Bus	259,517	12	21,509
Coach	262,983	26	10,114
Total	522,500	16.5	31,623

Note: The bus vehicle kilometres are estimated by multiplying the number of buses (Table 5) with an average driving cycle of 50,000 kilometres (AEA and Ricardo, 2011).

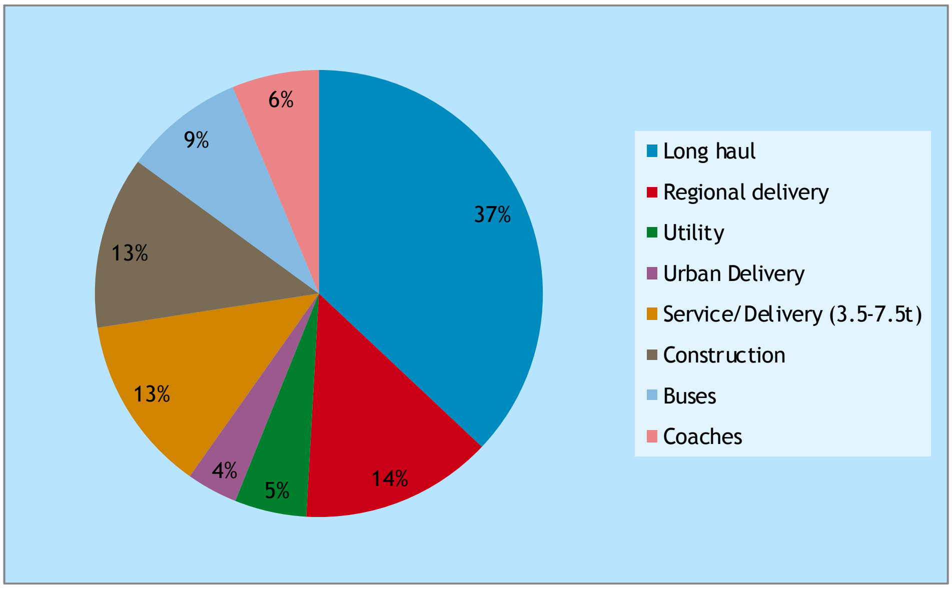
Source: SDG, 2009, cited in AEA and Ricardo, 2011, adjusted by CE Delft.

2.2.6 CO_2 emissions resulting from the EU HDV fleet

The different duty cycles and vehicle types vary in the CO_2 emissions they emit. This section provides a quick overview of the respective shares of the different EU mission profiles in the total CO_2 emissions.

According to AEA and Ricardo (2011), total CO_2 emissions from EU HDVs equal 241 Mt. Buses and coaches are responsible for a relatively small share (14%), while trucks cause the remainder of 86% (207 Mt of CO_2). A more detailed overview of the shares of different HDV mission profiles is given in Figure 10. It shows that the main share of HDV emissions are caused by long haul transport, followed by regional, service, and construction. The large share for long haul is the result of the high share in the fleet (see Figure 1) and the relatively high CO_2 emissions per vehicle, most likely caused by a relatively high annual distance per vehicle.

Figure 10 Share of different mission profiles in total EU HDV CO_2 emissions



Source: AEA and Ricardo, 2011.

2.3 European climate policy for HDVs

In this section we discuss climate policies for heavy duty vehicles. First, we provide a brief overview of options for CO_2 policies for HDVs, including a broad assessment of their main advantages and disadvantages. Next, the European policy process with respect to CO_2 emissions of HDVs is discussed.

2.3.1 Options for CO_2 policies for HDVs

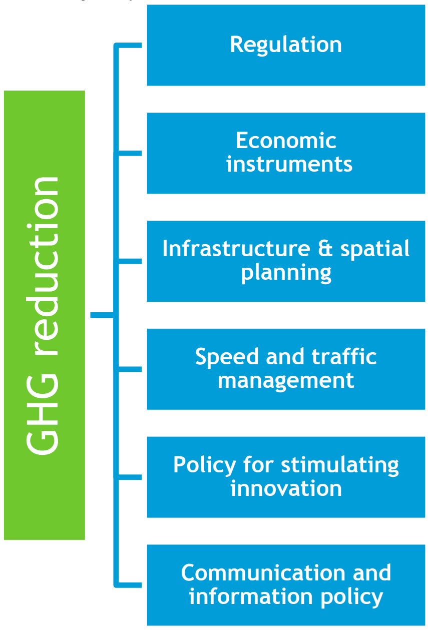
There are various options for reducing the CO_2 emissions of transport. Overall we can distinguish five main categories (CE Delft, 2012c):

1. Fuel-efficient vehicles.
2. Low carbon energy carriers.
3. Modal shift.
4. More efficient vehicle use.
5. Less demand growth.

Previous studies have shown that the technological GHG reduction potential (i.e. the first two options listed above) have the largest GHG reduction potential.

The various reduction options can be stimulated by a broad range of policies at various levels (global, EU, national, regional, local). Figure 11 provides an overview of the main types of climate policy that can contribute to greenhouse gas (GHG) reduction in transport.
Each of these policies can contribute directly or indirectly to several of the GHG reduction options, although they may trigger particular reduction options more than others. For example, CO_2 regulation of vehicles particularly stimulate energy efficiency improvements; but the price effects of tight standards can to some extent also affect modal split, load factors and long term demand growth. A measure like lower speed limits affects the fuel-efficiency of vehicles but has also an impact on modal split and long term impacts on the growth of transport demand.

Figure 11 Main categories of policy instruments that can contribute to GHG reductions in transport



Source: CE Delft (2012c).

This study focuses on policies at EU level targeting vehicle technology of HDVs. Therefore, the policy options that are further discussed in this section are limited to:

- *Information disclosure;* by providing information on the CO_2 performance (or fuel-efficiency), buyers/owners of vehicles could be incentivised to buy more fuel-efficient vehicles. A possible instrument to provide this kind of information are CO_2 (or energy) labels. In addition to the informative purpose of the latter-mentioned instrument, it may also be possible to link an economic instrument (e.g. registration tax, subsidies) to the label of the vehicle.
- *CO_2 (or energy) limit standards*; CO_2 emission (or energy intensity) targets are set for (parts of) the vehicle (or an average target for the fleet as a whole as is the case for passenger cars and vans). If these targets are not met by the manufacturers fines have to be paid. With some standard designs, enforcement by means of type approval processes could be an option (i.e. if the standard is not met, the vehicle cannot be sold).
- *Fuel taxation*; increasing fuel taxes for HDVs (or all road vehicles) may also provide incentives to reduce the (total) CO_2 emissions of these vehicles.

– *Including HDVs in the EU ETS*; currently the CO_2 emissions of the energy-intensive industries in the EU are covered by the EU Emission Trading Scheme (ETS). An option to apply a CO_2 policy to HDVs is to include these vehicles (or the entire (road) transport sector) in the EU ETS or to develop a separate ETS for HDVs or transport.

Other policies at EU level that could contribute to reducing the HDV CO_2 emissions of HDVs, such as speed or infrastructure policy, have no (significant) impacts on HDV technology and are therefore not relevant for this study.

It should be noted that each of these four policy options could be designed in various ways and that their (cost) effectiveness and feasibility depends strongly on the actual design of the instrument. However, in this section we will only discuss these instruments in general terms and therefore, no extensive assessment of the possible design options will be carried out. With respect to information disclosure (mainly focussed on labelling) and standards, the design of the instrument will be discussed thoroughly in the next chapters.

In the remainder of this section these four policy options are briefly assessed based on five criteria:
1. Effectiveness; to what extent is a CO_2 reduction in the HDV sector realised.
2. Cost-effectiveness; what are the costs of the reductions in CO_2 emissions realised.
3. Incentive for innovative technologies; does the policy stimulate investments and adoption of innovative technologies (e.g. electric vehicles).
4. Feasibility; could the policy be effectively implemented easily or are there large barriers for implementation.
5. HDV specific or not; could the policy be targeted on HDVs or are other modes also affected by the policy.

Effectiveness
Limit standards can be rather effective in reducing the CO_2 emissions of HDVs. Experiences with such standards for LDVs and pollutant emission standards for HDVs has proven that they can result in relatively fast and significant uptake of vehicle innovations. The effectiveness depends mainly on the quality of test procedures and the emission levels that are applied.

It should however be noticed that standards also have some limitations. They are applied on new vehicles only and in the short run therefore only partly affect the total fleet. In other words, the short term impact of standards on total HDV CO_2 emissions is smaller than the long term impact. Additionally, CO_2 standards only affects CO_2 emission reduction at the vehicle level; emission reduction realised by applying logistic improvements, a fuel-efficient driving style or reduced transport demand are not incentivized. Moreover, due to the lower fuel costs because of the more fuel-efficient vehicles, hauliers/shippers may be incentivize to lower the logistic efficiency of their transport or to transport more, resulting in an increase in CO_2 emissions. This rebound effect may partly compensate for the reduction in CO_2 emissions due to more fuel-efficient vehicles.

Compared to CO_2 standards the main advantage of (increased) fuel taxes is that these incentivise all kinds of reduction measures; vehicle users are stimulated to use more fuel-efficient vehicles, to use their vehicle in a more efficient way or to transport less. Consequently, no rebound effects (as for CO_2 standards) exist for this policy instrument. Additionally, this policy option does not only affect new vehicles, but the whole HDV fleet; therefore larger impacts may be expected on the short term compared to standards. On the other hand, (increased) fuel taxes do - in contrast to standards - not provide any certainty on the reduction in CO_2 emissions realised; this strongly depends on the price sensitivity of transport users.

Moreover the price sensitivity of the fuel consumption of HDVs for changes in fuel prices is relatively low. A 10% price increase results in 2 to 6% fuel and CO_2 reduction (Significance and CE Delft, 2010). For meeting modest reduction percentages of around 10% (as currently foreseen by most of the HDV CO_2 standards in other parts of the world), a diesel price increase of about 20 to 50% would be required. Such large price increases are unlikely to be feasible and could have significant impacts on the sector. This makes the reduction in CO_2 emissions from HDVs that can be achieved in practice are likely to be lower for fuel taxes than for CO_2 regulation of HDVs.

As for fuel taxes, also the inclusion of HDVs in the EU ETS incentivizes all possible reduction measures available to hauliers/shippers/transport companies. Additionally, it affects the whole vehicle fleet and not only new vehicles. In contrast to fuel taxes the inclusion of HDVs in the EU ETS also provides certainty on the CO_2 reduction that finally will be realised; this is set by the CO_2 cap that applies for the entire ETS. It is not guaranteed that CO_2 reduction will take place in the HDV sector though. The main characteristic of an ETS is that reduction of CO_2 emissions will take place in those sectors where the abatement costs are lowest. Since it is generally assumed that the CO_2 abatement cost of reduction options in the transport sector are relatively high compared to other economic sectors, it is expected that the main part of the CO_2 emission reduction will take place in sectors outside the transport sector. Although the overall CO_2 emission reduction target will be met, it is therefore uncertain which amount of CO_2 emission reduction will be realised in the HDV sector. By introducing a separate ETS for HDVs (or the entire transport sector) this 'disadvantage' of the inclusion of HDVs in the EU ETS could be avoided. However, depending on its design, such a scheme might result in rather high transaction and implementation costs which could negatively affect its feasibility.

Finally, the effectiveness of information disclosure is expected to be lowest, as is shown by several studies (e.g. AEA et al., 2009; OECD, 2002). In contrast to the regulative and economic instruments information disclosure do not change the consequences of a certain behaviour (e.g. buying a fuel-inefficient vehicle) and hence is expected to be less effective in changing behaviour of consumers. The effectiveness of information disclosure could be increased by combining it with other (hard) measures, like fiscal measures (AEA et al., 2009). However, as vehicle taxes for HGVs are relatively low, there is not much room for providing significant financial incentives.

Cost-effectiveness

The economic instruments (fuel taxation, inclusion in ETS) are, at least in theory, expected to be most cost-effective, since it provides vehicle owners/users the opportunity to choose the reduction option with the lowest costs. For example, a fuel tax may stimulate vehicle users to apply a fuel-efficient driving style, which is a rather cost-effective reduction measure (e.g. see AEA et al., 2012b). This reduction measure is, however, not stimulated by a standard or a labelling scheme and this will probably negatively affect the overall cost-effectiveness of these policy options.

From the economic instruments, the inclusion of HDVs in the current ETS is in the long term theoretically the most cost-effective option, since this scheme also covers other economic sectors where relatively cheap reduction options are available. This is not the case for fuel taxes, which only stimulates the application of reduction options in the transport sector. At the other hand, transaction costs of emission trading could well be higher. Furthermore, as long as there is no worldwide climate policy, it may well be more cost-effective to accept higher reduction cost in sectors that are not (much) exposed to intercontinental competition and so have low risks of so called 'carbon leakage'[2] (such as road transport) than in sectors that are exposed (such as steel production or refineries) (AEA et al., 2010b).

Moreover, it should be noticed that the higher cost-effectiveness of both fuel taxes and ETS compared to other policy options such as standards, is merely true in an ideal market situation. There is evidence, however, that various fuel-efficiency improvements that are cost-effective for the user, are not widely implemented in the road freight transport sector (CE Delft, 2012b). This suggests that there exist significant market barriers (e.g. related to information limitations, risk aversion or availability of investment capital).

From the four policy options considered in this section information disclosure is expected to be least cost-effective, which is mainly the result of the rather low effectiveness of this instrument.

To summarise, in case of limited transaction costs economic instruments (like fuel taxes and ETS) are expected to be cost-effective. At least at the short term, also standards are expected to be cost-effective (although this will depend on the standard design); from CE Delft (2012a) it follows that for all types of HDVs there are several emission reduction measures available with negative costs[3] that are not yet applied by transport companies (due to different kinds of market barriers). Stimulating manufacturers to apply these technologies may therefore be a cost-effective measure. At this moment, it is therefore not possible to judge which policy strategy has better overall cost-effectiveness. AEA et al. (2012a) concludes that 'there are a number of benefits of using regulation and economic instruments together to deliver GHG reductions from transport. The uncertainty associated with specific instruments and the benefits of using regulation and economic instruments together suggests that using a range of instruments is important to reduce transport's GHG emissions.'

Incentive for innovative technologies

The development of long term innovative vehicle technologies (e.g. hybrid or electric vehicles) may require another policy framework than stimulating fuel-efficient technologies which are already at the market. As mentioned before, currently there are a lot of cost-effective reduction measures for HDVs available at the market (see CE Delft, 2012a) and hence short term CO_2 standards for HDVs could probably be met by applying these technologies. As a consequence, these (short term) standards will not provide an incentive to invest in (the development of) more innovative technologies. However, by

[2] Carbon leakage means that, for reasons of costs related to climate policies, businesses transfer production to other countries which have less stringent climate policies. This could lead to an increase in their total emissions. The risk of carbon leakage is generally higher in certain energy-intensive industries operating on an intercontinental market.

[3] This means that the higher investment costs of these technologies are compensated by the savings on fuel costs over the lifetime of the vehicle.

setting (stricter) long term CO_2 standards OEMs may be stimulated to invest in the development of innovative technologies.

As mentioned by AEA et al. (2012a) sustainable reduction measures, such as electric and hybrid vehicles that may be needed to meet longer term reduction targets, have long lead times for reaching technical and economical maturity and can only reach this level of maturity if they start being applied in the market. Only through economies of scale and learning effects will costs go down and product quality improve. This means that these measures need to enter the market well before it is necessary for them to be applied at a large enough scale well before it is necessary for them to be used to meet potential future standards. In addition to standards economic instruments are therefore necessary in the short and medium term to enable market formation for these technologies. Fuel taxes or ETS could be used for this purpose, but economic instruments directly affecting the relatively high investment costs of these innovative technologies (e.g. subsidies) may be more effective. In addition, certainty on the standard limits on the longer term is important in order for manufacturers to justify investments in innovative technologies.

Economic instruments (like fuel taxes and ETS) in itself (i.e. without combining them with standards) may also stimulate innovative technologies. However, this requires a sufficient level of certainty on future price incentives provided by these instruments on which manufacturers and vehicle users could base their (long term) investment decisions in these technologies.

Finally, information disclosure does not provide an incentive to invest in innovative technology. However, by combining CO_2 labels with fiscal measures or subsidies targeted at the investment costs of innovative vehicles, they may effectively contribute to the market penetration of innovative technologies.

Feasibility

With respect to standards and information disclosure the most important feasibility issue is whether a reliable test procedure is available (TNO and CE Delft, 2010). An important issue in this respect is the correlation between the reduction measured in the test and effects on emission under real-world driving conditions. Recently, the European Commission has commissioned studies on the development of an improved HDV emission simulation tool, which could be used as basis for standards or labels/information disclosure. Assuming a reliable test procedure is realised, no significant issues hamper the feasibility of these options anymore. Reliable test procedures may be very hard to develop though, which is further elaborated on in Chapter 4.

Since fuel taxes are already charged in all EU Member States there are no problems with respect to increasing them. At the same time, tax increases needed to deliver significant GHG emission reductions are difficult to achieve. In 2011 the European Commission proposed a revising of the Energy Taxation Directive and replace the current minimum rates that are mainly based on volume by a combination of an energy related and a CO_2 related element (EC/MEMO/11/238). Adoption of the proposal may result in significant changes in the fuel taxes applied in the various EU Member States (CE Delft and Ecofys, 2011). However, it seems that the policy process got stuck and the proposal will not be adopted.

The feasibility of an inclusion of HDVs (or transport) in the current EU ETS depends strongly on the design of the scheme. A completely downstream approach (in which the vehicle owners have to submit the allowances) will probably not be feasible, mainly because in that case there are millions of (small) trading entities in the EU which results in rather high transaction costs. On the other hand, an upstream approach in which the refineries are required to submit the allowances may be problematic because at this level of the fuel supply chain it isn't clear yet which share of the fuels produced are consumed by HDVs and hence it is not possible yet (unless complex monitoring schemes are introduced) to define the CO_2 emissions related to HDVs. The most feasible option to include HDVs (or the whole transport sector) in the EU ETS is by applying a midstream approach in which the tax warehouse keepers (entity who is responsible for charging the fuel taxes) is appointed as the entity which has to submit the allowances. Given the relative limited number of these entities the transaction costs are rather low and they have the opportunity to differentiate between transport fuels and other fuels.

HDV specific or not

Currently CO_2 standards for passenger cars and vans are already applied. Introducing standards or a labelling scheme for HDVs would therefore be complementary to that scheme and have no overlap. Also other information disclosure instruments could be targeted to HDVs only.

With respect to fuel taxation, raising diesel taxes would also affect diesel-powered LDVs, as the same fuel tax rates apply for both types of vehicles. In some EU Member States a discount on fuel taxes for HGVs is applied, which is operationalized by tax refund schemes; truck owners have the opportunity to partly reimburse the fuel taxes paid. In theory, the same approach could be used here to compensate users of LDVs for higher fuel taxes. However, it should be noticed that the number of LDVs is much higher than the number of HDVs and hence the transaction costs of such a refund scheme will be significantly higher than for the existing schemes. Moreover, there are good arguments for harmonizing diesel and petrol taxes based on their energy content and CO_2 emissions per litre, which may be operationalized by raising the diesel taxes for all vehicles.

