GHG reduction measures for the Road Freight Transport sector

An integrated approach to reducing CO_2 emissions from Heavy Goods Vehicles in Europe

Final report for: **ACEA**
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Date: 17 September 2014

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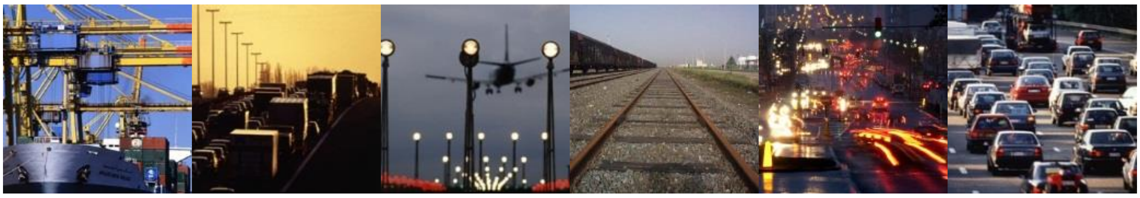

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Executive summary

Several studies have been published over the past years on the topic of CO_2 emissions of road freight vehicles, sponsored by governmental institutions like the European Commission or national governments. Their fact finding was mostly based on the results of independent laboratories, in some cases supported by the parties with the most knowledge on the matter: vehicle manufacturers.

As the representative organisation of European vehicle manufacturers, ACEA contracted Transport & Mobility Leuven (TML) to review and verify the information in these studies through a comparative literature study and a survey with the 6 largest European manufacturers of heavy duty vehicles: DAF, Daimler, IVECO, MAN, Scania and Volvo. The aim of this study was to consolidate the collective knowledge of manufacturers and frame it in the context of an integrated approach to reduce CO_2 emissions from the road freight sector, by combining vehicle modifications of a technical nature with measures to be taken by other actors in the field, like:

- tyre manufacturers,
- fuel producers,
- transport service suppliers,
- road infrastructure managers, and
- legislators.

A list of measures to be assessed was agreed between ACEA and TML.

Vehicle related measures were split into a number of packages, composed of individual measures of a similar nature. Their effect is presented in Table A below. Two drive cycles were considered in this study: the long haul cycle, which represents around 37% of HDV CO_2 emissions, and the regional delivery cycle, emitting 14% of CO_2.

Table A1: Vehicle related measures' reduction potential (OEM), for new vehicles

	Long Haul	Regional delivery
Engine efficiency	5.00%	4.50%
Auxiliaries management	1.50%	1.70%
Transmission	0.50%	0.50%
Alternative powertrains*	N/A	N/A
Axles	0.50%	0.50%
Driver assistance systems	2.50%	2.50%
Total OEM	**-9.67%**	**-9.38%**

**Insufficient data for assessment*

Table A2: Vehicle related measures' reduction potential (other parties), for new vehicles

Tyres	4.00%	3.00%
Aerodynamics: fairings, tails, etc.	4.00%	3.00%
Weight reduction	0.50%	0.90%
Total others	**-8.30%**	**-6.76%**

By 2020, new vehicles and trailers are expected to be 15-17% more fuel efficient than they are in 2014. Most of the benefits come from improvements to the engine, the tyres and the aerodynamics of the vehicle, while driver assistance systems will also contribute by guiding vehicle users to a more efficient driving style. To estimate effects on the total fleet, the market penetration of measures and the usage of vehicles (annual and lifetime mileage) was taken into account to transform the values for new vehicles from Table A1/2 to the fleet average values of Table B. Comparisons are possible between vehicle measures and actions taken by other parties to come to the integrated approach.

Table B: overview of HGV CO_2 reduction potential by 2020 via an integrated approach (reference year= 2014)

		Long haul	*Regional delivery*
Vehicle	OEM	-2.75%	-2.68%
	Other	-2.36%	-1.93%
Vehicle Total		**-5.05%**	**-4.56%**
Alternative fuels	Gaseous fuels	0.00%	0.00%
	Biofuel	-2.50%	-2.50%
Alternative fuels total		**-2.50%**	**-2.50%**
Vehicle operation	Driver training	-5%	-5%
	EMS	-2.00%	0%
	Speed management	-3.82%	-5.98%
	Improve load factors	No reliable estimates found	
	Cabotage	-0.55%	0%
Vehicle operation total		**-10.95%**	**-10.68%**
Road infrastructure management	Rolling resistance pavement	-1%	-1%
	Reduced inclination	0.00%	0%
	Improved flow	-2%	-2%
	Platooning	-0.46%	0%
	Road pricing (HDV only)	-1%	-1%
Infrastructure total		**-4.39%**	**-4.00%**
CO_2 legislation		Can strengthen market forces but does not create gains itself. Best option = fuel tax.	
Integrated effects		**-21.18%**	**-20.22%**

Not accounting for increased transport demand, road freight vehicles in long haul and regional delivery cycles could consume over 20% less by 2020, provided that all actors contribute to create optimal conditions.

- Vehicle related measures represent about a quarter of the potential improvement, but vehicle manufacturers themselves can only achieve 2/3's of that – the rest coming from tyre manufacturers and body or trailer builders.
- Over half of the potential improvement comes from more efficient vehicle usage, particularly from driver training. However, some of the listed measures can only play a role if a number of conditions are met (e.g. higher capacity vehicles generally permitted in cross border traffic).
- Alternative fuels have the potential to realise a much higher reduction than indicated in the table, but there is great uncertainty about how fast technology will advance and to which extent their increased usage will reduce (well-to-wheel) CO_2 emissions – if at all.
- Driver training, low rolling resistance tyres and aerodynamic improvements provide the best cost-effectiveness of all measures.

1 Introduction

1.1 General concept of the project

ACEA is closely following the current debates within the European Commission which are expected to produce CO_2 emission measuring standards for heavy duty vehicles (HDVs).

While the EC is involving stakeholders in these discussions, ACEA was interested to find out what the current situation on HDV greenhouse gas (GHG) emissions is. More precisely, it wanted to find out which evolutions have occurred in the past 10 years, and which technologies and policies are expected to have an impact in the coming decade.