In case of inclusion of transport in the EU ETS, the possibility of distinguishing HDVs and LDVs depends strongly on the design of the scheme. For example, in case an upstream approach is implemented in which the refineries are appointed as the entities that have to submit allowances, it will be rather hard to distinguish between the fuel consumed by LDVs and HDVs since at this level of the fuel supply chain it is not clear yet for which purpose fuels will be used. On the other hand, if a downstream approach is implemented (e.g. vehicle owners are appointed as entity which has to submit the allowances) such a distinction between HGVs and LDVs could possibly be made.

2.3.2 European CO_2 policy process for HDVs

The European Commission has set the objective to reduce the GHG emissions by 80-95% below 1990 levels by 2050 in order to limit the temperature increases to below 2˚C from pre-industrial times (EU, 2005). To meet this objective the GHG emission of transport should be reduced by 60% over the same time period, according to the Transport White Paper (EC, 2011b). In the impact assessment accompanying this White Paper it is assumed that HDVs will achieve a 40% improvement in their energy efficiency by 2050 (compared to 1990 levels).

Over the last years the European Commission introduced ambitious CO_2 policies for passenger cars and vans. For both categories CO_2 standards were introduced; in 2009 the European Commission set mandatory CO_2 standards for new passenger cars. Under this regulation, the fleet average to be achieved by all new cars is 130 grams of CO_2 per kilometre by 2015 and 95 g/km by 2020 (note that it concerns test cycle values) (EC, 2009; 2012). For vans a fleet average of 175 g/km is required by 2017 and 147 g/km by 2020 (EC, 2011a; 2012b).

For HDVs these kinds of CO_2 standards or other types of CO_2 policies are not introduced yet. However, currently the European Commission is developing an HDV CO_2 emissions strategy, which should be made public by the end of 2013. In preparation of this strategy the Commission is working on the development of a HDV CO_2 emissions simulation tool as well as an impact assessment of various EU policy options.

Simulation tools for estimating the CO_2 emissions of HDVs

The simulation tool that is currently being developed for the European Commission is called the VECTO model. This tool simulates the CO_2 performance of the whole vehicle and is based on input values from OEMs (for example on the aerodynamic drag, rolling resistance, and so on) on the one hand and on default values on the other. The tool is argued to be quite complex, as for most parameters vehicle-specific data is used. Thereby, the tool distinguishes the 8 European duty cycles described in the previous chapter. For some duty cycles, more default values are used than for others, as not all input parameters are relevant for all duty cycles for example. The first verifications of the VECTO simulation model show that it approaches real-world emissions quite closely, especially for long haul vehicles driving at relatively constant speeds (this does require the correct input data to be inserted). For such vehicles the deviation between simulation and on-road test results is about 3% or less (Fontaras, 2013). For shorter cycles (e.g. urban) the real-world conditions vary much more, therefore this is more complex to test and may be less accurate. Chapter 4, elaborates on the VECTO model in more detail.

In contrast, the simulation tool of the US is argued to be much more simplistic, as many of the truck details are fixed in the model (i.e. default values are used). OEMs only have to insert some main fuel-efficiency parameters, including aerodynamics, rolling resistance, light-weighting, and start-stop systems. The engine and transmission parameters are fixed in the vehicle simulation model, reducing the complexity of the simulation tool. Although the transmission parameter can be made vehicle-specific, the OEM has to conduct specific tests and the input has to be approved on a case by case basis by the EPA, which is expensive and time consuming and therefore not that common in practice.

Irrespectively of the simulation model chosen, real-world performance will always deviate somewhat from test results, as driving style, loads, routes, and other aspects have a significant influence on this real-world performance. This makes it very difficult to accurately simulate real-world performance.

At the stakeholder consultation meeting on Heavy Duty Vehicles CO_2 emissions of the 3rd of July 2012, the Commission presented the results of a preliminary assessment of the main EU strategy policy options (EC, 2012c). Three of the four CO_2 policies discussed in the previous subsector are also considered by the European Commission; only fuel taxation is lacking.

In addition, two more general policy scenarios are considered.
More specifically, the following five policy options are considered by the European Commission:

- *Baseline scenario*
  In this scenario – which only from a theoretical perspective could be considered a CO_2 policy scenario – only the policies which are already approved/proposed are considered[4]. Based on the impact assessment carried out, the European Commission concludes that in this option HDV transport would not significantly contribute to meeting EU GHG objectives and hence this option is considered to be not compatible with the CO_2 policy objectives announced in the Transport White Paper (60% CO_2 reduction in the transport sector).
- *Implementation of Transport White Paper actions*
  In this scenario a number of initiatives announced in the Transport White Paper[5] are taken into account. Although no explicit statements on the effectiveness of this policy scenario were provided by the European Commission, it is not expected that this policy option will result in significant CO_2 reduction for HDVs.
- *Improve knowledge and transparency of HDV CO_2 emissions*
  This policy scenario consists of three steps:
  1. Finalising the CO_2 emission simulation tool.
  2. Introducing registration and reporting legislation; this step is necessary before a labelling scheme could be introduced (Step 3), since some data should be available to develop a reliable labelling system. Registration would apply to new vehicles.
  3. Potentially a labelling scheme for HDVs is introduced.

  According to the European Commission, this option would not be expected to contribute sufficiently to the level of emission reductions required. This is in line with the results of the assessment carried out in the previous subsection.
- *Include HDVs in Emissions Trading Scheme (ETS)*
  As for the previous options this requires a reliable emission simulation tool to be available. As was also concluded in the previous subsection, the European Commission concludes that inclusion of HDVs in the Emission Trading scheme will probably have limited effectiveness in curbing HDV CO_2 emissions; the main share of the emission reductions will be realised in other economic sectors. However, meeting the overall CO_2 reduction target is guaranteed by this option.
- *Limits on HDV CO_2 emissions*
  The final option presented by the Commission was setting either engine-only CO_2 limits or whole vehicle limits. A main advantage of the previous option is according to the Commission that it is rather straightforward and practical since Euro VI legislation already covers measurement of engine CO_2 emissions. This option would have limitations in terms of reducing emissions. The second option – a whole vehicle limit – is considered a medium to long term option requiring the simulation tool to be finished, a registration and reporting system to be in place and an appropriate

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4 Including: Clean vehicles Directive 2009/33 on procurement of public authorities' HDVs, EU-funded R&D programme – Green car initiative, Fuel Quality Directive (setting 6% life cycle GHG reduction requirement by 2020), improved logistics and fleet management realised by the ITS directive (2010/40/EU), proposed revised energy taxation Directive (which sets new minimum fuel tax rates, recent revision of the Eurovignette Directive, tyre labelling and rolling resistance legislation.

5 Including: Clean Power for Transport Initiative, review of weights and dimensions legislation, E-Freight initiative, review of cabotage legislation, review of the Eurovignette Directive, zero emission urban logistics initiative.

dataset to be available from which to arrive at appropriate limits. According to the Commission, initial indications are that this option could be effective in contributing to meeting transport CO_2 reduction targets. The Commission did not seem to consider an option consisting of a combination of these two options such as that adopted in the US phase 1 HDV CO_2 emission standards.

3 Design options for CO_2 standards for HDVs

3.1 Introduction

In this chapter the options for CO_2 standards for HDVs are identified. First, in Section 3.2, an overview is provided of the CO_2 standards for HDVs implemented outside Europe. Next, a long list of design options is presented in Section 3.3. Finally in Section 3.4, a selection is made of the design options that will be assessed in the next chapter.

3.2 CO_2 standards for HDVs implemented outside Europe

Despite the complexity of the HDV market, several non-EU countries have now implemented CO_2/fuel consumption standards for this market. In the US, Canada, Japan and China, these standards have been implemented. While the standards of the US and Canada are well aligned, these are very different from those in Japan and China. Mexico is now planning to implement a standard similar to that of the US and Canada, but Europe is planning another measurement method, which may lead to yet another standard design (ACEEE and ICCT, 2013).

This section describes the standard design of the four countries that have already implemented a standard for HDVs: Japan, China, the US and Canada.

Japan: Fuel Economy Standard

Japan was the first country to implement a standard for HDVs. The Ministry of Economy, Trade and Industry (METI) has implemented the 'Fuel Economy Standard' in 2005, and targets have to be met from 2015 onwards (Transportpolicy.net, 2012).

The Japanese standard sets limits on the fuel consumption (km/l) of the vehicle. It includes all diesel fuelled freight HDVs with a GVW of ≥ 3,500 kg. Additionally, all passenger vehicles with a capacity of eleven persons or more are covered by the standard, also those that have a GVW of < 3,500 kg (ECCJ, 2005). Gasoline, LPG, or other alternative fuels are not covered by the standard.

The fuel economy limits (km/l) have been set at the level of the best fuel economy vehicles of the Japanese HDV fleet in 2002 (Transportpolicy.net, 2012). Different limits have been defined for five HDV categories:
1. Heavy Duty Transit Buses.
2. Heavy Duty General (Non-Transit) Buses.
3. Heavy Duty Trucks (excl. Tractors).
4. Heavy Duty Tractors.
5. Small Buses.

Each of the above mentioned HDV categories is further distinguished by GVW, which translates into 2–11 classes per HDV category (Transportpolicy.net, 2012). The fuel-efficiency is measured by computer simulations that are based on engine dynamometer testing. With this method, the parameters for the

engine and drivetrain (the inputs for the drivetrain are mainly related to transmission aspects; only one parameter of the drivetrain is related to the dynamic load radius of the tires) are based on vehicle-specific – actual - values, while the aerodynamic drag, rolling resistance and chassis size are based on standard values per HDV category (ECCJ, 2005). This implies that improvements will mainly result from improvements in the engine + transmission's fuel economy, and that other measures, such as improvements in aerodynamics, are not covered by the standard (ACEEE and ICCT, 2013). So although the standard sets one target for the whole vehicle, it can actually be considered an engine + drivetrain (mainly transmission) standard.
The ECCJ (2005, p. 16) indicates that standard values are determined for the vehicle's resistance and chassis size because 'Heavy vehicles vary widely in terms of various features including the vehicle form. Moreover, there is no established method for evaluating the driving resistance individually based on their actual specifications'.

It is expected that the fuel economy of the Japanese truck fleet will improve with 9.7-12.2% and the bus fleet with 11.1-12.8% (Transportpolicy.net, 2012).

China: National Fuel Consumption Standard

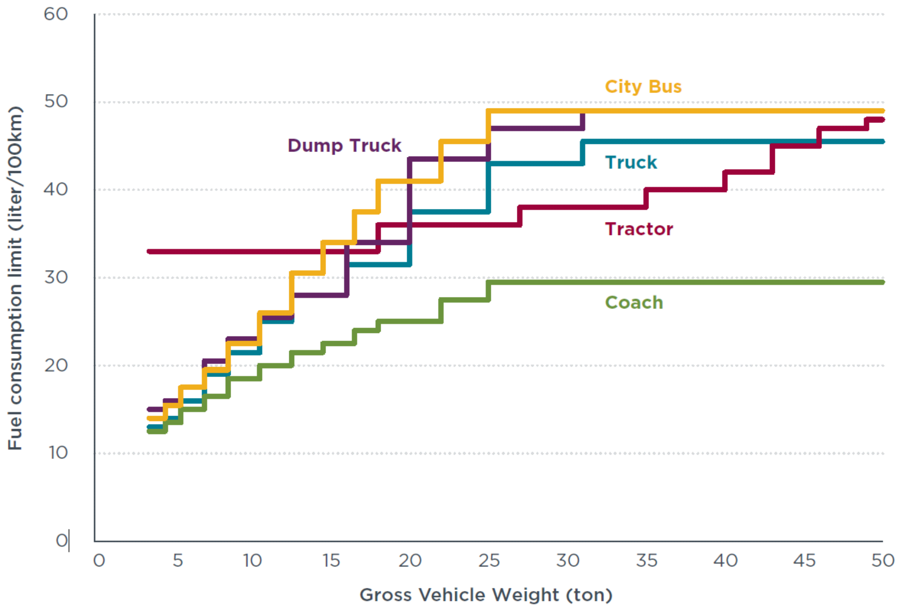
In January 2012, the Chinese Ministry of Industry and Information Technology (MIIT) implemented an industry standard ('Stage I standard') for HDV fuel consumption. This standard regulates the fuel consumption (l/100 km) of three categories of HDVs (commercial trucks, tractors, and coaches). All new vehicles that fall in one of these three categories will have to comply with the defined limits from July 2014 onwards (ICCT, 2013a). The fuel consumption limits that have been defined for the Stage I Standard have been based on the fuel consumption of the newest vehicles in the 2010/2011 Chinese fleet.
The fuel consumption reduction the MIIT aims to achieve with the standard is relatively low, which is a result of the limited knowledge available on the fuel consumption of existing fleets and on the HDV market in general (ibid.)
The standard covers the overall vehicle consumption and therefore can be considered as a standard for the whole vehicle.

In the same year, the MIIT announced a proposal to implement a 'National Fuel Consumption Standard' (Stage II Standard) that manufacturers will need to meet from July 2014 for new models and from July 2015 onwards for existing models. This standard will set fuel consumption limits (l/100 km) for five categories of HDVs with a GVW of over 3,500 kg:
1. Commercial trucks.
2. Tractors.
3. Coaches.
4. Dump trucks.
5. (city) Buses.

The latter two categories have not been covered by the Stage I Standard.
In both stages, specialised vocational vehicles have not been included.

For both standards, separate limits have been defined for the HDV categories mentioned above. Additionally, within each HDV category, limits are differentiated by GVW, as is shown in Figure 12 for the Stage II Standard.

Figure 12 Fuel consumption limits of the Chinese National Fuel Consumption Standard (Stage II)



Source: ICCT, 2013a.

For the three categories that were also included in the Stage I Standard (Truck, Tractor and Coach), the limits of the Stage II standard shown in Figure 12 are 10.5-14% lower than the Stage I limits (ICCT, 2013a). The fuel consumption is measured with chassis dynamometer testing for the base vehicle (the heaviest vehicle in each class), and with simulation modelling for the variant (i.e. other) vehicles (ibid.). The input parameters for aerodynamic drag and rolling resistance can be measured and reported by the manufacturers, but standard values are available as well.

The standard has separate limits for trucks and coaches consuming gasoline; these limits are 20% higher than the diesel limits (ICCT, 2013a).

US: Heavy-Duty National Program

The Environmental Protection Agency (EPA) and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) implemented a complementary set of standards that will set limits to the CO_2 emissions (EPA) and fuel consumption (NHTSA) of 2014-2018 HDV models and engines (EPA, 2011)[6].

The standards distinguish three main categories of HDVs ≥ 8,500 pounds (approximately 3,855 kg):

1. Combination tractors.
2. Heavy-duty pickup trucks and vans[7].
3. Vocational vehicles.

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[6] The EPA and NHTSA are equally strict, meaning that if a manufacturer meets the CO_2 standard he automatically meets the fuel consumption standard and the other way around. The reason for implementing two standards is purely legislative; the EPA and NHTSA had to implement a program together, but both had different authorities with respect to what they could regulate. The EPA is allowed to regulate emissions, while the NHTSA is allowed to regulate fuel consumption.

[7] In Europe, pickups and vans are usually LDVs with a GVW of < 3.5 t. The Heavy Duty pickup trucks and vans of this US standard are HDV vehicles with a GVW > 3.5 t.

For combination tractors and vocational vehicles a separate engine standard has been implemented, in combination with a standard covering the rest of the vehicle (EPA, 2011). The standards for the rest of the vehicle for combination tractors and vocational vehicles have been defined in gram per ton-mile (and gallon/1,000 ton-mile) and have to be met by the tractor and chassis manufacturers, respectively. The engine standards for these vehicle types are measured in gram CO_2/brake horsepower hour (bhp-hr) (and gallon/100 bhp-hr) and have to be met by the engine manufacturers (ACEEE and ICCT, 2013). The standards for the whole vehicle for pickups and vans are defined and measured as gram per mile (and gallon/100 mile), similarly as in the EU. Vehicle manufacturers are the regulated entity in this case.

For the engine standard, the GHG emissions/fuel consumption of the engine is measured by existing (air pollutant) emission test procedures (SET and FTP). The measurement methods for the standard for the whole/rest of the vehicle on the other hand, are based on chassis dynamometer testing (pickups and vans), or on the new vehicle simulation model (GEM) (vocational vehicles and combination tractors). For the GEM, several vehicle characteristics are measured separately and used as inputs in the model. These characteristics are related to the main fuel-saving technologies that can be applied to the vehicle. For combination tractors this includes aspects such as aerodynamic features, weight reductions, tire rolling resistance, speed limiters and idle-reducing technologies. For the vocational vehicles only tire rolling resistance values provide input to the model (ACEEE and ICCT, 2013).

Canada: Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations

Environment Canada implemented national emission standards for new HDV vehicles and engines in 2013. They have designed the regulation in such a way that the standards are highly aligned with those of the US (ICCT, 2013b). The timing, emission reduction targets, vehicle categories and measurement methods are the same as those described in the previous sub-section therefore.

Comparison of different HDV standards

As became evident from the previous sections, the standard designs of the HDV standards that have currently been implemented worldwide, are highly diverse. Table 7 summarises their main design options.

Table 7 Comparison of HDV standards worldwide

	Japan	China	US	Canada
	Fuel Economy Standard	*National Fuel Consumption Standard (Stage II Standard)*	*Heavy-Duty National Program*	*Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations*
Standard Type	Standard for the whole vehicle, but due to the simulation tool an engine + drivetrain (mainly transmission parameters) standard in practice	Standard for the whole vehicle	– Engine standard and standard for the rest of the vehicle for vocational and combination vehicles – Standard for the whole vehicle for heavy pickups and vans	Same as US
Vehicles included	Freight diesel vehicles with GVW ≥ 3.5 t and all diesel buses with capacity ≥ 11 passengers	All commercial vehicles with GVW ≥ 3.5 t	All commercial vehicles with a GVW ≥ 8,500 pounds	Same as US
Trailer included?	No	No	No	No
Differentiation	Vehicle category (5), GVW	Vehicle category (5), GVW	Vehicle category (3), GVW, cab configuration, roof height	Same as US
Metric used	Km/l	l/100 km	– Engine standard: gram CO_2/bhp-hr or gallon/100 bhp-hr – Standard for the whole/rest of the vehicle: gram CO_2/mile or gallon/100 miles (pickups and vans) and gram CO_2/ton-mile or gallon/100 ton-miles (other vehicles)	Same as US
Measurement method	Computer simulation based on engine dynamometer testing; parameters for engine and drivetrain based on actual values, driving resistance and chassis size based on standard values per HDV category	Chassis dynamometer testing for the base vehicles and simulation modelling for the variant vehicles; parameters for aerodynamic drag and rolling resistance measured by the manufacturers or standard value	– Engine standard: existing emission test cycles – Standard for the whole/rest of the vehicle: Chassis dynamometer testing (pickups and vans) and simulation modelling (vocational and combination vehicles). Parameters for vocational; rolling resistance, and for combination vehicles; aerodynamic features, weight reductions, tire rolling resistance, speed limiters and idle-reducing technologies	Same as US
% improvement targeted	Trucks: 9.7-12.2% km/l in 2015 compared to 2002 Buses: 11.1-12.8%	10-15% compared to the Stage I Standard, average for the whole fleet expected to be 11%	Engines: 3-5% in 2014, 5-9% in 2017 compared to 2010. Tractors and vocational Vehicles: 4-20% in 2014 (includes engine improvement) compared to 2010. Pickups and vans: 10-15% in 2018 compared to 2010.	Same as US
Timeline	Targets for 2015 and hereafter	July 2014, for new HDV models applying for type approval and July 2015 for all newly manufactured HDVs	– CO_2 targets for 2014-2018 – Fuel consumption targets voluntary in 2014 and 2015, obligated hereafter	Targets for 2014-2018
Other	Includes buses < 3,500 kg if capacity is ≥ 11 persons Gasoline vehicles not included	Gasoline vehicles included	Gasoline vehicles included	Same as US

Source: Transportpolicy.net, 2012 (Japan); ICCT, 2013a (China); EPA, 2011 (US); ACEEE & ICCT, 2013 (all); ACEEE & ICCT, 2013 (US); ICCT, 2013b (Canada).

3.3 Long list of design options

In this paragraph, an overview is presented of the various design options of CO_2 standards/labels. This overview for both standards and labels is based on a literature review.

There is a wide variety of design options possible when implementing a standard or a label. Standards or labels can be implemented for:
- the engine;
- the engine + transmission;
- the driveline;
- the entire powertrain (i.e. combination of the engine, transmission and driveline);
- the engine and the rest of the vehicle;
- the engine and whole vehicle;
- the engine + transmission and the rest of the vehicle;
- the engine + transmission and whole vehicle;
- the driveline and the rest of the vehicle;
- the driveline and whole vehicle;
- the entire powertrain and the rest of the vehicle;
- the entire powertrain and whole vehicle;
- multiple components (i.e. multiple separate standards; one per component/combination of components), such as the engine, engine + transmission, rolling resistance of the tires and wheels, aerodynamic drag, etc.;
- the whole vehicle (excluding trailer components);
- the whole vehicle (including trailer components);
- the trailer.

These standard designs will have different pros and cons. As it is not feasible to investigate every option in detail, an assessment will be made for a sub-set of the above-mentioned design options. The options for this analysis will be selected in the next section.

3.4 Selection of options

The selection of design options that have been chosen for the more detailed analysis were based on the following considerations:
- all options implemented elsewhere are included;
- the options we know/expect to be considered for the EU are included;
- any other option that is under consideration around the world is included.

Table 8 shows the selected options and the arguments for including this option in the analysis.

Table 8 Short list of standard/label designs

Standard (or label)	Reason(s) for including the standard in the analysis
Standard for the engine and standard for the rest of the vehicle	Implemented in the US and Canada.
Standard for the engine + transmission	Japan implemented a standard for the whole vehicle, but due to the design of the simulation tool, the parameters for which vehicle-specific input is used are almost exclusively related to the engine and transmission. In practice, it can therefore be considered an engine + transmission standard.
Standard for the whole vehicle	Implemented in China and expected to be of particular interest to the Commission. Although China excluded the trailer in its whole vehicle design, whereas the Commission may decide to include trailers.
Multiple component-based standards	Although not of much interest to the EU, this standard design provides a strong contrast to the standards mentioned above, which may provide interesting insights. Thereby, this can be an option for including trailers as well and may be a more interesting option in case the Commission chooses for labels rather than standards.
Standard for the engine + transmission and standard for the rest of the vehicle	Variant to the US and Japanese standards, which is one of the options the EPA considers for the 2nd phase of the US standard. It has the advantage of testing the entire powertrain at once, while still providing OEMs with the flexibility to choose how they want to comply with the engine + transmission standard (i.e. by implementing fuel-saving technologies for the engine and/or transmission).

The pros and cons of these different design options will be assessed in the next chapter (Section 4.2). The metrics that can be used when implementing these standards (e.g. g/kWh, g/vkm, g/tkm, etc.) will also be described in the next chapter (Section 4.7).

4 Assessment of design options

4.1 Introduction

This chapter present the assessment of the different design options.
A description of the assessment criteria that have been used to assess the pros and cons of the different design options is given in Section 4.2. Next, the various design options are assessed on these criteria in Section 4.3 to 4.6. Finally, Section 4.7 elaborates on other design features of standards, such as the metric used.

4.2 Assessment criteria

The design options as selected in the previous chapter, are assessed on the criteria given in Table 9. This analysis has been based on the evidence available in literature and on interviews with relevant stakeholders/experts.

Table 9 List of assessment criteria for the comparison of design options

Assessment criteria	Issues to be considered
Effectiveness	
Theoretical effectiveness	– What is the CO_2 reduction potential available for the various vehicle types/components? – Which technologies contributing to this reduction potential are (theoretically) stimulated by the standard/label?
Robustness	– To what extent do the design options ensure (long-term) CO_2 emission reductions in practice? – How robust is the standard in terms of variations in the real-world (e.g. different drive cycles, etc.)? – How reliable are the test procedures required? – What options do manufacturers have to circumvent the intended effects by tuning or gaming certain parts of the vehicle?
Market impacts	
End-user costs	– What are the marginal abatement costs (from the MACH model) of relevant fuel-saving technologies? – To what extent are manufacturers given the flexibility to implement the most optimal measures to comply with the standard?
Fairness	– To what extent is a fair level-playing field created for manufacturers?
Incentives for innovation	– To what extent are (innovative) technologies incentivized? – To what extent are manufacturers of vehicles/components provided with investment certainty?
Technical feasibility	
Complexity of the test procedure	– How complex is the test procedure to determine whether the standard is met? – To what extent are default values required and available?

Assessment criteria	Issues to be considered
Legislative impacts	
Legislative complexity	– Complexity of the test to be developed? – Are (parts of) the legislative arrangements/authorities already in place (e.g. for LDVs, for HDV engine emissions)? – Can the strictness of the limits be easily negotiated? – To what extent can a feasible system be implemented for monitoring and enforcement?
Alignment with air pollution standards	– To what extent do the various design options overlap/contradict with the existing pollution standards (e.g. due to different test cycles)?
Alignment with standards outside the EU	– To what extent is the standard aligned with existing standards outside the EU? – To what extent can the design option be adopted by other countries as well?

Where possible the criteria are assessed quantitatively. For example, the effectiveness of the standard designs can be compared by evaluating the share of the CO_2 reduction potential that is covered by the standard design. This will make the comparison of design options as objective as possible. However, this will not be possible for all criteria.

The remaining sub-sections each assign one of the four main assessment criteria outlined in Table 9. The main arguments made for each (sub)criteria are summarised in 0. If not stated explicitly, the arguments made also apply in case a label with the same design would be implemented. The main differences between standards and labels are discussed in Section 4.7.3.

If not stated explicitly, the arguments made also apply in case a label with the same design would be implemented. The main differences between standards and labels are discussed in Section 4.7.3.

4.3 Effectiveness

Two sub-criteria have been defined to assess the effectiveness of different standard designs in reducing (real-world) emissions: the theoretical effectiveness and the robustness of the design. While the theoretical effectiveness entails the CO_2 reduction potential and the fuel-saving technologies that will be stimulated with the standard, the robustness of the standard concerns the likelihood that emission reductions are realised in the real-world. Both sub-criteria are described in more detail below.

4.3.1 Theoretical effectiveness

- What is the CO_2 reduction potential available for the various vehicle types/components?
- Which technologies contributing to this reduction potential are (theoretically) stimulated by the standard/label?

The selected design options cover different HDV components and can cover different HDV duty cycles, which will impact the total CO_2 emissions reductions that can be realised with the related standards, as different HDV duty cycles and components differ in the potential emission reductions that may be obtained.

Reduction potential covered

Several studies have estimated the CO_2 reduction potential of different duty cycles and components. TIAX (2011) is a well-known study[8] and has done so for 8 HDV duty cycles in Europe and for 7 main fuel-saving categories recently. Their results are summarised in Table 10 for the European situation in the 2015-2020 timeframe. 0 provides a more detailed overview of the individual technologies per main technology category that contribute to these reduction potentials.

Table 10 **Relative reduction potential (%) of main fuel-saving categories in Europe from 2015-2020[a]**

Fuel-savings technologies	Duty cycle							
	Service/ delivery	Urban delivery/ collection	Municipal utility	Regional delivery\collection	Long haul	Construction	Bus	Coach
Aerodynamic improvements	2.5	8	0	7	7	0	0	6.5
Light-weighting of materials	1.25	4	0.95	2.2	2.2	0.3	6.25	1.1
Reducing rolling resistance from tires and wheels	1.5	3.15	2.7	11.7	11.7	11.1	1.5	1.9
Transmission and driveline improvements	5.9	0	4.25	1.25	1.25	1.25	0	1.25
Engine efficiency improvements	4.5	10.7	10.7	10.7	16.25	10.7	10.7	16.25
Hybridisation	25	30	22.5	10	10	30	35	11
Management	0	0	0	1.5	4.5	0	0	1.5
Cumulative reduction potential[b]	**37**	**46**	**35**	**41**	**47**	**45**	**41**	**38**

a TIAX (2011) provides the possible range of relative reduction potential (%) for each duty cycle and technology category; this table only shows *the central value* of this range.

b Note that the cumulative reduction potential is smaller than the sum of the reduction potentials of individual components.

Source: TIAX, 2011, adjusted by CE Delft [a].

As is evidenced in Table 10 the overall reduction potential varies from 35 to 47% and is largest for the long haul, urban, and construction segment (45-47%).

Table 10 also shows that the emission reduction potential does not only vary between different duty cycles, but also between different vehicle components (i.e. main categories of fuel-saving measures). In general, hybridisation has the highest potential to reduce emissions (10-35%), especially in short-distance duty cycles. From the measures that can be applied to conventional powertrains, improving engine efficiency has the largest overall potential to reduce emissions (10.7-16.25%), except in the service/delivery segment (4.5%). The combined potential of the engine (engine's efficiency and hybridisation) equals approximately 21-42%[9] for the various duty cycles, which represents a very large share in the total cumulative reduction potential (35-47%) for all duty cycles. The reduction potential of the tires and wheels

8 Another recent study on the CO_2 reduction potential of technological measures for HDVs is AEA and Ricardo (2011). CE Delft (2012a) shows that the estimated reduction potentials of AEA and Ricardo (2011) and TIAX (2011) are in the same range for most of the technologies. For that reason we only present the results from TIAX (2011) here.

(1.5-11.7%) and of aerodynamics (0-8%) also contributes significantly to the overall potential. For these components, the reduction potential depends more heavily on the duty cycle though (i.e. varies more significantly between duty cycles). The fuel-saving benefits from aerodynamics for example, are larger for urban, regional, long haul and coach vehicles (6.5-8%) than for the service, bus and construction segment (0-2.5%). It is important to note that the fuel-saving potential from aerodynamics result mainly from technologies applied to the trailer (e.g. side skirts on the trailer). The fuel-savings from tires and wheels result partially from trailer technologies (e.g. automatic tire inflation on the trailer) and partially from technologies applied to the truck/tractor.

The statements made above have some important implications for the design options. It becomes clear that implementing any component-based standard will not cover the full emission reduction potential of the vehicle (except when a standard or label is implemented for *each* component). Implementing only a standard or label for the tires and wheels would only cover the reduction potential of 1.5 to 11.7%, while the overall reduction potential of the whole vehicle is 35-47%. Interviewees do consider this as a significant disadvantage of implementing a component-based standard only (i.e. without a standard for the rest of the vehicle). The coverage of a component-based standard would be relatively highest if at least the engine is covered (≥ 20% to 42%[9]), as this component has the most significant share in the overall reduction potential in all duty cycles, especially as a result of the potential of hybridisation in reducing emissions.

The combined reduction potential of the engine and transmission (taking into account hybridisation) is approximately (21 to 42%[9]). An engine + transmission standard or label design would therefore cover 60-89% of the total reduction potential of the vehicle. Although this is a significant share, interviewees perceived this as a drawback of this design option, as it leaves 11-40% of the reduction potential unaffected.

In case an engine or engine + transmission standard/label would be combined with a standard or label for the rest of the vehicle, the coverage of the overall reduction potential increases to a 100%. This is also the case for the design option that targets the whole vehicle, although this design does not explicitly target the reduction potential of a particular component. However, for both these design options (i.e. whole/rest of the vehicle) the coverage may be less than 100% in reality, if the underlying parameters of the simulation tool that is used are not appropriately represented by vehicle-specific input. If default values are used for particular components (e.g. for aerodynamic drag) the actual coverage of the reduction potential will be lower than 100%, as OEMs have no incentive to reduce the emissions from these components. So although implementing a standard design for the whole vehicle or for the rest of the vehicle can potentially cover the full emission reduction potential of the vehicle, this does require a well-designed simulation tool that allows for vehicle-specific input for all relevant components.

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9 The combined potential of the engine + transmission is not equal to the sum of their respective individual reduction potentials, as the CO_2 savings the vehicle can obtain with one technology decrease when other measures have been taken as well. The cumulative potential of the engine (engine efficiency + hybridisation) of regional delivery trucks for example can be estimated with the following formula: 1- (1 – 0.107) * (1- 0.1) = 0.1963. The cumulated reduction potential is 19.63% therefore, while the sum of the reduction potential of the engine's efficiency and hybridisation would have been 20.7%.

Technologies incentivised

Most interviews argued that a component-based standard provides a very strong incentive for implementing innovative measures for that particular component. As a result, policy makers can use a component-based standard or label to ensure emission reductions are made in a particular component. This may be desirable from an environmental perspective if a particular component or technology (e.g. hybridisation, full electric powertrains) is relatively expensive to improve or implement, but does have the (long term) potential to generate deep emission reductions for example. Thereby, if such component-based standards are combined with a standard for the rest of the vehicle, this specific incentive for one or more components remains intact, while the reduction potential of the rest of the vehicle is also targeted (note that this would also be the case if a component-based standard would be implemented for each component). This was considered by some interviewees as an important argument for implementing a separate engine or engine + transmission standard in addition to a standard for the rest of the vehicle.

An often mentioned disadvantage of regulating one or more components separately, is that the optimisation of the interactions between components is not covered (i.e. explicitly targeted) by such a design. This interaction is argued to be especially important between the engine and transmission, as the transmission has a big influence on the overall powerpack system's efficiency. It helps to determine the load and speed where an engine will run. A standard design that regulates that engine and rest of the vehicle separately, does not explicitly target this interaction[10]. This is an important argument for some to advocate an engine + transmission standard (combined with a standard for the rest of the vehicle) instead of a separate engine standard. By providing one target for both components and by testing them together, such interactions between the transmission and engine are targeted by the standard design and OEMs are provided an additional incentive to optimise both. This design option would still not target the interactions between the powerpack and the rest of the vehicle though, but this is argued to be of less importance.

In contrast to component-based standards, a standard or label for the whole vehicle does not provide a strong incentive to improve a particular component. In this case, the type of measures likely to be chosen will be those that generate the lowest marginal abatement costs to the OEM, interviewees argued, which is further explained in Section 4.3. The types of measures that are incentivised with a whole vehicle design option are also dependent on the simulation tool though. If the benefits of a particular fuel-saving technology cannot be captured accurately in an underlying parameter of the simulation tool, or if a default value is used for the parameter a technology influences, the OEM would not be incentivised to adopt this technology. Note that this issue is also applicable to the types of measures that are incentivised with a design option that combines a standard for the rest of the vehicle with a component-based (i.e. engine/engine + transmission) standard. However, in this case it would only potentially affect the fuel-saving technologies that can be applied to the rest of the vehicle, as the engine or engine + transmission would not be simulated, and hence, the benefits of any fuel-saving technology applied to the engine and/or transmission would be measured in the test procedure.

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[10] Note that this does *not necessarily* mean that the interaction between the engine and transmission are not optimised. Rather, it implies that it will not be specifically targeted by the design option; the regular efforts for optimising both components that are already taking place in the market place today will (at least partially) remain in tact.

Interviewees also argued that a standard for the whole vehicle has the potential to cover the interactions between the different components, and may therefore incentivise OEMs to optimise the interactions between components. This latter-mentioned argument may be hard to realise in practice though, as it assumes a simulation tool with vehicle-specific parameters that captures all these interactions between all components. This is likely to be difficult to accomplish with any simulation tool design. Irrespectively, interviewees did perceive that interactions between components are important to take into account as thoroughly as possible, as the high fuel prices in Europe have caused that a lot of the individual components of the base truck have already been significantly improved. In the future, most added value for the fuel-efficiency of HDVs in Europe is expected to result from integrating different energy flows and aligning different components they argued. A standard that targets such interactions and incentives OEMs to take integrated measures will result in a relatively higher effectiveness.

The above-mentioned arguments from both sub-sections are summarised in Table 11.

Table 11 Theoretical effectiveness of different standard designs

Standard	Type of measures incentivised [a]	Coverage of emission reduction potential[a]
Standard for the engine and standard for the rest of the vehicle	– Engine technologies – Technologies for the rest of the vehicle – Targets some optimisation of interactions between different components, but not between the engine and rest of the vehicle	100% of the emission reduction potential of the vehicle is covered (at least in theory). In addition, specifically targets the emission reduction potential of the engine (20 to 42% depending on duty cycle)
Standard for the engine + transmission	– Engine and transmission technologies – Targets optimisation of interaction engine and transmission, but not between those components and the rest of the vehicle	Only covers the emission reduction potential of the engine and transmission: 21 to 42% depending on the duty cycle
Standard for the whole vehicle	– All possible technologies can be adopted – Targets optimisation of interactions between different components	100% of the emission reduction potential of the vehicle is covered (at least in theory)
Multiple standards for different components	– Technologies for those components that are regulated – Targets no optimisation between the regulated components	Depends on the components that are regulated
Standard for the engine + transmission and standard for the rest of the vehicle	– Engine and transmission improvements – Improvements in the rest of the vehicle – Targets optimisation of the engine and transmission, and some optimisation of interactions between other components, but not between the engine + transmission and rest of the vehicle	100% of the emission reduction potential of the vehicle is covered (at least in theory). In addition, design specifically targets the emission reduction potential of the engine and transmission (21 to 42% depending on duty cycle)

[a] As was explained in the paragraphs above, the true coverage of the design options and the types of measures incentivised are dependent on the underlying vehicle-specific parameters of the simulation tool (except for the engine-only/engine + transmission only standard).

Many interviewees stressed the importance of including trailers in the standard design. In the European market, OEMs are highly integrated and assemble most parts of the base truck themselves. Consequently, a lot of attention has already been given to optimising the base truck they argued. As a result, the main fuel-savings that can be realised result from optimising the truck-trailer combinations and from fuel-saving technologies that have to be applied to the trailer. This is partially contradictory to Table 10. Although the potential of optimising truck-trailer combination is not included (and may indeed be high), these reduction numbers show that significant reductions can still be obtained from improving the engine and transmission (and from hybridisation).

4.3.2 Robustness

- To what extent do the design options ensure CO_2 emission reductions in practice?
- How robust is the standard in terms of variations in the real-world (e.g. different drive cycles)?
- How reliable are the test procedures required?
- What options do manufacturers have to circumvent the intended effects by tuning or gaming certain parts of the vehicle?

The standards that have been currently implemented[11] are based on test cycle measurements and simulations. However, as mentioned by most interviewees, the actual impact of a standard in reducing emissions in practice is dependent on the 'real-world', on-road, fuel consumption. These two are often not very well aligned. This is caused by several factors, such as different driving styles and duty cycles, weather conditions, road conditions, and so on. So although a minimal theoretical emission reduction in test-cycle/simulated emissions is ensured with a standard, the actual effectiveness in reducing real-world fuel consumption and emissions on a particular vehicle may be different.
Two factors influence the gap between test results and real-world emissions; the sensitivity of the design to variations in real-world conditions and the reliability of the test procedures required in estimating on-road fuel consumption. Both are further described in the sub-sections below.