For that purpose, ACEA contacted Transport & Mobility Leuven, a neutral research organisation, to review available literature on the matter and perform a survey among ACEA's member organisations, with the aim of developing an integrated approach to CO_2 emission reduction. This integrated approach will cover the entire spectrum of CO_2 abatement measures, including technological improvements to the vehicle, advanced driver support, a better road network and innovative policy measures.

To obtain a useful scope for the project, it was decided that only information on Heavy Goods Vehicles (HGVs) would be collected, for two driving cycles: Long Haul (LH) and Regional Delivery (RD). Simulations were requested to be done using the EC's emission calculation tool (in development) named VECTO.

1.2 Literature review

The study started with a literature review. The main recent publications on CO_2 abatement technologies and policies were collected and reviewed.

These are:

- AEA (2011): Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles – Lot 1: Strategy
- Ricardo (2009): Review of Low Carbon Technologies for Heavy Goods Vehicles
- TIAX (2011): European Union Greenhouse Gas Reduction Potential for Heavy-Duty Vehicles
- TML (2010): GHG-TransPoRD Deliverable 2.1 "Ranking of measures to reduce GHG emissions of transport: reduction potentials and feasibility qualification

These documents contained both general and specific information about various CO_2 emission reduction measures for heavy duty vehicles. Additional sources, with a focus on just one or a few types of measures, were also consulted. The results of the literature review are presented in the paragraphs on the respective technologies and policy measures.

1.3 Setup of the survey

The survey was set up to anonymously ask HGV manufacturers about the technologies they aim to deploy in their new vehicles by 2020. It consisted of 4 parts:

1. Establishing a baseline of reference vehicles for the years 2005 – 2010 – 2014 and for both drive cycles, including their configuration and fuel consumption.
2. Effects of technological measures at the vehicle level, to be simulated with the VECTO tool, and packages per type of measure (cfr. infra).
3. Effects of measures not tied to the vehicle, ranging from driver behaviour over road management to government policy.
4. Effects of combinations of vehicle measures as a full vehicle package, a combination of all measures from part 2 including the interaction effects between them.

A second round of the survey was needed to get additional clarification and provide specific information to fill knowledge gaps that became apparent in the comments on the first round.

2 The recent past: definition of reference vehicles

The automobile industry has been one of the most innovative economic sectors since its inception. Always pushing for extra performance while decreasing energetic losses and improving overall safety and comfort of transport, numerous technological leaps have been made in the past.

While the main goal of the current study was to look into future technologies to further improve fuel efficiency in road freight vehicles, it is useful to first explore the current situation of these types of vehicles, and how they perform. Therefore, the first section of the survey was aimed at defining the reference vehicles for the years 2005, 2010 and 2014.

ACEA provided TML with basic description of the reference vehicles for both of the driving cycles that are the subject of this study:

<u>Long haul:</u>

- ACEA segmentation matrix: class 5 / long-haul
- 18 t tractor 4x2
- average long-haul configuration for 40 t semi-trailer combination
- 400 – 460 horse power range
- long cab, high roof
- roof spoiler, side fairing, side deflectors behind cab
- 12/14/16-speed transmission
- 1-stage hypoid rear axle, main seller rear axle ratio
- main seller tyre

<u>Regional delivery:</u>

- ACEA segmentation matrix: class 4 / regional delivery
- 18 t rigid 4x2
- average regional delivery configuration as solo truck without trailer
- Heavy duty engine, approx. 340 hp
- short cab, low roof
- roof spoiler only as aero devices
- 9/12/14-speed transmission
- 1-stage hypoid rear axle, main seller rear axle ratio
- main seller tyre

Manufacturers were then asked to provide for these reference vehicles:

- Which technologies that impact CO_2 emissions were present for each of the reference years;
- The fuel consumption (l/100 tkm), vehicle empty weight (t), load weight (t).

2.1 Technologies

Manufacturers were asked to provide information on the main technologies that impact CO_2 emissions/fuel consumption for the reference vehicles between 2005, 2010 and 2014. The following sections describe which were most commonly mentioned. No explicit splits of impact per technological measure were made.

2.1.1 2005

For 2005, 3 manufacturers provided an overview of the main technologies impacting CO_2 emissions.

For Long Haul vehicles, the most commonly mentioned measures were a limited (30-40%) uptake of Automated Manual Transmission and a more widespread use of aerodynamic adaptations to the vehicle (roof: up to 80%; side: around 25%).

For Regional delivery vehicles, the penetration of AMT is slightly lower (around 30%), and that of air deflectors a lot lower (5-30%) than for LH.

2.1.2 2010

The 2010 reference vehicles were described by all but one of the manufacturers, as here it was simpler to indicate the main differences with the 2005 vehicles.

The input shows a further increase in the uptake of AMT and other improvements to the transmission. Furthermore, the penetration of aerodynamic equipment is greater (as for 2005 more particularly for Long Haul vehicles), while measures to decrease mechanic resistance on both axles and tyres as well as improvements to the engine combustion are also mentioned. Finally, driver assistance systems like Eco-roll are showing up too.

2.1.3 2014

In 2014, the large majority of HGVs in the Long Haul and Regional Delivery systems are equipped with AMT.

The main trend with regard to 2010 is the increasing uptake of driver assistance systems (Eco-roll, Predictive Cruise Control, Acceleration control, etc.), while penetration of aerodynamic equipment and engine efficiency improvements continues to rise as well. Auxiliaries like the air compressor and water pump have also started getting attention in the quest to higher fuel efficiency.

A clear negative influence on fuel consumption for 2014 vehicles is EURO VI technology, which tends to come with a fuel penalty due to the need (in some, but not all cases) to combine DPF and SCR technology.

2.2 Vehicle empty weight

Vehicle empty weight is stable or slightly increasing between 2005 and 2014 for both driving cycles. It is remarkable that the range of answers is much smaller for the LH vehicles (all within 0.7t) than for the RD cycle (all within 2.1t). The explanation for this is unknown.