Sensitivity to real-world conditions

The EU market for HDVs is very diverse in terms of the types of trucks and trailers (and the truck-trailer combinations) on the market and the ways in which these HDVs are used. This complicates the design of effective standards, as it will not be possible to set one limit for the whole HDV market; an urban truck and a long haul truck differ completely in their fuel consumption and use patterns and in their emission reduction potential and hence it would be unfair to force the same limit on these vehicles. Therefore, for any standard design to approach real-world conditions, some distinction needs to be made in the limits set for different vehicle types/duty cycles; this is further described in Section 4.7.1.

In case a standard for the whole vehicle (or rest of the vehicle) is implemented, the trucks are measured with reference trailers. However, in most regions, including the EU, it is very common for transport companies to switch between trailers. These trailers, may not be necessarily comparable to the reference trailer. In this case, real-world conditions cause that the foreseen emission reduction in the test-cycle is not realised in practice. Ideally, such practices should be included in the standard, but it may be very difficult to operationalise and enforce this. Such real-world practices also

[11] For HDVs outside the EU and for LDVs both in and outside the EU.

indicate why it may be very difficult to include the trailer in the standard design for the whole vehicle. A component-based standard may provide an alternative for including the trailer though. A standard for all tires of the vehicle would automatically include the performance of the trailer's tires for example.

As HDV customers are highly diverse in their demands, supporting vehicle customisation may be an important advantage of a standard for the whole/rest of the vehicle and an important drawback from implementing the multiple component-based standard design. The multiple component-based standard was argued to be relatively least robust to aligning with specific consumer situations because the larger the number of components that are regulated separately, the fewer possibilities exist for customisation. For example, the OEM could deliver a highly aerodynamic truck to a customer that mainly drives its trucks at high speeds. This may result in relatively more emission reductions in practice than if a multiple component-based standard had been implemented and the OEM had to spread its efforts over multiple components rather than implementing all measures in aerodynamic features. Combining only one component-based standard (i.e. engine + transmission or an engine standard) with a standard for the rest of the vehicle still allows for (at least some) customisation.

An additional disadvantage of implementing multiple component-based standards is that this standard design only informs consumers about the fuel performance of individual components, but provides no information on the fuel-efficiency of the whole vehicle; consumers may therefore buy a truck that has higher emissions than if would have been the case with a standard for the whole vehicle. Again, the standard for the rest of the vehicle (combined with one component standard) is somewhere in between; it does provide more information on the overall performance of the truck, but still does not inform consumers about the whole picture (i.e. the combination of the component with the rest of the vehicle). The whole vehicle approach on the other hand, does provide one number on the overall performance of the vehicle[12], which was frequently mentioned as an advantage of this design option[13].

A final point made concerns the fact that it is not possible for all components to ensure emission reduction in practice (for a longer period of time). Tires have a short lifetime and some aerodynamic features can be eliminated from the truck or may not be replaced if damaged if a transport company desires this. Therefore, it is relatively more difficult to ensure emission reductions over time with measures applied to the rest of the vehicle as compared to the engine, which is less likely to be replaced or altered. As a result, a separate engine standard is relatively more robust in ensuring the emission reductions that were aimed for in practice (over the long term) than standards for the whole/rest of the vehicle. Note that in case of a standard for the whole vehicle the share of fuel-saving measures that are applied to the engine would therefore also be automatically enforced in practice. This is further elaborated on in Section 4.6.

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12 Although test cycle and real world numbers may deviate.

13 Note that if a component-based standard (e.g. engine/engine + transmission) would be implemented in addition to a standard for the *whole* vehicle, rather than for the *rest* of the vehicle, the consumer would also have information about the performance of the whole vehicle. In this case, the vehicle-specific performance of the engine would feed in to the simulation tool for the whole vehicle standard.

Reliability of the test procedures

Closely aligned to the sensitivity of a standard to real-world use patterns is the reliability of the test procedures in measuring these real-world emissions as accurately as possible. The more reliable the test procedure in measuring real-world emissions, the more robust the design will be in enforcing actual emission reductions in practice.

In general, interviewees argued that tests are relatively more reliable in estimating real-world emissions than simulation methods. This results from the fact that with testing, the component(s) is(are) actually measured, and do not require any (default) inputs and calculations. Hence, testing leaves less room for error than simulation modelling, which does require such inputs and calculations. Testing is appropriate for the engine and for the engine + transmission though. These standard designs are perceived as the most reliable ones therefore[14].

Testing the performance of other components than the engine or engine + transmission also becomes less reliable. Measuring an aerodynamic feature for example, is more complex, as it is more sensitive to the different vehicle configurations and duty cycles. Likewise, measuring the efficiency of the transmission separately is not accurate, considering that the main efficiency advantages of the transmission may result from its interaction with the engine. Determining the efficiency of such individual components for a multiple component standard may not always be accurate therefore.

Test procedures alone cannot be used with standards for the whole/rest of the vehicle, as there are too many vehicle configurations to test the whole vehicle. These standard designs will therefore require a simulation model. As was mentioned previously, this will require different inputs from manufacturers and is considered as more sensitive to errors than actual testing. The higher the number of input values required from OEMs, the higher the tool's accuracy in estimating emission will be. Also, as was mentioned earlier, it may be difficult to include parameters that correctly represent the effects of all types of fuel-saving measures and interactions between components. The VECTO simulation model that is currently being developed for the European Commission is argued to approach real-world emissions quite closely, especially for long haul vehicles driving at relatively constant speeds. The first verifications of the simulation model show a deviation of about 3% or less between the simulation results and on-road test results (Fontaras, 2013). For shorter cycles (e.g. urban) the real-world conditions vary much more, therefore this is more complex to test and may be less accurate interviewees explained, this is still being tested and fine-tuned.

In case the standard for the whole/rest of the vehicle would also include trailers, it will be more difficult to accurately estimate real-world emissions. For box types, this will be least complex, as OEMs and body builders can align the vehicle and trailer more easily and the size and form is relatively standardised. For other truck types (e.g. tipper) this may be more difficult and such the simulation tool can probably only use trailer-specific input values for aerodynamics and tires (i.e. reducing resistance). As for the truck-trailer combinations, the trucks of OEMs may be measured with standard trailers. The trailer manufacturers could then benchmark their trailer against this standard trailer in terms of aerodynamic features, the mass and the rolling

[14] Note that the performance of these components can also be measured with simulation models, this would then result in the same disadvantages as those described for the standard for the whole/rest of the vehicle.

resistance of the tires from the trailer. These specific values can be inserted in the model instead of the values for the reference trailer.
However, as discussed before, trailer switching of transport companies (especially relevant with truck-trailer combinations) may increase the deviation between the modelled and real-world emissions, reducing the reliability of the model.

Possibilities for gaming
Interviewees did frequently mention that the fact that the VECTO model requires a lot of specific information has a downside; it may provide possibilities for OEMs for tuning/gaming the measurements for the input values if these are not verified (see Section 4.6). The US-based simulation tool for the rest of the vehicle has much more fixed parameters, which results in a lower accuracy in estimating real-world emissions, but also provides less of such opportunities for gaming. One interviewee did point out that OEMs in the US can choose between different test procedures for determining the performances of (some of the) components, they will therefore choose the method that suits them best (i.e. results in the highest performance). In the EU approach it is more likely that each input value has to be measured with one specified method, which would reduce their opportunities for choosing a test procedure that would be most beneficial to them.

Either way, simulation leaves more room for gaming than actual testing of the engine/engine + transmission. Some interviewees did indicate that irrespectively of the measurement method, most OEMs will be less incentivised to act strategically at test cycles/simulations than for passenger cars, as they will lose their customers if real-world emissions are much higher than the tested/simulated emissions. Transport companies are better informed and more economically rational than customers in the LDV market and will pay more attention to such aspects. This may not apply to the component-based standards though, as transport companies do not know the efficiency of separate components (i.e. only the overall efficiency of the whole vehicle is visible to them), which may make it more attractive for vehicle OEMs to tune some components for the test cycles.

Any standard design is likely to distinguish different limits for the different duty cycles. This may also result in some opportunities for gaming by manufacturers. For example, if a lower limit is set for regional delivery trucks than for long haul trucks, there may be an incentive to sell/buy regional delivery trucks to long haul transport companies. This would reduce the emission reductions obtained in the real-world.

4.4 Market impacts

This section describes the market impacts of the different standard designs in terms of end-user costs, fairness, and the incentives for innovation, respectively.

4.4.1 End-user costs

- What are the marginal abatement costs (from the MACH model) of relevant fuel-saving technologies?
- To what extent are manufacturers given the flexibility to implement the most optimal measures to comply with the standard?

The previous section showed that different standard designs may stimulate different technologies. These technologies will result in different costs, which are likely to be passed on to end-users interviewees argued. The marginal abatement costs of fuel-saving technologies (i.e. the costs of reducing one ton of CO_2) provide a good estimate of the end-user costs. Note that there are other factors than marginal abatement costs that will have an impact on end user costs, such as regulatory complexity and technical uncertainty.
Such aspects are not considered in this study. Table 12 provides an overview of the marginal abatement costs of the most cost-effective fuel-saving technologies for different components, which have been estimated with CE Delft's MACH model. 0 provides a more detailed overview of the marginal abatement costs of the specific fuel-saving technologies of each main vehicle component.

Marginal abatement costs are highly dependent on the chosen values for these parameters. Therefore, the costs have been estimated for a best (i.e. high fuel price scenario, low discount rate, long vehicle lifetime) and for a worst (i.e. low fuel price scenario, high discount rate, short vehicle lifetime) case scenario. Technologies with negative marginal abatement costs (coloured green) in both scenarios have higher benefits to the end-user (in terms of fuel cost savings) than additional costs; they can be considered the no-regret technologies. The components with positive marginal abatement costs (coloured red) on the other hand, require an investment from the end-user that cannot be (completely) earned back with the cost savings from reduced fuel consumption.

Table 12 Marginal abatement costs of different fuel-saving technologies in two scenarios

Fuel-saving technology	Vehicle category															
	Service/ delivery		Urban delivery/ collection		Municipal utility		Regional delivery/ collection		Long haul		Construction		Bus		Coach	
	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case
VL	10	5	19	9	17	8	12	6	8	4	19	9	14	7	12	6
DR	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%
FP	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Measures for the engine																
Most cost-effective *engine efficiency* measure	-186	69	-229	-67	-277	-153	-279	-127	-301	-152	-265	-141	-304	-187	-208	15
Most cost-effective *hybridisation* measure	360	1,161	-175	49	-129	161	226	882	14	478	-230	-67	-272	-124	385	1,200
Measures for the transmission																
Most cost-effective *transmission* measure	-371	-300			-322	-247	-332	-234	-379	-309	-299	-215			-337	-243
Measures for the rest of the vehicle																
Most cost-effective *aerodynamic* measure	-365	-288	-284	-178			-236	-43	-335	-219					-295	-159
Most cost-effective *light-weighting* measure	-70	302	85	598	303	1,079	-33	364	-202	46	2	421	168	756	1,087	2,604
Most cost-effective *wheels and tires* measure	-383	-326	-251	-202	-319	-255	-354	-298	-387	-338	-310	-255	-295	-243	-313	-256
Most cost-effective *management* measure							-361	-289	-395	-339					-362	-293

Note: VL = Vehicle lifetime, DR = Discount rate, and FP = Fuel price scenario.
Source: CE Delft (2013); MACH model.

As can be seen in Table 12, the marginal abatement costs vary between components and duty cycles. In general, there are quite a few components for which cost-effective fuel-saving technologies are available in every duty cycle. Low rolling resistance tires and wheels result in the relatively highest benefits across duty cycles, followed by the transmission and aerodynamics of the vehicle. Improving the vehicle's engine's efficiency is cost-effective in the majority of scenarios as well, except for the coach and service segments with worst-case conditions.

Light-weighting is relatively most expensive to implement, as it results in high marginal abatement costs for most (but not all) duty cycles. In the worst case scenario it is costly for all duty cycles. Hybridisation is also a relatively expensive measure to take in most duty cycles, except for the construction and bus segments, where its implantation is likely to result in negative abatement costs in both scenarios. In the urban and municipal utility it depends on the chosen scenario whether the benefits will be higher than the costs.

The findings of the MACH model have several implications for the different design options. There is general agreement amongst interviewees that a standard for the whole vehicle results in the lowest end-user costs. This results from the fact that OEMs are left with maximal flexibility to choose which vehicle components they want to improve, and hence, which fuel-saving technologies they want to adopt. OEMs will then choose those technologies that have the lowest (preferably negative) marginal abatement costs for their product. According to interviewees, OEMs will pass any additional costs on to end-users, resulting in the most cost-effective design with lowest end-user costs.

The flexibility of the standard for the whole vehicle may result in the stagnation of continuous improvements in those components that are relatively more expensive to improve. Interviewees argued that improvements to the engine are relatively expensive and time-consuming to implement, and therefore expect that a standard for the whole vehicle would not provide enough incentives to significantly improve this component (unless a limit standard would be implemented and the limits for the whole vehicle are set strict enough). The results of the MACH model partially contradict these statements. Improving the engine's efficiency can result in higher benefits than costs for most scenarios. So this may still be an attractive measure to take, although there are also technologies with even higher negative abatement costs that OEMs may choose to implement first. However, improving the engine's efficiency was only part (25-50%) of the full reduction potential of the engine that was mentioned in Section 4.3.1. Hybridisation accounts for the main share (approximately 50 to 75%) of this reduction potential. Table 12 showed that the costs of hybridisation are indeed very high. As there are so many other technologies with lower marginal abatement costs, OEMs will unlikely adopt this measure with a standard for the whole vehicle.

Interviewees continuously mentioned that the implementation of one or multiple separate component-based standard(s) (with or without a standard for the rest of the vehicle) will reduce the flexibility of OEMs and force them to apply fuel-saving measures to that particular component. Their flexibility reduces with the number of separate standards implemented. The regulated components may well be relatively more expensive to improve than those that can be applied to other components. In case a separate engine or engine + transmission design would be implemented in Europe for example, the costs for service vehicles may be in the range of - € 371 to € 292 per ton of CO_2, while other measures, such as low rolling resistance tires would entail lower marginal abatement costs (- € 383 to - € 326). However, policy-makers may have other reasons to ensure improvements in a particular component (e.g. to obtain steep emission reductions in the future, because it may be easier to regulate, to provide a benefit on a specific type of vehicle or duty cycle, etc.), which may be reasons to accept the higher end-user costs of such a standard design.

It should be mentioned that while regulating the engine/engine + transmission separately may initially lead to *relatively* higher costs than in case a standard for the whole vehicle, this cost increase experienced by end-users may not be too significant as engine efficiency can be cost-effective in most cases. Thereby a separate standard for the engine may result in more investment certainty for engine (and transmission) manufacturers (see Section 4.4.3) which in turn may result in more competition between these component manufacturers and vehicle OEMs. This may lower the costs to end-users. However, once the benefits from engine efficiency improvements have been obtained, these design options may result in significantly higher costs, as realising the full reduction potential of the engine (i.e. incl. benefits from hybridisation) will have a cost to end-users.

Another often-mentioned reason to implement one or multiple component-based standard(s) (with or without a standard for the rest of the vehicle) may be to get rid of low hanging fruits (i.e. of cost-effective measures that are not implemented). A recent study of CE Delft (2012b) found that there are several barriers to the implementation of seemingly cost-effective fuel-saving measures (e.g. lack of reliable information on a technology's fuel-savings). Table 12 shows that there are some technologies, such as low rolling resistance tires, that are cost-effective in all vehicle segments, both in the best, and in the worst case scenario; a separate standard for this component (e.g. tires) could force OEMs to take this cost-effective measure.

4.4.2 Fairness

– To what extent is a fair level-playing field created for manufacturers?

The impact of a standard on the competitive position of different types of OEMs will vary with different standard designs. According to the interviewees, this impact will mainly differ between vertically integrated OEMs (those that manufacture most parts of the truck themselves) on the one hand, and the more horizontally integrated OEMs (i.e. those that buy many parts from others) and component manufacturers on the other.

The more horizontally integrated OEMs and component manufacturers are likely to prefer one or more separate component standard(s). The horizontally integrated OEMs often do not manufacture the engine themselves for example, so for them it is easier to buy a certified engine, rather than to force engine manufacturers to deliver an improved engine to comply with a standard for the whole vehicle. Likewise, for component manufacturers a component-based standard is argued to level their playing field, as vehicle OEMs have to meet the same standard as the component manufacturer and all component manufacturers have an equal target to comply with as well.

Vertically integrated OEMs on the other hand, generally prefer a standard for the whole vehicle; they manufacture the main parts of the truck themselves and can choose which parts to adapt to comply with the standard. As a result, each OEM can determine himself which technologies are most profitable or simple to implement and none of the OEMs is forced to improve a component that is expensive or difficult to improve for that particular manufacturer.
Any combination of standards (e.g. engine or engine + transmission standard and a standard for the rest of the vehicle) would increase the overall complexity. In this case, they would have to implement test procedures for and comply with two different standards. This places an additional burden on vertically integrated OEMs interviewees argued.

A standard for the whole vehicle may also result in some difficulties for component manufacturers. Different vehicle OEMs will focus on different parts of the truck to comply; therefore, different OEMs may demand/expect completely different performances from component manufacturers.
For example, some OEMs may demand highly efficient hybrid transmissions to reach the standard, while others will demand simple and cheap transmissions and comply through implementing other improved components. This may be a confusing and difficult situation for component manufacturers as they do not know which targets they have to meet. One interviewee pointed out that this has also been the case prior to the implementation of the standard though, as then no clear targets existed either. This does not necessarily mean that it is a preferable situation for component manufacturers.

Although the above-mentioned arguments can apply to any country, the OEMs in the EU are relatively more integrated than those in the US for example. Therefore, the arguments in favour of a component-based standard may be less important for the EU than for the US, where a significant share of the engines is delivered by a separate engine manufacturer. However, still, the OEMs in the EU also buy some of their components from specialised component manufacturers, so an uneven and difficult playing field for component manufacturers may still result with a standard for the whole vehicle.

4.4.3 Incentives for innovation

- To what extent are (innovative) technologies incentivized?
- To what extent are manufacturers of vehicles/components provided with investment certainty?

Strength of the incentive

With any standard design, the incentives for innovation are highly related to the strictness of the limits that are set. If limits are not stringent enough, manufacturers will not be stimulated to innovate and can comply with the standard by implementing technologies that are already available.

The standard design does have an influence on where the incentive for innovation is placed[15]. This has been described in much detail in Section 4.3.1. In general, interviewees agreed on the fact that component-based standards provide a strong incentive to innovate in that particular component, such an

[15] Note that the technologies that are incentivised are highly related to the underlying simulation model; if certain parameters are assigned default values, no incentive to implement technologies that positively influence these parameters is given (e.g. if the aerodynamic drag parameter is assigned a default value, no incentive is given to innovate in aerodynamic technologies).

incentive is absent in a standard for the whole vehicle. In this latter case, emission reductions are still stimulated, but manufacturers can innovate in any component they want or can innovate a bit in every component to reach the overall standard. Most likely, the incentive for innovation is provided to those components that are cheapest to improve. As was discussed before, these are unlikely to be the engine or other powertrain technologies. However, if limits are strict enough, innovation in the powertrain is likely to be stimulated as well.

A standard for the engine and for the rest of the vehicle incentivises both fuel-saving technologies for the engine and for the rest of the vehicle. Likewise, an engine + transmission standard (with a standard for the rest of the vehicle) incentivises innovation in the engine and in the transmission (and in the rest of the vehicle)[16].

Trailers are not included in any of the currently implemented standards; therefore, those standards will not provide an incentive to develop innovative trailer technologies to improve the aerodynamic drag, rolling resistance, or weight of the trailer. If no default values would be used for the parameters related to the trailer, this would not be the case.

Investment certainty

The incentive to innovate will not only depend on the strictness of the limits that are set, but will also depend on the timeframes provided. If OEMs are ensured that limits will be continuously tightened in the future, OEMs will be more likely to innovate than if such promises are not made. This will be the case for any standard design; the stronger the promises made for long term implementation of the standard, the larger the investment certainty provided. For vertically integrated vehicle manufactures this timeframe will be a more important factor for their investment certainty than the standard design itself. If a component-based standard is implemented they are provided with certainty to (continuously) invest in that component, and if a standard for the whole vehicle is implemented, they are provided with certainty that they can (continue to) invest in any component they want and still comply with the standard.

For component manufacturers on the other hand, the investment certainty provided will not only depend on the timeframe provided, but also on the standard design. In case a long term standard is implemented for the whole (or rest of the) vehicle, component manufacturers of components for which no separate standard is set are still not provided the required certainty to innovate. In this case, it is the vehicle OEMs that determine which components they want to focus on. A manufacturer of highly advanced automatic tire inflation systems may be reluctant to further innovate in such an expensive system, as vehicle OEMs may well choose to focus on the engine or on aerodynamic improvements. I.e. component manufacturers are not provided with certainty that demands for fuel-saving technologies will be focused on their component. In case a component standard would be implemented for each component of the vehicle, this problem would be solved, and all manufacturers would be given a certain level of investment certainty.

16 Note that the design that is used in the US, currently does not stimulate any innovative technologies in the transmission, as a default input is used in the GEM model; the manufacturer is allowed to use an actual value (transmission specific input), but this would require additional testing, which is costly and therefore not attractive in most cases. However, this is not necessarily the case with this standard design, as long as vehicle-specific input is used for the transmission in the chosen simulation model.

Engine and engine + transmission standards (combined with a standard for the rest of the vehicle or not) provide investment certainty to engine and transmission component manufacturers, but not to manufacturers of other components.

The investment certainty provided with the different standard designs is summarised in Table 13.

Table 13 **Investment certainty provided with different standard designs**

Standard	Investment certainty provided	No investment certainty provided
Standard for the engine and rest of the vehicle	Engine manufactures Vertically integrated vehicle OEMs	Component manufacturers of other components than the engine
Standard for the engine + transmission	Engine manufactures Transmission manufactures Vertically integrated vehicle OEMs	Component manufacturers of other components than the engine and transmission[a]
Standard for the whole vehicle	Vertically integrated vehicle OEMs	Component manufacturers
Standard for the engine + transmission & for the rest of the vehicle	Engine manufactures Transmission manufactures Vertically integrated vehicle OEMs	Component manufacturers of other components than the engine and transmission
Multiple component standard:		
One standard for each HDV component	Component manufacturers Vertically integrated vehicle OEMs	--
Multiple component standards for some components	Component manufacturers of those components for which a standard is implemented Vertically integrated vehicle OEMs	Component manufacturers of those components for which no standard is implemented

a Note that this is less relevant for this standard design, as improvements in other components than the engine and transmission do not contribute to complying with the standard.

4.5 Technical feasibility

The technical feasibility of any standard design is mainly related to the complexity of the test procedure to be developed, which is further described below.

Complexity of the test procedure

- How complex is the test procedure to determine whether the standard is met?
- To what extent are default values required and available?

In order to implement and enforce a standard, an appropriate test procedure is required. There are two main measurement methods used for the currently implemented standards; actual testing of components and simulation modelling with input data (which is also based on test results).
These measurement methods can be applied to the different standard designs, which will result in different levels of complexity.

In general, the standard for the whole (or rest of the) vehicle is considered as the most complex standard in terms of the measurement tool required. This results from the fact that the measurement procedure for this standard cannot be (completely) based on testing and a simulation tool is required. As was discussed before, the VECTO model, is highly complex and requires a lot of vehicle-specific input data from component and vehicle manufacturers. For most components, specifically measured input values are used rather than default values, although this differs between duty cycles. For some duty cycles, such as construction, relatively more default values are used (e.g. aerodynamic drag) as not all features are relevant for these vehicles and this duty cycle has a relatively low market share. Either way, the detailed (specific) input values used in the model are beneficial for the accuracy of the tool, but may also result in opportunities for gaming (see Section 4.3) and difficulties for monitoring and verifying the inputs that are used by OEMs (Section 4.6).

The simulation model that is currently being developed in the EU also includes trailer-specific input data, which further increases the complexity of the measurement procedure, interviewees argue.

In contrast, the simulation tool of the US for the rest of the vehicle is argued to be much more simplistic to use by OEMs, as many of the truck details are fixed in the model (i.e. default values are used). This reduces the accuracy of the tool in correctly estimating the emissions, but will provide less opportunities for gaming (see Section 4.3) and will be easier to monitor and enforce the inputs that are used by OEMs (Section 4.6).

In contrast to the simulation tools, the test procedures to measure the performance of the engine are considered as relatively simple and reliable. No simulation is needed, as the actual performance of the engine can be tested (i.e. measured in a test facility). These test procedures are already in place and as a result, the fuel-efficiency of the engine can be measured during the same test cycle. The performance of the engine + transmission can also be measured with actual test cycles, although this requires a slightly more complex power pack test. Extending the test facilities from the engine only to the engine + transmission would require an upgrade in the test facilities, but is still considered as less complex to implement than a simulation model for the whole vehicle. Rather than testing the performance of the engine + transmission, a simulation model provides an alternative approach, which may be useful if the metric chosen is g/tkm or similar rather than g/kw-hr. However, according to some of the interviewees, it is very complex and difficult to accurately simulate the performance of the engine + transmission, as the interactions between both are very difficult to model accurately. Therefore, interviewees preferred testing the performance of both instead of simulating this. Whichever method is chosen (i.e. testing or simulation) the measurement procedure for an engine + transmission standard will be relatively more complex than for an engine-only standard.

Finally, interviewees agreed on the fact that the measurement methods required for multiple component standards would be the most complex (with the exception of the engine and engine + transmission components). It would be difficult to separately estimate the CO_2 emissions (and reduction potential) of individual components for each mission cycle. Also, it would require OEMs to conduct a lot of different tests, which increases the complexity and the costs of complying with such standards.

4.6 Legislative Impacts

The legislative impacts have been analysed for three main topics: the legislative complexity of the design, the alignment with air pollution standards for HDVs and the alignment with other countries. Each of these topics is further described below.

Legislative complexity

- Complexity of the test to be developed?
- Are (parts of) the legislative arrangements/authorities already in place (e.g. for LDVs, for HDV engine emissions)?
- Can the strictness of the limits be easily negotiated?
- To what extent can a feasible system be implemented for monitoring and enforcement?

Implementing a standard requires several legislative arrangements to be made: test procedures have to be developed, regulated entities have to be appointed and the limits of the standards have to be agreed upon. Also, once the standard is implemented, a system to monitor and enforce compliance and to verify the input data used is needed. These aspects are easier to arrange for some designs than for others, which is further described below.

Complexity of the test procedure

Prior to implementing any standard, the appropriate test procedures have to be in place. The previous section described the complexity of different measurement procedures that are subject to the different standard designs. The more complex the measurement procedures required, the longer it will take before a standard can be implemented. When taking into account this complexity, interviewees argued that an engine standard is relatively easiest to implement as the required test procedures for measuring the engine's performance are already in place for the measurement of air polluting emissions. These existing legislative arrangements would only have to be adjusted slightly for the implementation of an engine standard; for all these reasons, this standard is expected to enable quick implementation.

Likewise, the engine + transmission standard will also have a relatively short implementation period. As was mentioned in the previous section, it does require an upgrade of the test facilities, as current test facilities only measure the engine separately. This may be costly and requires sufficient space for testing. However, this upgrade will require relatively less time than the development of a simulation tool and therefore, can be implemented faster than a standard for the whole/rest of the vehicle.

As for the standards that regulate the whole (or rest of the) vehicle, simulation tools are required that will be time-consuming to develop. This standard design will require some lead time to be implemented therefore. However, the organisations that are currently developing the VECTO simulation model are progressing well; this simulation tool could be used to implement the standard for the whole vehicle, or with some slight adjustments, for the rest of the vehicle (if combined with a separate engine or engine + transmission standard).

Finally, a multiple component standard would require separate test procedures for each regulated components, which is very time consuming. A component-based standard does not align well with the VECTO model, as the focus of the VECTO model lies on estimating the performance of the whole vehicle rather than on the performance of separate components. However, in theory, it would be possible to set standards on the input required for the model (e.g. set a limit for the aerodynamic drag or on particular engine parameters, etc.).

Appointment of the regulated entity

Irrespectively of the progress that is made with the development of the simulation tool, difficulties in appointing the regulated entity may delay the implementation process of a standard for the whole/rest of the vehicle. The vehicle OEMs would be the most logical and appropriate party to regulate, which requires new legislative arrangements. However, OEMs may object to this regulatory structure, as they would be held responsible in case a bought component performs worse than was promised. This may be perceived as an unfair situation resulting in their resistance. From a regulatory point of view, this is not a relevant issue though; the OEMs would simply be held responsible, so this is more of a problem to OEMs than to regulators. Thereby, a penalty system could solve such issues, as vehicle OEMs could then make contract arrangements with their component suppliers to pass on (part of) the penalty if a particular performance threshold is not met. An advantage of regulating vehicle OEMs is that it would result in a low number of entities to regulate.

Appointing a regulated entity with the implementation of a component-based standard may be less complex from a regulatory point of view. The manufacturers actually making the component would have to be regulated. In this respect, combining an engine/engine + transmission standard with a standard for the rest of the vehicle may reduce the legislative complexity somewhat (in contrast to one standard for the whole vehicle), as it would at least regulate the component manufacturers of the main component(s) of the vehicle separately. It should be kept in mind that most OEMs are vertically integrated in Europe and assemble most of the main HDV components themselves, which may reduce the relevance of this issue to some extent when compared to some other countries. The number of entities to regulate would increase with the number of components that are regulated, which increases the complexity of monitoring the regulated entities. This was also an argument made as to why a standard for the trailer is not feasible from a regulatory point of view; there are too many (small) trailer manufacturers.

Negotiating the limits

Another aspect that needs to be agreed upon, is the strictness of the limits that will be set for the different HDV categories/components. In this light, a multiple component standard is argued to be most time consuming, as this standard design would require significantly more research and discussion; for each component (and probably also for each duty cycle), estimates of reduction potentials would have to be made and separate limits would need to be agreed upon with the market. Obviously, the required time and complexity increases with the number of separately regulated components. Thereby, OEMs will demand lower limits to compensate for their reduced flexibility in case a separate limit would be set for each component. I.e. public acceptance may decrease with the number of components that are regulated separately. This will differ between components though; limits for engine-specific fuel consumption would be easier to determine than setting a limit on an aerodynamic feature for example, as this latter-mentioned component varies much more between different truck types and real-world conditions.

Setting limits for the whole/rest of the vehicle also requires significant research and discussion, but these designs only require research in the reduction potential of the whole/rest of the vehicle for the seven duty cycles. Thereby, the standards for the whole (or rest of the vehicle) will be easier to agree upon with the market, as OEMs are allowed flexibility in deciding where they want to make improvements; they may therefore accept more stringent limits.

Monitoring and enforcement

Once the standard has been implemented, compliance with the standard will have to be monitored and enforced, and the data provided by OEMs will have to be verified. The level of monitoring and enforcement required will vary with the number of separate standards that is implemented and with the underlying test procedures. In this light the engine + transmission standard may be easiest to monitor and enforce; it requires monitoring mechanisms for one standard, which is most likely to be based on (one) test-procedures rather than on simulation. Such test procedures are argued to be less prone to gaming by OEMs. In the EU, it is mandatory to have test procedures verified by type approval engineers (or similar), which would also apply to the engine + transmission' powerpack test. These costs would be reduced if the air pollution test cycles would be adjusted to allow the measurement of the combined performance of the engine + transmission, resulting in synergies in monitoring, measurement and enforcement.

Although a standard for the whole vehicle would require manufacturers to be monitored on their compliance with only one standard as well, most interviewees expressed concerns about the monitoring mechanism needed for this standard design for two main reasons.

Firstly, the highly complex measurement procedures that accompany this standard design, requires a lot of vehicle-specific input data. Ideally, this data should be based on independent tests, which may not be feasible for all component input parameters. If OEMs test the components themselves, these results should be verified (e.g. by independent type approval engineers, other governmental employees, etc.), as this is more sensitive to gaming by manufacturers than actual test procedures. This may be quite difficult to realise in practice though and will be very time-consuming (as multiple component tests need to be verified). If a simpler simulation model would be implemented with the standard (i.e. fewer input values required) the costs of monitoring would decrease.

Secondly, a standard for the whole (and especially rest of the) vehicle would ideally require continuous monitoring after the certified vehicle has been sold. This is likely to be unfeasible from a regulatory point of view (extremely high monitoring costs). As a result, enforcement of continuous compliance is likely to be difficult. Tires have a relatively short lifetime for example, but without compliance transport companies may well decide to replace the (low rolling) tires they bought with the vehicle with cheaper, less performing tires. Likewise, some aerodynamic feature (e.g. side skirts) can be removed easily from the vehicle if the transport company perceives other problems (e.g. with maintenance of the tires, safety reasons, etc.) with the technology.

As a result the emission reductions obtained in practice may be lower than what was aimed for. Two notes should be made in this respect. Firstly, OEMs may also apply fuel-saving measures to the engine (partially depending on the strictness of the limits) in case of a standard for the whole vehicle. As the engine has a very long lifetime, the share of the total emission reduction resulting from engine measures would therefore be automatically enforced in practice. Secondly, low rolling tires and most aerodynamic features have higher fuel-saving benefits than costs (i.e. are no-regret technologies, see Section 4.4.1). Therefore, profit seeking companies may well choose the same components in case these need to be replaced. However, this cannot be enforced with certainty, and there may be several market imperfections that hamper this from happening in practice (CE Delft, 2012).

In case an engine or engine + transmission standard is combined with a standard for the rest of the vehicle, the same issues and requirements with verifying input data for the simulation model and with enforcing the maintenance of fuel-saving technologies apply (for the rest of the vehicle standard). Given the high percentage contribution to the overall improvement opportunity the engine + transmission presents it may be sufficient to focus monitoring and enforcement provisions on those elements. These design options have two contradicting effects in terms of monitoring and enforcement costs. On the one hand, additional monitoring and enforcement systems would be required, as compliance with two separate standards needs to be checked. However, the fact that synergies would be obtained with the monitoring and enforcement of the air pollution standards on the other hand, would lower the costs of monitoring and enforcement. With an engine + transmission standard such synergies may also be obtained, but this would require an adjustment to the existing air pollution test cycles.

An additional advantage of setting a separate engine/engine + transmission standard in combination with a standard for the rest of the vehicle is the fact that at least the emission reduction from the engine and transmission components can be enforced in practice. These components have a very long lifetime and are unlikely to be replaced within the lifetime of the vehicle itself. Therefore, it is also unlikely that transport companies will replace the engine/transmission system with worse performing components. As a result, the emission reduction aimed for is automatically enforced in practice.

Finally, a multiple component-based standard requires most monitoring and verification, as for each component regulated, compliance needs to be verified. In addition, all test procedures of independent components need to be verified, and these may be most sensitive to gaming as consumers cannot verify the performance of individual components (see Section 4.3). I.e. in addition to verifying the underlying test procedures of each component, the multiple component standard also requires monitoring of compliance with the limits set for each component (in case of a limit standard), rather than only for the whole vehicle.

4.6.1 Alignment with air pollution standards

– To what extent overlap/contradict the various design options with the existing pollution standards (e.g. due to different test cycles)?

Several regions, including the EU, have implemented HDV standards for air polluting emissions. In the EU, the air pollution standards limit the CO, HC, NO_x and PM emissions of HDV engines (EURO I to EURO VI engines). Limits have been defined in g/kWh. These emissions are tested with the World Harmonized Transient and World Harmonized Stationary Cycle (WHTC and WHSC) measurement procedure.
It was already mentioned earlier in this section that an engine standard can be implemented within a short time frame, as the fuel consumption (and hence CO_2 emissions) can easily be measured at the same time of testing the engines for air polluting emissions. This may have several advantages in terms of the efficiency of the test procedures (OEMs would only have to test their engines once, both for air pollution and CO_2 standards) and will prevent that OEMs tune their engines differently for both test procedures.

If a separate test would be used to measure the engine performance for a CO_2 standard (for example to determine the simulation model input), this would result in higher costs for OEMs as they have to measure the performance of their engines twice. It would also result in opportunities for tuning the engines differently for both measurements, which can result in deviations between the fuel consumption figures resulting from these measurements. Although this deviation is likely to be small with the current design of the VECTO model[17], a standard for the whole vehicle will align relatively less with the measurement procedure for air pollution than an engine standard and the synergies that may be obtained from measuring the engine only once are lost.

The engine + transmission standard would not automatically fully align with the WHSC/WHTC measurement procedure as a powerpack test would be needed rather than testing the engine only. This would result in fewer synergies between the measurement and enforcement procedures of both standards if no adjustments in test procedures are made. If adjustments are made, It may be possible to align the required test procedure for the engine + transmission standard with the measurement procedures for air pollution.

Whether the multiple component-based standard will align with the air pollution standard depends on the components that are regulated, but if the engine is regulated separately, similar synergies would be obtained as those described above for the engine standard.

17 The engine specific input for the VECTO model is closely linked to the WHSC/WHTC test procedure, but is not used directly as the WHSC and WHTC do not 'fully cover all engine operating conditions, which shall be relevant in the driving cycles for CO_2 certification' (TU Graz et al., 2012, p. 24). Therefore, this test procedure is supplemented with a steady state fuel map, which will be used as input for the simulation (ibid.). However, as OEMs may optimise their engines for both purposes, a 'WHTC correction factor' is applied, which is based on the difference between the simulated steady state fuel map and the fuel consumption outcomes of the WHTC measurement procedure (ibid.). This correction factor shifts the results from the fuel map closer to the WHSC results.

4.6.2 Alignment with standards outside the EU

- To what extent is the standard aligned with existing standards outside the EU?
- To what extent can the design option be adopted by other countries as well?

The former sections of this chapter have described the differences between the different standard designs, including those already implemented in the US/Canada (standard for the engine and rest of vehicle), China (whole vehicle) and Japan (engine + transmission). Any standard design implemented in the EU would therefore never be completely aligned with all existing standard designs. In this light, a multiple component standard would deviate most from the currently implemented standard designs; none of the above-mentioned countries has chosen for such a design. As for the other standard designs, the EU may align with some countries but not with others. However, when also looking at the countries that have not implemented a standard yet, the design option combining an engine standard with a standard for the rest of the vehicle may be relatively easiest to be adopted by other countries (or at least the separate engine standard will). This results from the fact that the testing of the engine would be based on the WHTC and WHSC test procedures for air pollution (EURO VI). It is likely that these test procedures will also be adopted by non-EU countries, as has also been the case for previously developed air pollution test procedures (e.g. ESC and ELR tests).