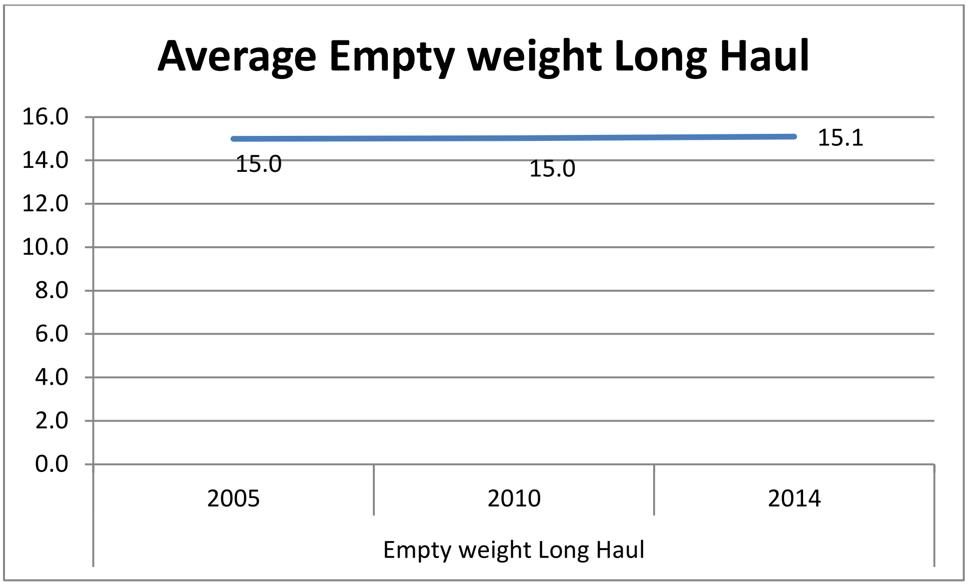


Figure 1: Empty weight of reference vehicles for Long Haul cycle

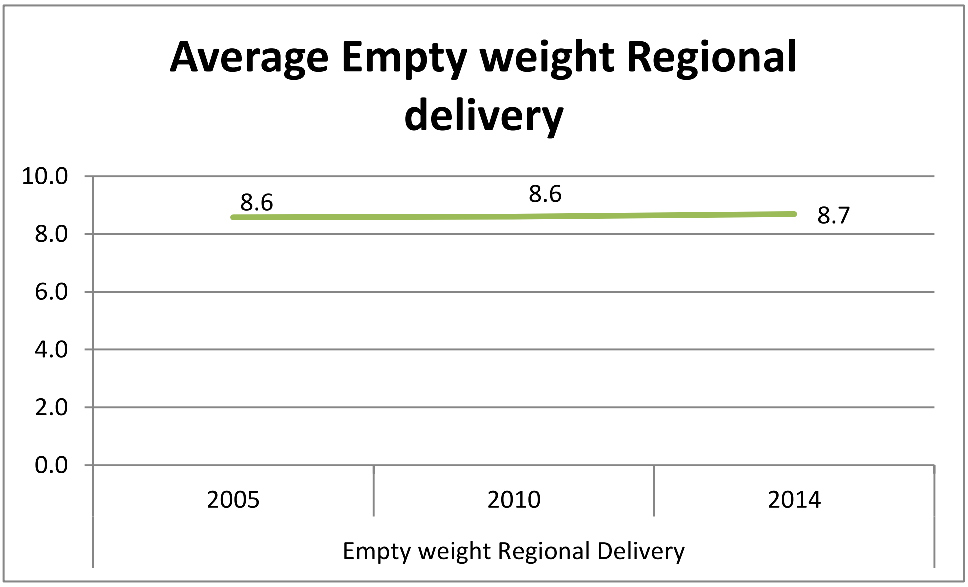


Figure 2: Empty weight of reference vehicles for Regional Delivery cycle

2.3 Load weight

For the load weight, standardised values were given in the ACEA White Book:

- Long haul: 19.3 tonnes;
- Regional delivery: 4.4 tonnes.

All but one of the manufacturers used these standard values.

2.4 Fuel consumption

Manufacturers were asked to provide diesel fuel consumption estimates for the reference vehicles, expressed in l/100 tkm. Given that all but one of the manufacturers used the same cargo weight, these values are not just useful as a reference for the rest of the survey, but also comparable to each other. The averages below do not take the outlier value into account.

The trend between 2005 and 2010 is clear: for both drive cycles, all manufacturers report a decrease of fuel consumption. Between 2010 and 2014, the trend is more ambiguous: some report a further decrease of fuel consumption, while for others consumption increases. In all cases, the improvement in fuel efficiency is about twice as high for LH vehicles than for RD vehicles. For LH vehicles, consumption decreases from 1.85 l/100tkm (35.8 l/vkm) to 1.69 l/100tkm (32.5 l/100 vkm). For RD vehicles, the 2005 average is 5.42 l/100tkm (23.9 l/100vkm) which evolves to 5.16 l/100tkm (22.7 l/100vkm) in 2014.

For the conversion of fuel consumption to CO_2 emissions, we will apply following factor: *1 litre of diesel fuel = 2.65 kg of* CO_2.