Some of the interviewees stressed that it may not be possible nor desirable to align fully with the standard designs of other countries. This results from the fact that the appropriate standard design will depend on the country's characteristics. The engine + transmission standard that has been implemented in Japan, is appropriate for this small and hilly country where the main emission reductions have to come from improvements in these main components. Other measures, such as aerodynamics for example, would result in far less emission reductions. However, Europe is significantly larger and enables higher speeds over larger distances. If the Japanese standard design would be implemented in Europe, the significant reduction potential from other components, such as aerodynamics, are not captured. Therefore, it is important to look at the country-specific emission reduction potential of different components when designing a standard.

Likewise, interviewees pointed out that differences in the OEM market structure may also be a reason for not aligning standard designs. In Europe, the HDV OEMs are highly vertically integrated and manufacture most parts of the powertrain themselves. This may have two implications for the design of the standard. Firstly, it means that a lot of attention has already been given to optimising the base truck and most CO_2 savings can be gained from optimising the truck/trailer combinations (because this integration is not yet optimised). Therefore, it may be especially important to somehow include the trailer in the standard design in the EU. Secondly, it implies that component manufacturers deliver relatively less parts of the truck than in some other countries, such as the US or Canada; a separate engine or engine + transmission standard may have relatively less added value in this integrated market than in other, less integrated markets where a larger share of the engines and transmissions are delivered by component manufacturers. However, a whole vehicle standard may have less added value in other global regions that are latter adopters of EU regulations (i.e. where the market may be less vertically integrated).

Although it may not be feasible to align all standard designs worldwide, there are standard aspects that would be both valuable and feasible to align. One aspect that was frequently mentioned was the alignment of measurement methods. At the moment it can occur that the same component of a manufacturer receives different efficiency numbers in different countries due to differences in test procedures, which is complex and difficult for both component and vehicle manufacturers. These different test procedures also increase the costs of testing significantly for manufacturers. Every country that has already implemented a standard, uses simulation (sometimes combined with testing of the engine) with partially overlapping input parameters so in theory, it should be possible to align the measurements of the required inputs.

Additionally, there was some disagreement amongst the interviewees about the possibility to align the strictness of the targets. One interviewee pointed out that this can be done and that this is important: if the limits are in the same order of magnitude, the same component of a manufacturer could be supplied in different countries (although some small customisations may be required), while if limits vary significantly, the component of one manufacturer may not be appropriate for all countries. It may require a manufacturer to supply two components with completely different performance to the market. However, another interviewee argued that aligning targets will not be feasible, due to differences in country characteristics (e.g. in duty cycles) and in reduction potentials.

4.7 Other standard design features

Two main features are necessary to decide upon with any standard design; the level of differentiation and the operationalisation metric. Both aspects are described in this section. In addition, an analysis is made in Section 4.7.3. in case the policy maker would decide to implement an information disclosure system instead of a standard.

4.7.1 Differentiation

Any standard design will have to take into account the different vehicle types, vehicle duty cycles, or similar aspects in order to be effective. Firstly, the policy maker will have to decide which categories will be covered by the standard, and hereafter it may be decided upon to differentiate the limits between the included categories. Both aspects are further described in this sub-section.

Coverage of standard

Section 2.2 showed the wide variety of vehicle types and duty cycles in the EU market contributing to the total CO_2 emissions of the EU freight transport industry. Ideally, any standard would cover all vehicle types and duty cycles, in order to maximise the emission reductions that will result from it. However, as was also pointed out by some interviewees, it may be too complex or expensive to regulate all HDV vehicles/duty cycles. In this case, a decision would have to be made on which categories to include. Several criteria were mentioned in this respect, including the share in the total CO_2 emissions/fuel consumption and the availability of (cost-effective) technologies to reduce emissions.

As was shown in Figure 10 of Chapter 2, long haul (37%), regional delivery (14%) and construction and service (both 13%) contribute most to the total CO_2 emissions. Moreover, for each of these segments at least some cost-effective fuel-saving technologies are available. Therefore, if it is not possible to include all segments, regulating these categories (and long haul vehicles in particular) may provide a good starting point. Another option could be to start with regulating just one component (e.g. tires or engines) for all duty cycles, and to expand the regulation in later years. This would also lower the coverage of the standard (see Section 4.3.1), but may be easier/faster to implement.

Differentiation of limits

In order for a standard to be effective, limits should be differentiated between different categories. A long haul vehicle will have a completely different reduction potential from an urban or service vehicle, and hence it would make no sense to set the same targets for these different vehicles. This was acknowledges by all interviewees. However, differentiating limits may provide manufacturers an opportunity of gaming: if a lower limit is set for regional delivery trucks than for long haul trucks for example, customers would be provided an (undesired) incentive to buy regional delivery trucks and use these vehicles for long haul transport. The higher the level of differentiation, the more opportunities will be created for gaming. As a consequence of these pros and cons of differentiating limits, interviewees' opinions about the basis and level of detail of this differentiation differed as well.

Interviewees agreed that the standard should at least be differentiated between heavy duty freight and passenger transport. This was especially considered important if a standard for the whole/rest of the vehicle would be implemented, as most interviewees had a preference for the g/tkm and g/pkm metric (see Section 4.7.2) instead of the g/vkm, which requires such a distinction. If possible, the limits should be further distinguished between the eight European duty cycles (see Section 2.2) they argued, which would result in six categories for freight transport and in two categories for passenger transport.

Some of the interviewees did point out that the differentiation of limits should be based on duty cycles (or vehicle types for that matter).There was no agreement on whether limits should be differentiated any further than by duty cycle. In general, a higher level of differentiation will result in a standard that is aligned closer to the real-world vehicle configurations. However, increasing the number of categories will also make the standard more complex to implement and enforce.

If policy makers would decide to differentiate further than by the different duty cycle, the vehicle types used within each duty cycle were mentioned quite frequently as well. This could either be operationalised by differentiating to the number of axles (13 axle configurations are included in the VECTO simulation tool), by GVW, or by body type (box vs. alternative or rigid vs. tractor/trailer). One interviewee argued the type of goods transported should also be used to distinguish between heavy goods and voluminous goods, while others argued this is not a relevant issue to take into account. There was also disagreement as to whether the simulation model should distinguish the parameters for different Member States to take into account the hilliness of some countries for example. However, several interviewees argued that this is not important, as the EU OEMs deliver their trucks to all European countries. For labels this may be a more relevant issue to take into account, as with a label it is aimed for to provide information to the consumer. Such information is more valuable if it aligns with the real-world fuel consumption.

In case a standard for the whole/rest of the vehicle is implemented, it is theoretically possible to also included trailers. This may require an additional level of differentiation, such as by trailer type (semi-trailer, trailer with wheels in the middle, trailer with wheels at both ends of the trailer).

One interviewee mentioned the possibility of using a limit value curve similar to the one that has been used for the EU CO_2 standard for passenger cars.[18] A limit value curve would still ensure a fleet average CO_2 emission reduction, but does not require all manufacturers to meet the same target. The limit curve means that HDVs which score high on certain indicators (e.g. mass) are allowed higher emissions than vehicles which score low on that indicator, while preserving the overall fleet average. Potential indicators for a limit value curve are: mass, load capacity, footprint, horsepower, etc. However, further research would be required to determine the optimal (set of) indicators. The advantage of using a limit value curve is that it enables tighter standards, since the target does not have to be customized to the manufacturer with the highest baseline emissions.

4.7.2 Metric

An appropriate operationalisation metric differs slightly between standard designs. The current engine standard in the US, has been defined as g/bhp-hr, which is considered as an appropriate metric by most interviews in case a separate engine standard is set. The main argument for this metric is that it aligns with the metric of the air pollution standard, and will result in more synergies as a consequence (e.g. in terms of speed of implementation, possibilities for strategic gaming by OEMs, etc.).

The g/bhp-hr may also be an appropriate metric in case a separate engine + transmission standard is implemented (especially if a powerpack test is required for measuring performance). Although Japan has an engine + transmission standard in practice (as these are the only parameters manufacturers can change in the vehicle simulation model), the metric implemented is in g/tkm. According to some interviewees, it is very difficult to accurately simulate the combined performance of the engine + transmission and hence it is better to test performance in a powerpack test. In this case, it will be difficult to transform the g/bhp-hr results of the powerpack test to a g/tkm metric though. Therefore, the g/bhp-hr may be more appropriate for a separate engine + transmission standard.

The standard for the whole vehicle and for the rest of the vehicle (in case it is combined with a component standard), is unlikely to use the g/bhp-hr metric. The main options are to use a g/tkm and g/pkm metric or to use a g/vkm metric. Most interviewees expressed a preference for the former mentioned metric, as this metric takes into account the commercial function of the vehicle (i.e. it informs the user of the vehicle about the efficiency of moving freight or passengers). This metric can be based on an empty load, average load or full load; the average load may be most desirable interviewees argued.

[18] Notice that this is just another way to design the differentiation of the limits.

Some of the interviewees are not in favour of a g/tkm and g/pkm metric, as it may result in some unintended consequences, such as hauliers starting to use larger trucks. Therefore a capacity neutral metric should be used (g/vkm, g/kWh, etc.) they argued. Also, g/tkm or g/pkm do not take into account a factor of time; the speed with which the vehicle is driving influences the CO_2 emissions, which may be optimised in the test procedure. However, in practice higher speeds may result in higher CO_2 emissions. A g/bhp-hr does take this into account.

Finally, the appropriate metric for multiple component standards depend on the components that are regulated. Multiple metrics are likely to be needed to correctly measure each component.

4.7.3 Mandatory targets vs. information provision

Instead of implementing mandatory CO_2 standards for HDVs, policy makers could (first) mandate the disclosure of CO_2 measurement results (with or without a label system). In principle, information disclosure can be based on the same design options as those discussed for standards (i.e. measuring and disclosing information on the performance of an engine, of a whole vehicle, etc.). Obviously, the main difference is that policy makers would not have to determine any mandatory emission reduction targets with information disclosure. Some argue that this will result in a lower effectiveness in reducing emissions, while others argue that it may result in faster emission reductions as competitiveness between manufacturers is encouraged (i.e. the power of consumers is used by harmonising the information). However, with standards, manufacturers may also decide to disclose information voluntarily, which would result in similar benefits.
Three main point of views were expressed during the interviews. On the one hand, there were stakeholders who perceived information disclosure as a very useful step that can be implemented prior to the implementation of mandatory standard. Their main argument is that this will enable sufficient testing of the simulation tool, and that this would result in an enormous database with relevant data on the HDV fleet en their emissions. When such information is available, it would be easier to set appropriate limits for the different HDV categories.

However, on the other hand there were interviewees who argued that information disclosure/labels require the same measurement methods to be implemented. Therefore, this cannot be implemented faster than a standard, and hence, it is better to implement the standard immediately (to force emission reductions). Thereby, information disclosure/labels would be even more visible to consumers than standards, which implies that it would be even more important that the measurement results are correct. Testing the measurement results with labels or other forms of information disclosure therefore has not much added value they argued. Additionally, labels will provide the consumer information for one or several particular situation(s) (e.g. a vehicle with a full load and/or with an average load), when the consumer uses the vehicle differently in practice, a different CO_2 performance would result, which in turn may confuse the consumer. In this light, an online simulation tool to disclose information, in which the consumer can insert specific inputs on mileage, loads, and so on, would be better, as it would result in specific information that applies to the consumer’s situation.

Finally, there was a group of interviewees who preferred a combination of labels/information disclosure and standards; they argued that for those components for which reliable test procedures are available (e.g. engine, engine + transmission, or whole powertrain), standards could be implemented, while for the less reliable components, labels would be useful until the measurement procedures are accurate. Likewise, some interviewees mentioned that it may be very difficult to include the trailer's performance in a standard, but that labels for trailer components may be a good option to supplement standards that focus on the truck itself.

5 Conclusions and recommendations

5.1 Introduction

This chapter will first provide an overview of the main pros and cons for each standard design. Then, a short section on the implications of these findings for the EU are discussed. Finally, Section 5.4 summarizes the main recommendations for further study.

5.2 Main advantages and disadvantages of different standard designs

The following sub-sections each describe the main advantages and disadvantages of the five design options that have been evaluated in the previous chapter.

5.2.1 Engine standard and standard for the rest of the vehicle

This design option regulates the engine and the rest of the vehicle separately. If the simulation tool is well-designed to capture all advantages of fuel-saving measures and interactions between components, it has the potential to result in a full coverage of the emission reduction potential with an additional focus on the potential of the engine. Setting a separate standard for the engine ensures continuous innovation and improvements to be made in the engine (in addition to the rest of the vehicle). This may be important as the engine may not be the first component vehicle OEMs choose to improve due to its relatively higher marginal abatement costs but as indicated in Section 5.2.2 the engine offers a relatively high share of the improvement potential. The costs of improving the engine's efficiency are still in the same order of magnitude as these other technologies, so it may be especially important to ensure that hybridization measures are being taken, which are much more expensive but have a significant share in the engine's overall reduction potential. Therefore, hybridisation may be desirable from an environmental or political point of view, to obtain deep emission reductions in the future. If the engine is not regulated separately, such innovations may be hampered (as they are not incentivised).

Regulating the engine separately does have the disadvantage that the engine is not necessarily aligned with other components (which are covered in a separate standard). This may be mainly a problem for the interactions with the transmission. Optimisation between the engine and transmission may still take place as this is already a point of focus in the current market, but in this design option these interactions are not explicitly targeted, so this is not certain (in contrast to an engine + transmission standard for example).
The standard for the rest of the vehicle does potentially target the optimisation between other vehicle components, but this does assume a simulation model that has defined the vehicle-specific parameters in such a way that these interactions are covered. This may well be very difficult.

Setting a separate engine standard in addition to a standard for the rest of the vehicle reduces the flexibility of vehicle OEMs somewhat, as they are forced to also make improvements in the engine (or to buy more efficient engines from engine manufacturers). This lower level of flexibility reduces the possibility for OEMs to (only) take the most cost-effective measures, which has a cost to end-users. In case limit standards are implemented, the relative cost increase may not be too significant in the initial phases of the standard. In this case, limits may not be too strict yet, which may enable compliance by only improving the engine's efficiency. This is a measure that is often cost-effective and is only slightly more expensive than improvements in other components. However, in order to utilise the full reduction potential of the engine (and in case very strict engine limits are set), hybridisation measures are needed. This would result in a significant increase of end-user costs, as the engine hybridisation measures are large in reduction potential, but also have significantly higher marginal abatement costs.

Setting a separate engine standard does provide clear targets to engine manufacturers as to the level of improvements they need to make, which is argued to level their playing field and to provide investment certainty to both engine manufacturers and vehicle OEMs. This may increase the level of competition between both players and may reduce overall end-user costs somewhat. Other component manufacturers are not provided clear targets and investment certainty in this design; to them it will be uncertain which components vehicle OEMs decide to improve, which may well be in other components and may result in a loss of their invested resources.

This design option is further argued to place an additional burden on integrated vehicle OEMs, as they have to comply with two standards in this design option. The performance of the engine can easily be tested in the existing WHSC/WHTC measurement procedure for HDV air pollution standards though. Considering that most legislative arrangements are already in place for these standards, a separate engine standard can be implemented fast and efficiently. Additionally, this leaves little room for OEMs to tune their engines differently for both goals in the test procedures. Thereby, the separate engine standard is automatically enforced in practice, as engines have a long lifetime. This reduces the risk that transport companies would replace their engine for a worse performing engine after some period of time.

For the other part of this design option, the regulation of the rest of the vehicle, a simulation tool has to be developed. Simulation tools require input from OEMs, which leaves room for gaming and strategic behaviour of OEMs. Therefore, all input values need to be verified and monitored, which can be a time-consuming, complex, and expensive process for which hardly any procedures are already in place. Thereby, it can be difficult to enforce the emission reductions that are aimed for in practice, as transport companies may decide to replace some of the components with worse performing components. The extent to which this may happen is unclear, as in theory, transport companies are profit-driven and most of these technologies have negative marginal abatement costs (i.e. result in long-term cost savings).

Regulating vehicle OEMs and engine manufacturers results in a few entities to regulate. However, it may also result in an unfair situation if vehicle OEMs fail to comply as a result of bought components that perform worse than was promised. A penalty system may resolve such issues, as OEMs could then make contract arrangements with component manufacturers to share the penalty if this situation occurs.

5.2.2 Engine + transmission standard

The main disadvantage of setting a standard for the engine + transmission only is that it covers only a limited share (approximately 21 to 42%) of the overall emission reduction potential (35-47%). This standard design does cover the main parts of the vehicle and provides a strong incentive to improve the engine, the transmission, and the interactions between both components, but not between the engine + transmission and the rest of the vehicle. The interactions between the engine and transmissions are the most important in terms of the efficiency advantages that can be obtained from optimising components though, so this is definitely an advantage of testing both components together.

This design option provides investment certainty (i.e. clear, long term targets) to all players impacted by the standard (i.e. engine, transmission, and vehicle OEMs). Some amount of uncertainty may still remain for the relevant component manufacturers though, as some flexibility would still exist for vehicle OEMs in which combination of engine and transmission they choose. Engine and transmission manufacturers therefore still are not provided with complete certainty that the state-of-the art engines or transmissions they have developed will be bought by the market. However, it still provides relatively more certainty to these component manufacturers than would have been the case with a standard for the whole vehicle. This in turn, may result in a higher level of competitiveness between component and vehicle OEMs, which may result in somewhat lower costs (for these components) to the end-user.

On the other hand, regulating a combination of components) separately is argued to reduce the flexibility of OEMs to take the most cost-effective measures. Engine and transmission technologies are not always those with the lowest marginal abatement costs. As a consequence, OEMs (and hence end-users) will experience some cost increases. This cost increase is dependent on the emission reduction that is aimed for, as some of the engine's reduction potential can be utilised with only slightly higher costs than would have been the case if some other measures (e.g. tires, aerodynamics) would have been applied. However, a significant share of the reduction potential of the engine + transmission is very expensive to utilise. It mainly concerns measures related to hybridisation. Adopting such measures will increase end-user costs significantly. Still, this may be desirable from an environmental point of view, as these hybrid technologies can result in very significant emission reduction in the future . Due to the high costs, innovations in such alternative drivetrains could hamper (or at least are not incentivised) if the engine and transmission are not regulated separately.

In case a limit standard is implemented, it may be difficult for policy makers to set these limits; OEMs may demand some compensation for their loss in flexibility, for example by negotiating weaker limits.

This standard design can be operationalised with two measurement methods; the performance can either be tested with a powerpack test or with a simulation tool. However, accurately simulating the combined performance of the engine + transmission is argued to be very difficult. The powerpack test is considered a more reliable measurement method, but it does require an upgrade in the test facilities of OEMs. This could be implemented relatively more quickly than a standard with a simulation tool though. The synergies that can be obtained with testing the engine in the WHTC/WHSC test cycles are likely to be reduced without adjustment in the test procedures of air pollution standard. If test procedures can be adjusted, synergies are likely to reduce the costs of monitoring and enforcing this design option.

An additional advantage is the fact that this standard design automatically enforces the emission reductions that are aimed for in practice. The engine and transmission have a long lifetime and are unlikely to be replaced before the end of the vehicle's lifetime. This in turn reduces the risk of the engine or transmission to be replaced by a less well performing set within the lifetime of the vehicle.

5.2.3 Engine + transmission standard and standard for the rest of the vehicle

This design option combines the advantages and disadvantages of the two previously described designs. The design has the potential for full coverage of the emission reduction potential of the vehicle assuming that a well-designed simulation model is implemented. Additionally, the design explicitly targets the reduction potential of the engine and transmission and the interaction between both. This last-mentioned benefit is considered to be very important and to improve the overall effectiveness. Interactions between the engine + transmission with the rest of the vehicle are not covered, but these interactions provide fewer possibilities for optimisation (and hence efficiency gains) than optimising the engine and transmission. Within the standard for the rest of the vehicle, the interaction between other components is targeted for optimisation well, although it may be difficult to capture such interactions in a simulation model.

As was already argued before, setting a separate engine + transmission standard may be necessary to stimulate innovation in the more expensive technologies (i.e. especially hybridisation), which may be desirable from an environmental point of view (i.e. deep emission reductions) but will increase end-users' costs. In earlier stages of the regulation this cost increase may not be too significant yet, as there are at least some engine/transmission technologies that are only slightly more expensive compared to the measures to other components. End-user costs may further increase due to the costs of upgrading OEMs' test facilities (for the powerpack test), and of complying with two rather than one standard. On the other hand, this standard design does provide integrated OEMs and engine and transmission manufacturers, investment certainty (i.e. clear targets for the combined performance of engine and transmission). This may increase the level of competition between component and vehicle OEMs, which may lower the end-user costs somewhat. However, engine and transmission manufacturers will still not know the exact level of performance that OEMs will demand for their components and other component manufacturers are provided with even less investment certainty though (although they have slightly more certainty than with a standard for the whole vehicle, as vehicle OEMs have even more options when choosing which components to improve with the latter-mentioned design).

The performance of the engine + transmission can be tested reliably with a powerpack test (see Section 5.2.2 for the advantages and disadvantages of this test method). Thereby, the emission reductions from the engine and transmission that are aimed for will be automatically enforced in practice, due to their long lifetime. The performance of the rest of the vehicle will have to be measured with a simulation tool, which is argued to be less reliable in accurately simulating emissions than actual testing. It results in more expensive and complex monitoring systems to verify the data, may result in some room for gaming by OEMs and may be perceived as unfair in some cases (for a more detailed elaboration see Section 5.2.1).

5.2.4 Standard for the whole vehicle

A standard for the whole vehicle has the potential to result in a full coverage of the emission reduction potential, if the simulation tool uses vehicle-specific inputs for all components. In addition, this standard design has the potential to also specifically target the interactions between all components of the truck, which would stimulate OEMs to optimise them. This results in the relatively highest effectiveness in reducing the total emissions of the vehicle. However, as was the case for a standard for the rest of the vehicle, this does require the parameters of the simulation tool to be defined in such a way that the vehicle-specific parameters cover such interactions. This is difficult to accomplish effectively.

Regulating the whole vehicle instead of separate components, does leave OEMs with maximal flexibility to customise trucks for their main groups of consumers (e.g. providing a highly aerodynamic truck to consumers driving on relatively constant and high speeds, while providing a truck with an optimised engine and transmission to consumers driving long distances in hilly countries for example). This can prevent a bad alignment between the vehicles and customer situations, which would have result in a relatively high real-world emissions.

Another main advantage of this design option is that it realises emission reductions against the lowest cost possible. OEMs are provided full flexibility on how to improve their vehicles and they will focus on those technologies that have the lowest marginal abatement costs as a result. Also, they only have to comply with one CO_2 standard, reducing the burden placed on integrated vehicle OEMs. Both aspects result in the fact that this design is considered as the most cost-effective one. However, this also implies that innovations in very expensive component technologies (mostly hybridisation) may not be incentivised (except with a limit standard that has very strict limits). Policy makers may perceive this to be undesirable, as it may stagnate the improvement of expensive concepts that potentially result in (longer term) large environmental benefits in terms of climate change and air pollution (see Section 4.3.1 for the large reduction potential of hybridisation for example).

The standard for the whole vehicle provides investment certainty to vehicle OEMs: they know the level of improvements they have to realise, and can decide themselves where to make these improvements and how to comply. Hereafter they may decide to set internal targets for the separate component divisions for example. Component manufacturers on the other hand, are not provided with such investment certainty in this design option. This may result in an uneven playing field to these component manufacturers, as consistent targets are not provided on how much they need to improve their component. It may happen that a component manufacturer invests a lot of resources in developing a state-of-the-art and highly efficient component, while vehicle OEMs can decide to buy other advanced components.

With this standard design, vehicle OEMs are the most logical entity to regulate, which results in a low number of regulated entities[19]. It will be relatively easy for policy makers to agree on the limits for the standard with this entity, as the OEMs can decide how to meet the standard themselves. With this high level of flexibility, they may be willing to accept relatively

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19 Note that engine manufacturers would still be regulated for the pollution standard, so in principle this standard design results in the same total number of regulated entities (i.e. total for both air pollution and CO_2) as when an engine and rest of the vehicle standard design would be chosen for.

stricter limits than would be the case if separate components would be regulated. Still, as was the case with the other standards, OEMs may perceive it to be unfair to be regulated if they fail to comply with the standard due to unexpected lower performances from components they have bought from other manufacturers.

A standard for the whole vehicle may take a while to implement as it requires the development of a simulation tool, which is most complex for the whole vehicle. The simulation tool for the whole vehicle thereby requires most input from OEMs, which also leaves most room for manufacturers to tune their component test procedures. In order to ensure that the provided data is reliable, all input data would have to be verified, which will be very difficult and time-consuming. In addition, the results of the WHTC/WHSC test cycles for air pollution cannot be used in the simulation model directly (due to different metric requirements), which may result in less synergies between air pollution and CO_2 standards as manufacturers may have options for tuning their engines for each test procedure separately.

Whether the emission reductions that are aimed for over the lifetime of the vehicle will be truly realised in practice is uncertain. The reductions resulting from fuel-saving technologies that have been applied to the engine and transmission will be automatically enforced, as these components have a long lifetime. The reductions resulting from fuel-saving measures adopted for other components on the other hand may not be realised over the entire lifetime of the vehicle if the transport company decides not to keep a particular component in place. Tires for example, have a relatively short lifetime, it may be difficult for policy makers to enforce transport companies to continuously invest in low rolling resistance tires. The extent to which this may lead to lower emission reductions in practice is uncertain, as (some of these) technologies are no-regret options with higher benefits than costs, transport companies may well decide to keep investing in such a technology.

5.2.5 Multiple component-based standards

The implications of this standard design are highly dependent on the chosen components to regulate. In theory, full coverage of the emission reduction potential can be obtained, by setting a standard for each component of the vehicle. In this case, a strong incentive would be given to improve all components of the vehicle, and the whole market (both integrated OEMs and component manufacturers) would have a completely levelled playing field with full investment certainty for every player (i.e. targets for improvements for each component). However, it completely eliminates the flexibility of OEMs to only apply the technologies with the lowest marginal abatement costs, which results in the relatively highest end-user costs (unless limits are set in such a way to only force low-hanging fruits). In addition, it eliminates OEMs options for customising the trucks for their main groups of customers. This in turn, may force undesirable truck concepts into the market that are not the most appropriate for reducing emissions of particular consumer groups. Thereby, this standard design ensures emission reductions per component, but it ignores the interactions (and efficiency improvements that may be obtained from optimising these interactions) between the components. This is likely to result in a lower overall effectiveness in reducing real-world emissions than the other designs that do force such optimisations and as a result it is not possible to know beforehand the overall CO_2 performance of the vehicle.

An alternative approach would be to not implement a component-based standard for each component, but to regulate a subset of components (e.g. the components with the highest potential or those that can be measured most reliably). The main arguments of the previous paragraph still apply in this case, but the coverage of the emission reduction potential (and hence the overall effectiveness) would decrease significantly.

The implementation of multiple component-based standard would regulate those manufacturers actually manufacturing the component, which is likely to be perceived as a fair situation, as every manufacturer can be hold responsible for its own component. However, this would result in a high number of entities to be regulated (and hence monitored for compliance). In addition, negotiating the limits will require significantly more research than for the other standard designs, as the costs and reduction potential has to be investigated for each of the individual components and for each duty cycle (e.g. regulating five components for eight duty cycles would require 40 limits that would have to be negotiated). Thereby, OEMs are likely to resist very strict limits, as they have no flexibility in deciding which components to improve. This will be especially troublesome for those components that are harder to accurately measure and for which it is difficult to determine the different potentials for each duty cycle (e.g. for aerodynamic drag).

The required measurement procedures are also dependent on the components that are regulated. If a separate engine standard is implemented, synergies can be obtained with the measurement procedure for air pollution. The other components' performances will be harder to measure reliably, and regulating each component separately may provide a larger incentive for OEMs to act strategically in the test procedure; consumers cannot evaluate the performance of individual components, so the risk of losing consumers when a truck performs worse than promised in the real-world is smaller. Therefore, the inputs and test procedures of the different components would have to be verified and monitored closely. Additionally, compliance with each component standard has to be monitored and enforced. Such procedures are not in place yet for most components (except for the engine).

5.3 Implications for the EU

The European Commission is cooperating with the market to develop a measurement simulation tool for HDVs at the moment (VECTO). A standard for the whole vehicle aligns closely with the design of this measurement tool. This design would have the most significant benefits in terms of the flexibility provided to integrated OEMs as they can implement the technologies with the lowest marginal abatements costs and can customise the trucks with consumer demands. It also stimulates the optimisation of the interaction between different components, which is considered an important option for further realising fuel-savings from HDVs in Europe where a lot of attention has already been given to the optimisation of the base truck. This last mentioned aspect may be difficult to obtain in reality, as it is difficult to design a simulation model with vehicle-specific parameters that capture all interactions.

There are three main disadvantages of this standard design that should be kept in mind when deciding on which standard design to implement. Firstly, regulating the whole vehicle may not provide sufficient incentives for making deep improvements and innovations in the engine (unless a limit standard is implemented with very strict limits). This is likely to mainly be the case for hybridisation measures, which are very expensive. As mentioned in the previous section, this may be undesirable from an environmental point of view, as such technologies can potentially lead to steep emission reductions in the future. Two options can prevent the stagnation in the development of such technologies; on the one hand, the standard for the whole vehicle could be implemented with very strict limits, which would require improvements in the powertrain to comply with the standard. The other option is to implement a separate standard for the engine or engine + transmission, which would also provide sufficient incentive to innovate in these relatively more expensive components.

Secondly, the metric that is likely to be applied to a standard for the whole vehicle (g/vkm, g/tkm or g/pkm) is unlikely to result in synergies between the WHTC/WHSC test cycles (g/kWh, g/bhp-hr) for air pollution and the test procedure required to determine engine parameters for the simulation tool. I.e. the results from the former mentioned test procedure can be used to determine the input, but cannot be directly inserted in a simulation tool. This may enable OEMs to tune their engines differently for both measurements, to obtain the most desirable results for both goals. It should be mentioned that the VECTO simulation model of the EU has taken measures to correct for any discontinuities between both test results, however, setting a separate engine standard in addition to a standard for the rest of the vehicle would align better with the air pollution standard, creating less opportunities for gaming by OEMs and would result in greater synergies in terms of monitoring and enforcement.

Finally, a standard for the whole vehicle provides investment certainty to integrated OEMs, but not to component manufacturers. A component manufacturer may develop a highly efficient (and expensive) component without knowing whether vehicle OEMs choose to improve that particular component to comply with the standard. If vehicle OEMs decide to focus on other components, the money invested by the component manufacturer would be lost. Component-based standards (implemented with or without a standard for the rest of the vehicle) would provide the relevant component manufacturers with more certainty, levelling the playing field. However, it should be kept in mind that the EU market is a highly integrated one, which may make this a less relevant issue than for some other regions. In addition, this situation (i.e. no clear targets for the efficiency of individual components) is also existent in the current EU market (i.e. in a market without standards) so at least the situation for component manufacturers would not get worse.

Setting a separate standard for the engine (in addition to a standard for the rest of the vehicle) will thus solve some of the disadvantages of a standard for the whole vehicle. However, this standard design has disadvantages as well (which in turn would be solved by implementing a standard for the whole vehicle). This design reduces the flexibility of OEMs in implementing the most cost-effective measures, increasing end-user costs. It also ignores the alignment of the engine with other components (in particular with the transmission). This latter-mentioned aspect would not apply in case it would be chosen for to implement an engine + transmission instead of an engine standard, which is a significant advantage of this standard design. However, an engine + transmission standard that is combined with a standard for the rest of the vehicle in turn results in a more complicated test procedure (in contrast to an engine-only standard). It is likely to require an upgrade in OEMs test facilities and would result in less synergies with test cycles for air pollution if no adjustments are made to these test cycles.

The two other investigated standard designs (i.e. standard for the engine + transmission only and the multiple-component standard) may be less relevant to consider, as these not only align worse with the simulation tool that is being developed, but are also likely to have significant limitations in their effectiveness (due to their limited coverage) and are likely to result in the highest end-user costs.

In summary, each of the standard designs has advantages and disadvantages that should be taken into account when deciding on a standard design to implement. There is not a superior standard available that scores best on all assessed criteria. Once policy makers have decided which design will result in the most desirable benefits for the EU, the metric and level of differentiation can be decided upon. In general it can be argued that more levels of differentiation will result in a more accurate design, but will also lead to a higher level of complexity in terms of monitoring and enforcement.

An alternative approach is to mandate information disclosure of the simulation results to consumers prior to the implementation of a standard. This would enable policy makers to test the complex simulation tool and underlying test procedures first and would result in an enormous database of information on the HDV fleet. This information would be very helpful in setting appropriate limits for any standard designs in a later stage. At the other hand, an approach that merely relies on information provisioning by OEMs to customer’s risks that emission reductions will not be as fast as required for meeting the long term GHG emission reduction targets.

5.4 Recommendations for further study

Depending on the choice of the European Commission to further develop a standard, a label, a methodology for information on CO_2 performance by OEMs or a combination of these, various topics for further study are recommended:

- Choice of the metric: this study has provided a first elaboration on the possible metrics and the disadvantages and advantages of different metrics. However, this initial analysis is unlikely to capture the whole picture. For example, in case a g/tkm metric is chosen, which load should then be used in the model (empty, full, average, etc.)?
- Level of differentiation to be applied: there are many possibilities for differentiating limits between categories, including duty cycles, truck types, number of axles, GVW, etc. The impact of different levels of differentiation could be elaborated on further.
- Possibilities of differentiating with a limit value curve: the CO_2 standard for passenger cars makes use of a limit value curve to differentiate limits. Potentially this could be applied to a standard for HDVs as well. However, as the HDV market is much more complicated, this would require a significant amount of further research. Relevant questions to consider are on which indicators the curve should be based (e.g. GVW, load capacity in tonnes, load capacity in cubic metres; number of seats for buses, footprint, etc.) and whether this would be sufficient to fully cover all vehicle types used, or whether a number of limit value curves would be needed, etc.
- Strictness of the limits in case of standard: the limits set in the standard will have important questions on its effectiveness, innovation, costs, and so on. A study exploring the impact of different limits would be valuable.

- Coverage of the standard or label: It may not be feasible to regulate the whole HDV market at once. It would be valuable to investigate which categories should be included, what the impact of excluding particular categories would be (e.g. in terms of effectiveness, strategic behaviour), and whether some categories would be eligible for an exemption.

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Annex A Interviews

A.1 List of organisations and experts that have been interviewed

In total, eleven organisations have been interviewed, which includes experts, policy makers, NGOs and manufacturers. More details on the interviewees can be found in Table 14.

Table 14 List of interviewed organisations

Category	Organisation	Name expert or contact person	Interview date
Experts	TNO	Ruud Verbeek	July 25th
	TU Graz	Stefan Hausberger	July 31st
Policy makers	EPA	Matthew Spears	September 11th
	Government UK	Bob Moran	September 11th
NGOs	IRU	Marc Billiet	July 23rd
	Transport & Logistiek Nederland	Rob Aarse & Paul Poppink	August 21st
	Transport & Environment	William Todts	September 3rd
	ICCT	Rachel Muncrief	August 28th
Manufacturers	Scania	Helen Mikaelsson	September 25th
	US-based component manufacturer		August 21st
	ACEA	Stefan Larsson	September 9th

It is important to emphasise that the content of the report and the conclusions does not necessarily represent the point of view of individual organisations. The content of the report is based on the various views that were expressed in the interviews, on literature, and on CE Delft's own knowledge on the topic. The conclusions represent the most often expressed point of views of the different stakeholders.

A.2 Project introduction and interview topics sent to interviewees

Prior to each interview, an introduction of the research and questionnaire were sent to the interviewees:

Topics for interview on design options for CO_2 standards for HDVs
CE Delft, 22 July 2013.

Background of the study
The European Commission is currently preparing a strategy to address the fuel consumption and CO_2 emissions from HDVs, which is expected to be launched in December 2013. The design of the CO_2 policy and regulatory instrument(s) have yet to be determined. A wide variety of policy design options can be thought of, such as the EU ETS, CO_2 labels, or CO_2 standards. The last mentioned instrument is most likely to be implemented. This measure could be applied to the entire vehicle, to the engine, to the engine and driveline, or to separate components for example. However, at the moment, the EU is still working on a methodology to measure the CO_2 emissions of HDVs, which is a necessary first step for implementing a standard at a later stage.

Although CO_2 standards for Light Duty Vehicles (LDVs) are widely deployed in a variety of countries, including in the EU, such a policy instrument is relatively novel for HDVs. Amongst other reasons, this may have resulted from the fact that the HDV segment is much more complicated (e.g. a wider variety of vehicle designs) than that of LDVs, which makes the design of a CO_2 standard more complex as well.

Despite the complexity of the HDV market, several non-EU countries (the US, Canada, Japan and China) have now implemented CO_2 standards for this market or will do so in the near future.

The design of these standards indicate that CO_2 standards (or labels) for HDVs can have a different coverage, for example an engine standard or a standard for the whole vehicle. Additionally, other options, like standards for the engine + driveline or standards for the different components of the vehicle, are possible. Obviously, differences in standard (or label) design will also result in differences in the impacts that can be expected.

Aim of the study

Considering that the EU still has to design a CO_2 standard (or label), our client would like to explore the different impacts that may be expected for different design options of the standards (or labels). Therefore it requested CE Delft to carry out a study on the advantages and disadvantages of different CO_2 standard/label designs for HDVs.

Part of this study is a set of interviews with selected stakeholders and experts in the field.