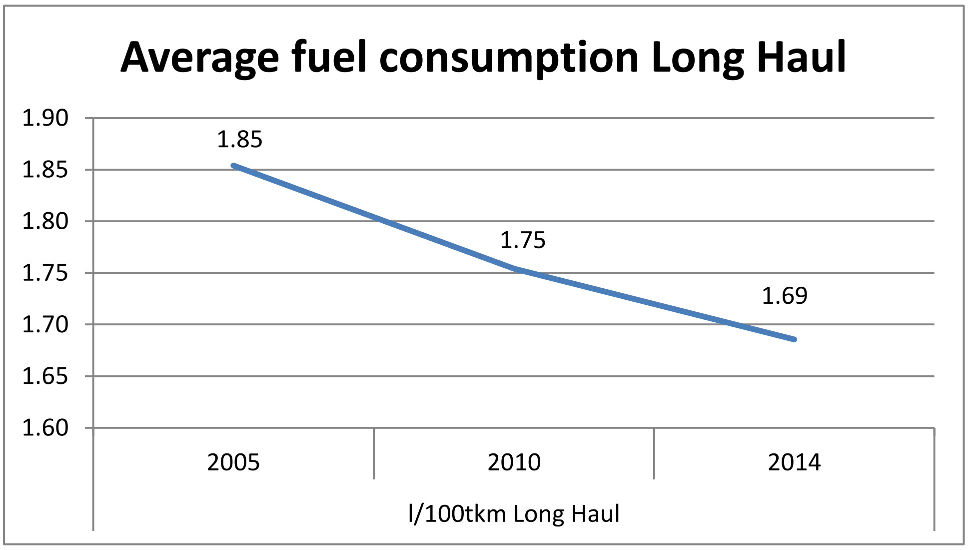


Figure 3: Fuel consumption of Long Haul reference vehicles

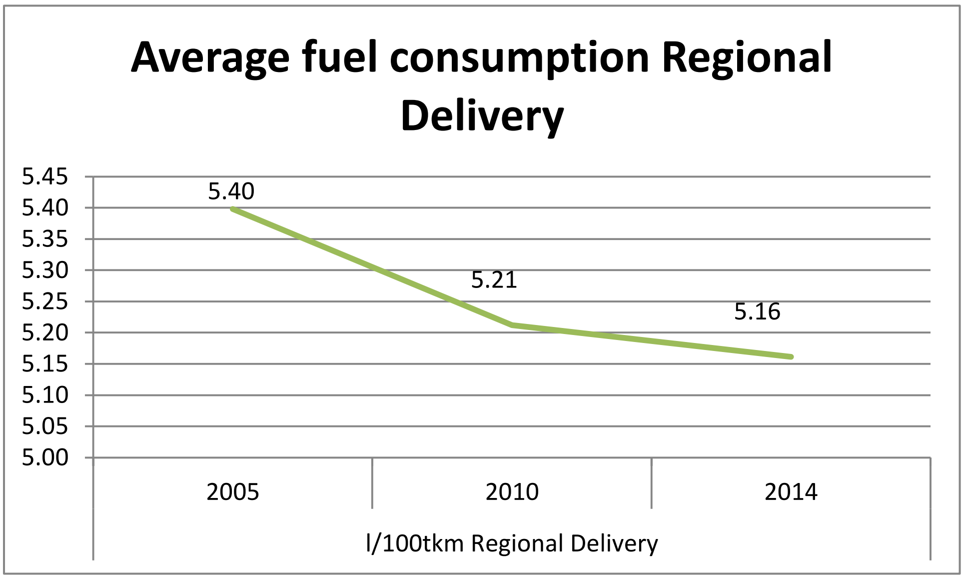


Figure 4: Fuel consumption of Regional Delivery reference vehicles

Table 1: evolution of the average fuel consumption

Average evolution	2010 vs. 2005	2014 vs. 2005	2014 vs. 2010
Long Haul	-5.4%	-9.1%	-3.9%
Regional Delivery	-3.4%	-4.4%	-1.0%

2.5 Reference vehicles and total fleet

The reference vehicles described above are typical vehicles sold in the given years. They do not represent the average freight vehicle on European roads in those years. This is a critical consideration in the further sections of this report. Indeed, the technical measures related to vehicle design apply only to newly sold vehicles, and their uptake – and thus their effect on overall CO_2 emissions of the road freight sector - depends strongly on the renewal rate of the fleet.

The total EU28 HGV fleet in 2010 was around 6.3 million vehicles (source: TRACCS study[1]), split as follows:

Heavy Duty Trucks	>3,5 t	Gasoline	167,671
Heavy Duty Trucks	Rigid <=7,5 t	Diesel	1,469,155
Heavy Duty Trucks	Rigid 7,5 - 12 t	Diesel	893,762
Heavy Duty Trucks	Rigid 12 - 14 t	Diesel	247,765
Heavy Duty Trucks	Rigid 14 - 20 t	Diesel	773,592
Heavy Duty Trucks	Rigid 20 - 26 t	Diesel	616,731
Heavy Duty Trucks	Rigid 26 - 28 t	Diesel	164,025
Heavy Duty Trucks	Rigid 28 - 32 t	Diesel	168,691
Heavy Duty Trucks	Rigid >32 t	Diesel	82,405
Heavy Duty Trucks	Rigid	All	4,416,126
Heavy Duty Trucks	Articulated 14 - 20 t	Diesel	184,126
Heavy Duty Trucks	Articulated 20 - 28 t	Diesel	109,800
Heavy Duty Trucks	Articulated 28 - 34 t	Diesel	76,064
Heavy Duty Trucks	Articulated 34 - 40 t	Diesel	421,456
Heavy Duty Trucks	Articulated 40 - 50 t	Diesel	860,833
Heavy Duty Trucks	Articulated 50 - 60 t	Diesel	38,369
Heavy Duty Trucks	Articulated	All	1,690,648
Heavy Duty Trucks		Total	6,274,445

Total sales of heavy and medium freight vehicles (>3.5t GCW) in 2013 amounted to 304,333 (source: ACEA statistics)[2,3]. This puts the overall renewal rate for the entire fleet at around 5%. HGV over 16t GCW represented about 75% of those sales: 231,662 vehicles. For this category, which forms the bulk of the vehicles performing the Long Haul and Regional Delivery trips, the renewal rate is significantly higher at 6.8%. New vehicles are used more frequently and for longer trips than older vehicles (the TRACCS study shows a clear drop off in annual mileage after year 5), but it is clear the penetration of new technologies in the total fleet is a slow process.

This demonstrates that technical vehicle measures, useful as they may be, should not be seen as the final solution, but rather as one of many steps to be taken to reduce the emissions of the road freight sector. If measures can be taken that have an impact on the entire fleet, their impact is likely much greater and faster than any adaptation to newly sold vehicles. This is an important consideration to take on board while reading the rest of this report.

[1] http://traccs.emisia.com/

[2] http://acea.be/press-releases/article/commercial-vehicle-registrations-1.0-in-2013-34.7-in-december

[3] Not including Bulgaria and Malta.

3 Future reduction measures

This part describes the effects of different measures to reduce fuel consumption of heavy duty freight vehicles. It reflects both the findings of the literature review and the replies of the HDV manufacturers to the survey. For each measure, a brief description is provided, along with the estimated effects on CO_2 emissions.

3.1 Vehicle related measures controlled by OEMs

The construction of a vehicle starts with the so called OEM: Original Equipment Manufacturer. They develop and assemble the powertrain and frame of the vehicle to make the chassis. Then, the OEM may choose to build a body or other vehicle components himself, or leave this to other market players. In most cases however, the core business of automotive OEMs is the chassis. This section focusses on the elements of the chassis where OEMs are the only party affecting fuel consumption of the vehicle.