Interview topics

The aim of these interviews is to gather information on the following topics:

1. *The European HDV market and freight transport industry:*
   - When taking into account the main characteristics of the EU freight transport industry, what are the most important implications for the standard/label design?
   - How should the design of a new CO_2 label/standard take account of the HDV market structure, in particular:
     - HGVs and buses;
     - submarkets such as long haul, medium haul, city distribution;
     - various types of goods;
     - differences between Member States;
     - tractor-trailer combinations vs rigid trucks;
     - exchange of trailers between transport operators.
   - How should the design of a new CO_2 label/standard take account of other relevant developments, such as:
     - developments with respect to vehicle and energy technology;
     - other types of legislation.
2. *Design options of CO_2 standards/labels for HDVs:*
   - Which of the following design options are relevant to be considered by the EU for CO_2 standards for HDVs:
     - standards/labels for the whole vehicle (China);
     - multiple component-based standards/labels for certain parts of the vehicle: the engine, transmission, driveline, entire powertrain (engine, transmission and driveline), tyres, and/or aerodynamics, etc.;
     - engine + transmission standard (Japan);
     - engine standard and standard for the rest of the vehicle (US);

  - engine + transmission standard and standard for the rest of the vehicle.
- Which of these design options would you recommend? Why?
- More specifically, what are the pros and cons of these various design options, with respect to:
  - effectiveness of the standard/label;
  - robustness;
  - end-user costs;
  - incentives for innovation;
  - technical feasibility;
  - monitoring and enforcement;
  - legislative complexity;
  - speed of implementation;
  - alignment with other standards (e.g. for air pollutants);
  - alignment with other countries.
- How could these design options be operationalized (e.g. g/kWh, g/vkm, g/tkm)?
- What different pros and cons of the various design options should be considered for labels for HDVs?
- Are you familiar with the standards of the US/Canada, China, and/or Japan, and if so, which standard design do you consider most appropriate for the EU?

Annex B CO_2 reduction potential HDVs

Table 15 Relative emission reduction potential (in %) of different technologies in the 2015-2020 timeframe

Fuel-saving technology	Vehicle category							
	Service/ delivery	Urban delivery/ collection	Municipal utility	Regional delivery\collection	Long haul	Construction	Bus	Coach
Aerodynamics								
10% reduction in aerodynamic drag	2-3							
Aft box taper		1.5-3						
Boat tail				2-4	2-4			
Box skirts		2-3						
Cab side extension or cab/box gap fairings		0.5-1						
Full gap fairing				1-2	1-2			
Full skirts				2-3	2-3			
Roof deflector		2-3						
Streamlining								3-10
Light-weighting								
Material substitution	1-1.5	3-5	0.7-1.2	2.2	2.2	0.3	5-7.5	1.1
Tires and wheels								
Automatic tire inflation on vehicle/tractor				0.6	0.6	0.6		0.4
Automatic tire inflation on trailer				0.6	0.6			
Low rolling resistance tires	1-2	2.1-4.2	2.4-3				1-2	1-2
Low rolling resistance wide-base single tires				9-12	9-12	9-12		
Transmission and driveline								
Aggressive shift logic and early lockup	1.5-2.5		0.5-1					
Increased transmission gears	2.7-4.1		2-3					
Transmission friction reduction	0-1		1	1-1.5	1-1.5	1-1.5		1-1.5
Energy efficiency								
Improved diesel engine	4-5	9.4-12	9.4-12	9.4-12	14.6-17.9	9.4-12	9.4-12	14.6-17.9
Hybridisation								
Dual-mode hybrid	20-30			8-12	8-12			
Parallel hybrid		25-35				25-35		9-13

Fuel-saving technology	Vehicle category							
	Service/ delivery	Urban delivery/ collection	Municipal utility	Regional delivery\collection	Long haul	Construction	Bus	Coach
Parallel hydraulic hybrid			20-25					
Series hybrid							30-40	
Management								
Predictive cruise control				1-2	1-2			1-2
Route management					0-1			
Training and feedback					1-4			

Source: TIAX, 2011.

Annex C Cost-effectiveness of different fuel-saving measures

Fuel-saving technology	Vehicle category															
	Service/ delivery		Urban delivery/ collection		Municipal utility		Regional delivery\collection		Long haul		Construction		Bus		Coach	
	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case
VL	10	5	19	9	17	8	12	6	8	4	19	9	14	7	12	6
DR	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%
FP	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Aerodynamics																
10% reduction in aerodynamic drag	-365	-288														
Aft box taper			-284	-178												
Boat tail							-236	-43	-335	-219						
Box skirts			-266	-140												
Cab side extension or cab/box gap fairings			-64	283												
Full gap fairing							-172	87	-303	-155						
Full skirts							-79	273	-229	-7						
Roof deflector			-275	-160												
Streamlining															-295	-159
Light-weighting																
Material substitution	-70	302	85	598	303	1,079	-33	364	-202	46	2	421	168	756	1,087	2,604
Tires and wheels																
Automatic tire inflation on vehicle/tractor							1,774	3,979			1,319	3,202			-166	99
Automatic tire inflation on trailer							-237	-44	-335	-219						
Low rolling resistance tires	-383	-326	-251	-202	-319	-255							-295	-243	-313	-256
Low rolling resistance wide-base single tires							-354	-298	-387	-338	-310	-255				
Transmission and driveline																
Aggressive shift logic and early lockup	-371	-300			-322	-247										
Increased transmission gears	-203	35			-195	21										

Fuel-saving technology	Vehicle category															
	Service/ delivery		Urban delivery/ collection		Municipal utility		Regional delivery\collection		Long haul		Construction		Bus		Coach	
	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case	Best case	Worst case
VL	10	5	19	9	17	8	12	6	8	4	19	9	14	7	12	6
DR	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%
FP	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Transmission friction reduction	-74	292			-306	-213	-332	-234	-379	-309	-299	-215			-337	-243
Energy efficiency																
Advanced engine	-186	69	-229	-67	-277	-153	-279	-127	-301	-152	-265	-141	-304	-187	-208	15
Hybridisation																
Dual-mode hybrid	360	1,161					226	882	14	478						
Parallel hybrid			-175	49							-230	-67			385	1,200
Parallel hydraulic hybrid					-129	161										
Series hybrid													-272	-124		
Management																
Predictive cruise control							-361	-289	-395	-339					-362	-293
Route management									-231	-12						
Training and feedback									-366	-281						

Note: VL = Vehicle lifetime, DR = Discount rate, and FP = Fuel price scenario.

Source: CE Delft (2013); MACH model.

Annex D Summary assessment criteria for each design options

Table 16 Summary of main arguments of each assessment criteria for each standard design

Assessment criteria	Standard design				
	Engine and rest of vehicle	**Engine + transmission**	**Whole vehicle**	**Multiple components**	**Engine + transmission and rest of vehicle**
Effectiveness					
Theoretical effectiveness					
Reduction potential covered	All of the emission reduction potential of the vehicle is covered (at least in theory). In addition, specifically targets the emission reduction potential of the engine (20 to 42% depending on duty cycle)	Covers the emission reduction potential of the engine + transmission: 21 to 42% (depending on the duty cycle)	All of the emission reduction potential of the vehicle is covered (at least in theory)	All or part of the emission reduction potential of the vehicle is covered (at least in theory) depending on the components and duty cycles that are regulated	All of the emission reduction potential of the vehicle is covered (at least in theory). In addition, specifically targets the emission reduction potential of the engine + transmission (21 to 42% depending on duty cycle)
Technologies incentivised	– Engine technologies – Technologies for the rest of the vehicle – Targets some optimisation of interactions between different components (if well-designed simulation tool), but not between the engine and rest of the vehicle	– Engine technologies – Transmission technologies – Targets optimisation between interaction of engine and transmission, but not between those components and the rest of the vehicle	– All available technologies can be adopted (if simulation tool is well-designed) – Targets optimisation of interactions between all components (if well-designed simulation tool)	– Technologies for those components that are regulated – No optimisation between component interactions targeted	– Engine technologies – Transmission technologies – Technologies for the rest of the vehicle – Targets some optimisation of interactions between different components (if well-designed simulation tool) but not between the engine + transmission and rest of the vehicle

Assessment criteria	Standard design				
	Engine and rest of vehicle	**Engine + transmission**	**Whole vehicle**	**Multiple components**	**Engine + transmission and rest of vehicle**
Robustness					
Sensitivity to real-world conditions	– Rest of vehicle: sensitive to trailer switching – Some customisation of the vehicle for the consumer possible – Engine standard: Emission reductions targeted are automatically enforced in practice due to the long life-time of the engine – Rest of vehicle: not all targeted emission reductions may be enforceable over the whole lifetime of the vehicle	– Not sensitive to trailer switching – Customisation of the vehicle for the consumer possible but any CO_2 saving not recognised – Emission reductions targeted are automatically enforced in practice due to the long life-time of the engine and transmission	– Sensitive to trailer switching behaviour – Vehicles can be fully customised for the consumer – Emission reductions from the engine/transmission are automatically enforced in practice due to the long life-time of the engine and transmission, but other targeted emission reductions may not be enforceable over the whole lifetime of the vehicle (e.g. tires)	– Not sensitive to trailer switching – No/very limited customisation of the vehicle for the consumer possible - Emission reductions from the engine/transmission are automatically enforced in practice due to the long life-time of the engine and transmission, but other targeted emission reductions may not be enforceable over the whole lifetime of the vehicle (e.g. tires)	– Sensitive to trailer switching behaviour – Some customisation of the vehicle for the consumer possible - Emission reductions from the engine/transmission are automatically enforced in practice due to the long life-time of the engine and transmission, but other targeted emission reductions may not be enforceable over the whole lifetime of the vehicle (e.g. tires)
Reliability of test procedures (incl. gaming possibilities)	– Engine can be measured very reliably with test-cycles; less room for gaming by manufacturers – Rest of the vehicle more difficult to measure, and provides more opportunities for gaming, especially if OEMs can choose between different tests to calculate inputs	– Engine + transmission can be measured reliably with powerpack test – Less room for gaming by manufacturers	– Relatively less reliable than engine/engine + transmission tests, especially for those duty cycles/components with default inputs – A lot of the input has to be provided by OEMs, which may result in gaming, especially if OEMs can choose between different tests to calculate inputs	– Individual performance of a component is difficult to measure, can be unreliable (except for engine and engine + transmission) – For components that have to be simulated, there may be much room for gaming, as consumers cannot see the performance of individual components	– Engine + transmission can be measured reliably – Rest of the vehicle more difficult to measure, and provides more opportunities for gaming, especially if OEMs can choose between different tests to calculate inputs

Assessment criteria	Standard design				
	Engine and rest of vehicle	Engine + transmission	Whole vehicle	Multiple components	Engine + transmission and rest of vehicle
Market impacts					
End-user costs	– Forces OEMs to adopt at least some engine technologies; relatively less flexibility than standard for the whole vehicle – Engine improvements are relatively expensive, especially hybridisation measures, which increases overall end-user costs (especially if limits are strict)	– Forces OEMs to adopt engine/transmission technologies; limited flexibility provided to OEMs – Engine and transmission improvements are relatively expensive, especially hybridisation measures, which increases overall end-user costs (especially if limits are strict)	– Maximal flexibility provided to OEMs; OEMs will implement the technology with lowest abatement costs, minimising end-user costs	– Forces OEMs to adopt technologies for particular components, which may not necessarily be the cheapest technologies – Limited flexibility provided to OEMs	– Forces OEMs to adopt at least some engine/transmission technologies; relatively less flexibility than standard for the whole vehicle – Engine and transmission improvements are relatively expensive, especially hybridisation measures, which increases overall end-user costs (especially if limits are strict)
Fairness	– Forces integrated OEMs to comply with two standards – Forces integrated OEMs to improve the engine, which may be more expensive for some than for others – Levels the playing field for engine manufacturers (i.e. clear targets for the engine)	– Forces integrated OEMs to improve the transmission and engine, which may be more expensive for some than for others – Levels the playing field for engine and transmission manufacturers (i.e. clear targets for the engine + transmission)	– Integrated OEMs can each take the measures that are cheapest for their own situation – Does not level the playing field for any type of component manufacturer (i.e. no clear targets for component improvements)	– Forces integrated OEMs to improve particular components, which may be more expensive for some than for others – Levels the playing field for the relevant component manufacturers (i.e. clear targets for relevant components)	– Forces integrated OEMs to comply with two standards – Forces integrated OEMs to improve the engine and transmission, which may be more expensive for some than for others – Levels the playing field for engine and transmission manufacturers (i.e. clear targets for engine + transmission)

Assessment criteria	Standard design				
	Engine and rest of vehicle	**Engine + transmission**	**Whole vehicle**	**Multiple components**	**Engine + transmission and rest of vehicle**
Incentives for innovation					
Strength and focus of incentive	– Strength of the incentive is dependent on the strictness of the limits – Strong incentive to innovate in engine technologies – Incentive to innovate in any other vehicle/trailer technology (for which the simulation does not use defaults)	– Strength of the incentive is dependent on the strictness of the limits – Strong incentive to innovate in engine and transmission technologies – No incentive to innovate in other vehicle/trailer technologies	– Strength of the incentive is dependent on the strictness of the limits – Focus of innovation on any vehicle/trailer technology (for which no default values are used), but most likely the cheapest/easiest components (often not the powertrain)	– Strength of the incentive is dependent on the strictness of the limits – Strong incentive to innovate in those components for which a standard is implemented – No innovation in the trailer stimulated if defaults are used in the simulation	– Strength of the incentive is dependent on the strictness of the limits – Strong incentive to innovate in engine and transmission technologies – Incentive to innovate in any other vehicle/trailer technology (for which the simulation does not use defaults)
Investment certainty	– Investment certainty provided to: integrated OEMs and engine manufacturers – No investment certainty provided to all other component manufacturers	– Investment certainty provided to: integrated OEMs and engine and transmission component manufacturers – No investment certainty provided to all other component manufacturers	– Investment certainty provided to: integrated OEMs – No investment certainty provided to component manufacturers	– Investment certainty provided to: integrated OEMs and all component manufacturers for which a standard is set – If standards are set for all components, every manufacturer will be provided investment certainty	– Investment certainty provided to: integrated OEMs and engine and transmission component manufacturers – No investment certainty provided to all other component manufacturers
Technical feasibility					
Complexity of the test procedure	– Engine standard: test procedure already in place for air pollution, which is relatively easy – Rest of vehicle: simulation model is required, which is relatively more complex than testing	– Engine and transmission can be tested together in a powerpack test, relatively easy as no simulation model is required	– Simulation model required, which is relatively more complex than testing	– For the engine and engine + transmission test procedure is relatively easy; no simulation required – For all other components, individual tests/simulations are very complex	– Engine and transmission can be tested together, relatively easy as no simulation model is required – Rest of vehicle: simulation model is required, which is relatively more complex than testing

Assessment criteria	Standard design				
	Engine and rest of vehicle	Engine + transmission	Whole vehicle	Multiple components	Engine + transmission and rest of vehicle
Legislative impacts					
Legislative complexity					
Complexity of the test procedure	– Engine test procedure is already in place; fast implementation – Rest of the vehicle may take longer as simulation model and underlying test procedures for component inputs are needed	– Requires upgrade in engine test facilities/adjustment in air pollution test cycles, but relatively faster to implement than standards for whole/rest of the vehicle	– Relatively complex to develop a simulation model and underlying test procedures for component inputs; may require a longer implementation time	– Relatively complex to develop a simulation model/component tests for most components (except for engine and engine + transmission); may require a longer implementation time	– Requires upgrade in engine test facilities, but relatively faster to implement than standards for whole/rest of the vehicle – Rest of the vehicle may take longer as simulation model and underlying test procedures for component inputs are needed
Appointment of the regulated entity	– Engine standard: regulated entities are already appointed for pollutant emissions – Rest of the vehicle: vehicle OEMs are most logical, which are relatively few entities to regulate – May result in some difficulties in case of non-compliance if OEMs cannot hold component manufacturers accountable	– The vehicle OEMs are most logical, which are relatively few entities to regulate – May result in some difficulties in case of non-compliance if OEMs cannot hold component manufacturers accountable	– Vehicle OEMs are most logical, which are relatively few entities to regulate – May result in some difficulties in case of non-compliance if OEMs cannot hold component manufacturers accountable	– Regulates the manufacturers actually making the component, which may result in fewer difficulties in case of non-compliance – Number of entities to regulate is large	– The vehicle OEMs are most logical, which are relatively few entities to regulate – May result in some difficulties in case of non-compliance if OEMs cannot hold component manufacturers accountable

Assessment criteria	Standard design				
	Engine and rest of vehicle	Engine + transmission	Whole vehicle	Multiple components	Engine + transmission and rest of vehicle
Setting the limits	– Requires research in overall reduction potential of the engine and of the rest of the vehicle for different duty cycles – May be a bit more difficult to agree on limits with integrated OEMs than for a whole vehicle limit, as they are forced to take measures in the engine and may demand some compensation for this (less stringent limits?)	– Requires only research in overall reduction potential of the engine and transmission for different duty cycles – May be difficult to agree on limits with the market, as they are forced to take measures in these components and may demand some compensation for this (less stringent limits?)	– Requires only research in overall reduction potential of the vehicles used in the different duty cycles – May be easiest to agree on limits with the market, as the market is left with a lot of flexibility for compliance (stricter limits?)	– Requires research in reduction potential of each separate component in different duty cycles – Vehicle OEMs may demand compensation for their complete loss in flexibility (relatively least stringent limits?). However, component manufacturers may be less difficult	– Requires research in overall reduction potential of the engine and transmission and of the rest of the vehicle for different duty cycles; – May be difficult to agree on limits with integrated OEMs, as they are forced to take measures in these components and may demand some compensation for this (less stringent limits?)
Monitoring and enforcement	– The engine standard has a reliable test procedure, which can be verified relatively easily – All input for the simulation tool needs to be verified – Compliance with two standards has to be checked	– Requires least monitoring and verification; test procedure is reliable and relatively easy to verify – Compliance with only one standard has to be checked	– Requires significant monitoring; all input for the simulation tool needs to be verified – Compliance with only one standard has to be checked	– The engine and engine + transmission can be tested reliably, which can be verified relatively easily – All other components require verification of test procedures – Compliance with multiple standards has to be checked	– The engine + transmission standard has a reliable test procedure which can be verified relatively easily – All input for the simulation tool needs to be verified – Compliance with two standards has to be checked

Assessment criteria	Standard design				
	Engine and rest of vehicle	Engine + transmission	Whole vehicle	Multiple components	Engine + transmission and rest of vehicle
Alignment with air pollution standards	– Most synergies with the air pollution measurement can be realised (after some small adjustments), which prevents tuning/conflicting measures by OEMs	– Less synergies with air pollution measurement as a power pack test is needed, adjustment in the test cycles for air pollution may be possible to obtain these synergies	– Least synergies with air pollution measurement, as the engine specific input is only partially based on the air pollution measurement; may result in some tuning/conflicting measures by OEMs	– If a component standard is implemented for the engine only, synergies can be obtained with air pollution measurement, which prevents tuning by OEMs – Not possible for other components	– Less synergies with air pollution measurement as a power pack test is needed, adjustment in the test cycles for air pollution may be possible to obtain these synergies
Alignment with standards outside the EU	– Aligned with the US/Canada – Most potential to be adopted by countries that have not implemented a standard yet (as air pollution test cycles have been copied in the past as well) – Alignment of design may not be desirable when taking into account difference in country characteristics – Alignment with measurement procedure is desirable and possible	– Aligned with Japan – Alignment of design may not be desirable when taking into account difference in country characteristics – Alignment with measurement procedure is desirable and possible	– Aligned with China – Alignment of design may not be desirable when taking into account difference in country characteristics – Alignment with measurement procedure is desirable and possible	– Does not align with any other country – Alignment of design may not be desirable when taking into account difference in country characteristics – Alignment with measurement procedure is desirable and possible	– Does not align with any other country – Alignment of design may not be desirable when taking into account difference in country characteristics – Alignment with measurement procedure is desirable and possible