The survey collected data on the CO_2 reduction potential, the costs of a measure and its market uptake potential for individual measures. For confidentiality reasons, the detailed reduction potential data were omitted from this document, and the findings are reported at the "package" level, i.e. a group of measures of a similar nature, for the year 2020. Cost data are also not included in this report.

3.1.1 Package 1: Conventional engine efficiency

Conventional diesel technology is likely to remain the dominant propulsion type in heavy duty vehicles for the near and medium future. Investments in the development of efficiency-increasing techniques can be written off over at least a full vehicle replacement cycle, which guarantees the value of the OEMs' efforts to push forward. Various types of improvements are currently being developed, including turbocompounds, combustion improvement, thermal management, engine friction and aftertreatment systems. For each of these classes, there are different possibilities, and OEMs may choose to focus on just a few of them.

The survey suggests that by 2020, a reduction potential of 4.5% (regional delivery) to 5% (long haul) is realistic, with a maximum around 9%.

3.1.2 Package 2: Auxiliaries

Auxiliary systems only represent a small part of the vehicle energy consumption, but nonetheless there is a non-negligible capacity to reduce their energy demand and thus vehicle fuel consumption. The main path to improvement seems to lie in the electrification of currently mechanical accessories, which allows for a reduction of power supply when possible. The reduction potential is around 1.5% for long haul, and 1.7% for regional delivery.

3.1.3 Packages 3 and 4: Transmission and driver assistance

Improvements in the transmission system can be either mechanical (mainly reducing friction) or aimed at reducing the losses from the act of gear shifting by (partially) automating the process. The next step is the use of driver assistance systems that indicate the optimal moment to shift gears, or even do the gear sift themselves, combined with information on the road and traffic situation. In addition, they can also manage acceleration and deceleration in function of fuel efficiency.

The reduction potential for the transmission only is around 1%. The efficiency gains of driver assistance systems (like predictive cruise control, green zone indicator, acceleration control, ecorolling, etc.) depend greatly on the specific driving circumstances, but all in all, a reduction of fuel consumption of 2.5% can be expected by 2020. The potential at the level of the individual vehicle is around 5-7%. There could be an interaction between the effectiveness of driver assistance systems and driver training (see 3.5.1)

3.1.4 Package 5: Alternative powertrains

The most common form of alternative powertrain is heavy duty freight transport is hybridisation (start/stop, mild, full) with an electromotor and battery. While the use of hybrid vehicles is currently still limited and may not expand much by 2020 in the long haul and regional delivery cycles, significant gains can be achieved in some applications. However, due to the large discrepancies between survey respondents, it was not possible to make a good assessment of the overall reduction potential.

3.1.5 Package 6: Axles

Reducing axle friction is a simple and inexpensive manner to reduce fuel consumption, albeit only by 0.5%.

3.2 Other vehicle related measures

Outside of chassis construction, other vehicle parts like the body, the trailer and the tyres can be developed by OEMs, but in practice, this is often done by third parties. In these elements of vehicle design, there exists a significant potential to improve fuel efficiency too. This section discusses the main fields where OEMs and/or third parties play a role in determining the vehicle's CO_2 emissions. For each, an indication will be given of the share of responsibility carried by each party.

3.2.1 Package 7: Tyres

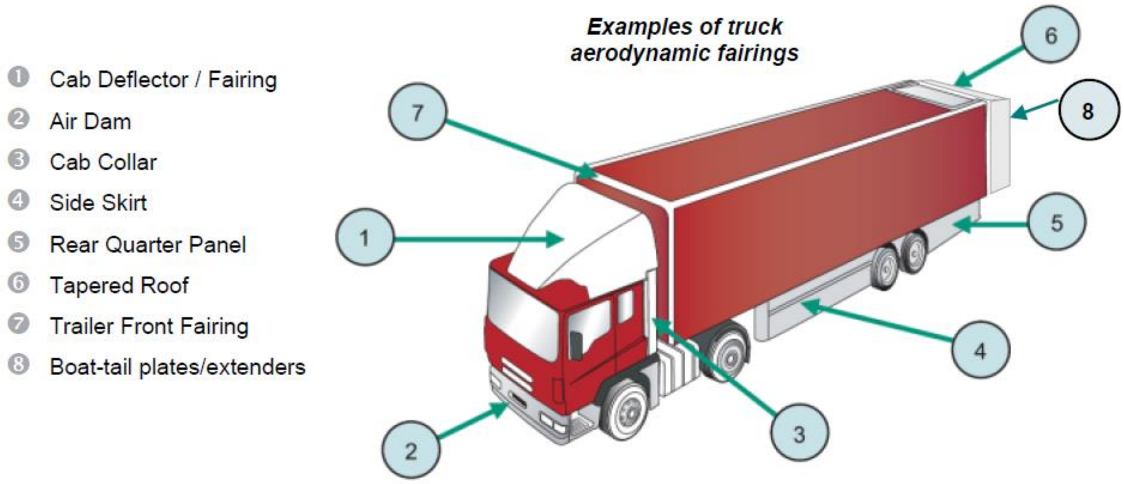
Improvements in tyres could be in the material composition (low rolling resistance tyres, but also in the dimensions (single wide tyres) or tyre pressure monitoring.

The largest improvement on tyres comes from the application of low rolling resistance tyres, which offer significant benefits at little or no extra cost. Wide single tyres could provide further improvements. The total benefit is estimated at 4% for long haul and 3% for regional delivery.

3.2.2 Package 8: Aerodynamics

Equipment to improve aerodynamic properties has been used for a long time, but its applications are limited due to existing EC dimensions regulation not allowing for vehicle extensions that could create great gains in fuel efficiency. The ongoing update procedure of Directive 96/53/EC should remove some of these barriers.

Aerodynamic improvement can be made all over the vehicle, and for their assessment, the full vehicle approach should be used. The cab's nose, top and front can be streamlined, while side panels on the chassis and trailer also have reduction potential. The highest gains can probably be achieved in the design of the trailer, either by adding tail flaps or by completely redesigning the trailer (e.g. in a 'teardrop' shape).



The improvement in aerodynamic properties should reduce fuel consumption of new vehicles by 4% (long haul) or 3% (regional delivery), half of which can be realised by OEMs; the other half is to come from trailer/body builders.

3.2.3 *Package 9: Weight reduction*

The use of lightweight materials in the vehicle not only reduces fuel consumption, it also increases the maximal payload a vehicle can carry (for weight-limited loads), as this is based on gross vehicle weight.

The weight reduction potential can be realised by substituting steel for aluminium alloys, which according to literature could save around 1.1% of fuel for each tonne weight reduction. The total weight reduction potential according to literature is around 2 tonnes for both Long Haul and Regional Delivery, thus generating a benefit of 2.2% in the short to medium term (long term: up to 20%). The survey suggests that a reduction of 600-700 kg is more realistic, spread about evenly between the chassis and the trailer/body. This would reduce consumption by 0.5% (LH) or 0.9% (RD).

3.3 Packages of vehicle related measures

At the full vehicle level, all of the measures above can be combined to form a "most likely" vehicle for given years, taking into account projected penetration rates of the different technologies and any interactions there may be between them. These vehicle level estimates are useful to estimate the progress that is being made by manufacturers to reach a certain emission target, but they do not reveal how much CO_2 is actually saved in a given year. This is determined by the amount of vehicles in the fleet with efficiency-improving technologies on board, and the amount of vkm they drive each year. This paragraph covers both aspects.

3.3.1 *Reduction potential per vehicle*

The last part of the survey asked vehicle manufacturers to compose packages of measures for the entire vehicle. The estimates of reduction potential from the packages per type of measure are shown in Table 2 (OEM measures, covered in section 3.1) and

	Long Haul	Regional delivery
Engine efficiency	5.00%	4.50%
Auxiliaries management	1.50%	1.70%
Transmission	0.50%	0.50%
Alternative powertrains*	N/A	N/A
Axles	0.50%	0.50%
Driver assistance systems	2.50%	2.50%
Total OEM	**-9.67%**	**-9.38%**

**Insufficient data for assessment*

Table 3 (other party measures, discussed in section 3.2) below. The reference year for these reductions is 2014.

Table 2: Vehicle related measures' reduction potential ("most likely" packages, for OEM), for new vehicles

	Long Haul	Regional delivery
Engine efficiency	5.00%	4.50%
Auxiliaries management	1.50%	1.70%
Transmission	0.50%	0.50%
Alternative powertrains*	N/A	N/A
Axles	0.50%	0.50%
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Table 3: Vehicle related measures' reduction potential ("most likely" packages, for other parties), for new vehicles

Tyres	4.00%	3.00%
Aerodynamics: fairings, tails, etc.	4.00%	3.00%
Weight reduction	0.50%	0.90%
Total other	**-8.30%**	**-6.76%**

By 2020, new vehicles and trailers combined are expected to be 15-17% more fuel efficient than they are in 2014. Most of the benefits come from improvements to the engine, the tyres and the aerodynamics of the vehicle, while driver assistance systems will also contribute by guiding vehicle users to a more efficient driving style.

3.3.2 Market penetration and effect on total fleet

As already indicated in section 2.5, the vehicle replacement cycle has an important effect on the reduction potential of technical vehicle measures. About 6.8% of HDV are replaced per year, for a fleet renewal rate of 15 years. This implies that it would also take 15 years for a technology that first enters the market in a given year, to achieve its full market potential throughout the entire fleet. On the other hand, vehicles are driven more and on longer distance routes when they are younger and more reliable, thus "accelerating" the CO_2 benefits created by technological evolutions.

During the 15 year vehicle lifetime, the long haul vehicle drives around 1.5 million vkm (articulated 34-40t TRACCS class), while the regional delivery vehicle accumulates at total mileage close to 780.000 vkm (rigid 14-20t TRACCS class). About half of those are driven in the first six years of operation, as indicated in Figure 5. From consultation with ACEA and its members, we learned that long haul vehicles generally only operate in that cycle during those 6 years, and are then switched to the regional delivery cycle. TRACCS data confirms this.

Note that this does not imply that vehicles do not remain in the fleet after their 15th year of operation. They are however used less, and for operation mainly outside the long haul and regional delivery cycles. There is no notable difference in the (relative) evolution of mileage between both drive cycles.

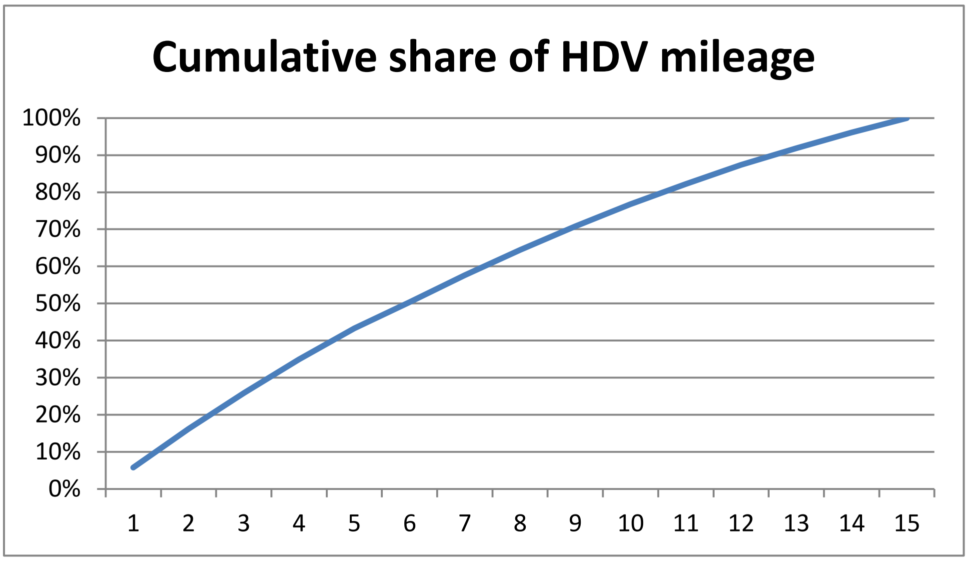

Figure 5: Cumulative evolution of HDV mileage as a % of 15 year total mileage

This is equivalent to the speed of impact of new technologies. In the first year of introduction, only 5.7% of the total fleet mileage is performed by new vehicles that (can) have the technology on board. By the end of the third year after introduction, this goes up to 26%.

If we assume that improvement is gradual overt time, the fuel efficiency of the fleet is expected to improve by around 5% by 2020, if only vehicle technical measures are implemented.

3.4 Alternative fuels

The use of alternative fuels in EU transport as a whole is limited, with great divergence in national policies and practices. In some countries, very high blends of biofuel are the norm due to higher availability of feedstocks or more supporting (private or public) policy, while other countries have highly developed distribution networks for alternative fuels like CNG and LPG – which is very much influenced by consumer demand for passenger vehicles and thus by fiscal policy.

We make the distinction between two types of alternative fuels based on their origin: those from a fossil source, and those from a renewable source (a.k.a. biofuels). The standard fuel for most HDV transport is fossil diesel fuel. Other fossil fuels like CNG and LNG could play a role in reducing HDV CO_2 emissions. In many cases, a fossil fuel also has a biofuel equivalent. They have almost identical tailpipe (tank-to-wheel) emissions - at least for CO_2 -, but the main benefit of biofuels lies in the fuel production process (well-to-tank), if they capture CO_2 that would normally be left in the atmosphere and transform it into a fuel that is ready to be applied in a similar way as their fossil equivalent. Biofuel content of fuel is regulated by Directive 2009/28/EC, and requires that the share of renewable sources in the fuel mix should be at least 10% in every EU country by 2020. No targets are fixed beyond this horizon. It also sets standards for the production process of biofuels to guarantee that the fuel provides net GHG reductions in an overall sustainable manner. The Fuel Quality Directive 2009/30/EC covers this as well. Biofuels considered in this study are FAME, HVO and BTL as replacement for diesel; and biogas (GTL) as replacement for CNG. Battery Electric Vehicles and Hydrogen Fuel Cell vehicles are not considered to be cost-effective CO_2 reduction measures in the selected HDV drive cycles.

In the following sections, we will first cover the adaptations needed at the vehicle level to work with alternative fuels and the costs they entail. Then, we will address the well-to-tank modalities of the different kinds of alternative fuels – arguably one of the measures with the most CO_2 reduction potential for the road transport sector.

This section is based for a large part on the reports of the JEC's reports on biofuel[4], apart from the other main sources presented in section 1.2.

3.4.1 Vehicle

At the vehicle level, using biofuels instead of fossil fuels generally does not require much adaptation, particularly for the new generation of biofuels. Low blends of fossil fuel and biofuel are the current standard. This has evolved from a 0% blend (B0) in 2005, to 5% (B5) in 2010 and 7% (B7) at the present time (2014). First generation biodiesel (FAME) is known to cause problems in conventional diesel engines at higher blending rates (due to deposit formation), but BTL and HVO are essentially synthetic diesel and can be used without restrictions.

The application of CNG (or LNG) in HDV operations does require modifications to the vehicle, whether it is in a single or dual fuel diesel-CNG configuration. The estimated costs of these modifications are in the range of several thousands of euros (wide range of answers from the survey).

3.4.2 Fuel

3.4.2.1 Gaseous fuels

The application of CNG in HDV is widespread, but mainly in specific, local operations, such as urban buses or utility vehicles. An important reason for this is the current lack of refuelling infrastructure along Europe's roads; a single refuelling point in an urban area could suffice, but especially in long distance freight transport, supply is insufficient to allow further penetration of CNG powered engines. Moreover, the amount of space required on the vehicle for CNG tank cuts into storage capacity of the vehicle, which is clearly undesirable. In theory, monofuel CNG or dual fuel engines (CNG/diesel) could provide a 10-15% reduction in CO_2 emissions on a per-vehicle basis. In practice, a market share of 2-3% in Long Haul would already be on the optimistic side, while 5-10% in Regional Delivery could be achievable.

CBG/Biogas as the renewable, fully substitutable equivalent of CNG, faces the same challenge: without a large enough distribution network, its significant CO_2 reduction potential will not be realised. That potential is indeed very large: it ranges from 60% to 200% compared to fossil diesel when considering the entire GHG balance (not just CO_2 but also CH_4 and other GHG gasses),

[4] JEC (2014): WELL-TO-WHEELS Report Version 4.a http://iet.jrc.ec.europa.eu/about-jec/jec-well-wheels-analyses-wtw

depending on the pathway in fuel production; a negative GHG balance would occur when the feedstock is manure, which would normally emit CH_4 into the atmosphere.

LNG/LBG (liquid natural/bio gas) works in much the same way as CNG, but due to its different production method (by cooling instead of compressing) allowing for greater energy storage for the same tank volume, it is deemed to be more interesting for long haul transport. The gain in efficiency is the same for both fuel types though, again with the renewable equivalent generating significant reduction potential.

3.4.2.2 Liquid fuels

Alternative fuels working in conventional engines and able to use the same distribution infrastructure as fossil diesel will be much faster to contribute to the (WTW) reduction in CO_2 emissions, as they would be very easy to distribute. The biofuel that is currently most used is FAME/FAEE (fatty acid methyl/ethyl esters), which in Europe are mainly produced from rape and soy. The fuel produced from these feedstocks can save around 35% of WTW GHG emissions compared to fossil diesel. Achieving a 7% average blend between 2005 and 2014 has thus been responsible for a decrease of CO_2 emissions of 2.5%. Given the issues FAME creates at higher blending rates, this is not expected to increase further. FAME is thought to be economically viable when crude oil price is around $80-100/barrel, which has been the case for a few years now.

Other diesel substitutes then come into play. The first candidate is Hydrogenated Vegetable Oil (HVO), which can use largely the same feedstocks as FAME, but these are then processed through hydrogenation rather than esterification, creating a much purer fuel which can be blended up to 100%. Its WTW GHG reduction potential is in the range of 40-60%. Despite its apparent advantages over FAME, HVO has not yet achieved higher market penetration due to its higher production cost, estimated to be around 20% higher than that of FAME. When commercialised and blended at its maximum potential, this fuel can thus reduce WTW road transport CO_2 emissions by around 50%.

A main concern with both FAME and HVO is the land use (direct and indirect) of their feedstocks. A concern with most first generation biofuels, this has been a main driver of research and development of a new generation of biofuels based on waste products or natural products with little or no other economic value. BTL (Biomass-to-liquid) is one example, able to generate WTW reductions of 60-90%. Due to high production costs, this fuel type has not yet been commercialised. Other potential alternative fuels to come from the survey are DME (Di Methyl Ether) and ED95 (Ethanol 95%).

Future biofuels to be used could come from lignocellulosic biomass, or algae. The research towards making these fuels commercially viable is still very much in its infancy however.

3.4.2.3 Restrictions

The different alternatives for current, principally fossil diesel propelled vehicles each face different restrictions that have so far limited their reach.

For 1st generation biodiesel FAME, this is mainly the modifications needed to the engine before it can be used at higher blending rates. At 7%, it has probably reached its maximum economic potential. The land use issues and resulting limits to production capacity further restrict a wider application.

HVO does not face the problem of maximum blending rate, but with its higher production cost, it needs higher fuel prices (around $120/barrel) before it becomes an economic alternative to fossil diesel. It faces similar land use issues as FAME and could therefore also be considered only a stopgap solution to reduce HDV CO_2 emissions.

New generation biofuels, e.g., BTL, are mainly restricted by their economic viability: oil prices will need to rise substantially (starting from $140/barrel) before the transformation processes for this 2nd generation biofuel have commercial appeal on a large scale.

On a longer timescale, 3rd generation biofuels based on lignocellulosic biomass or on algae have the potential to remove most concerns about land use. Little is known at this moment about the mass production costs of these fuels.

For CNG/CBG/LNG/LBG, the main restriction is the current lack of refuelling infrastructure. Only a few countries currently have a dense enough network of refuelling points, and without government support, this situation is not likely to improve. Their current EU penetration potential is therefore very limited. If we assume this network is extended along the EU's busiest freight routes, a small contribution is possible.

3.4.3 Conclusion on reduction potential

Biofuels are expected to be the main contributor to the realisation of the Renewable Energy Directive targets for 2020.[5] If indeed 10% of all transport fuels (energy based) at that time are from a renewable source, the CO_2 reduction potential is between 4% and 6% versus a scenario with only fossil fuels. Given that around 2.5% of that is already achieved in 2014 (with a 7% blend in current diesel), the additional potential is 1.5-3.5% (average 2.5%).

For gaseous fuels, the time horizon of 2020 is probably too short to achieve a CO_2 reduction, due to the need for an extensive network of refuelling infrastructure.

3.5 Vehicle use

This section deals specifically with how HDVs are operated: driver style, speeds, routes and loads.

3.5.1 Driver training

The EC has created legislation governing the training requirements for professional drivers in directive 2003/59/EC. It covers both the initial formation to obtain the Certificate of Professional Competence (CPC) and the periodic training which has to be repeated every five years.

While the aim of the directive was mainly to improve road safety, the regulation can provide an excellent platform to disseminate the principles of ecodriving to HDV drivers all over Europe, with immediate effects for the entire fleet. Indeed most EU countries have included ecodriving into the curriculum of the mandatory training.

[5] European Expert Group on Future Transport Fuels (2011): Future transport fuels http://ec.europa.eu/transport/themes/urban/cts/doc/2011-01-25-future-transport-fuels-report.pdf

According to McKinnon (2008)[6], savings of up to 10% per vehicle are possible. At the fleet level in the UK, Faber Maunsell (2008)[7] projects a reduction of consumption of 2-8%, with an average of around 5%. Effects are however likely to fall off as time goes by, meaning that regular repetition of the training is recommended. Effects of driver training are also likely to be limited by the use of driver assistance systems, and the combination of both measures is likely lower than the effects of individual applications. When vehicles are equipped with driver assistance systems, effects will be closer to the lower range of 2%.

Driver training is likely to be more effective in situations where a lot of driver action is needed; i.e. in urban areas rather than motorway driving. For the purpose of this study, this means that the effects in the regional delivery drive cycle will probably be higher than in the long haul cycle. The survey results confirm that the 2-8% range is a realistic estimate. 5% is taken as the fleet average, though this may decrease a bit as driver assistance systems become more prevalent.

3.5.2 Increased capacity: longer, heavier vehicles based on EMS

The application of high capacity vehicles (25.25m, 60t and higher) under the flag of EMS (European Modular System) has been a much debated subject in Europe for several years. Directive 96/53/EC is the governing directive, and it is currently being reviewed for an update. Sweden and Finland have used these vehicles for several decades, and other countries (Netherlands, Denmark, Germany) have had successful trials with these longer, heavier vehicles (LHVs).

There could be significant CO_2 benefits for the road freight transport sector from increasing the capacity of Heavy Duty Freight Vehicles along those lines. At the individual vehicle level, TML (2008)[8] concludes that a reduction of CO_2 emissions of 12.45% per tonne-km is possible; other studies like ITF (2010)[9] suggest that a reduction at the individual vehicle level of 11% is achievable.

To gauge the effects on CO_2 emissions of the overall fleet, several assumptions are needed on the penetration rates of LHVs and the effect their reduced operational cost has on demand and modal shift within the different market segments. The assumptions that were made in TML (2008) lead to an overall decrease of CO_2 emissions in the road freight transport sector of 3.8 Mt CO_2 annually, which is just over 1% of the 2010 road freight emissions (2% of long haul emissions). This assumes a penetration rate of EMS of around 8%, a figure that is supported by JRC (2009)[10]. This assumes that EMS are only used on those trips where they provide a benefit, i.e. with high payloads and on suitable parts of the network not passing through urban areas.

Other studies, like JRC (2009)[11], VTI (2008)[12] and TRL (2008)[13], come to varied conclusions on the overall effects of introducing EMS in Europe – mostly based on the expected secondary effects on other transport modes.

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[6] McKinnon, A.C. (2008) 'Advice on CO_2 emissions from the UK Freight Transport Sector' Committee on Climate Change, London.

[7] Faber Maunsell, 2008, Fuel Efficiency Trials Research, conducted for Freight Best Practice, May 2008

[8] TML (2008), Effect of adapting the rules on weights and dimensions of heavy commercial vehicles as established within Directive 96/53/EC

[9] OECD + ITF (2010), Moving Freight with Better Trucks

[10] JRC (2009): Longer and Heavier Vehicles for freight transport

[11] JRC - Introducing Megatrucks: A Review For Policy Makers (2009)

[12] VTI - The Effects of Long and Heavy Trucks on the Transport System (2008)

[13] TRL - Longer and/or Longer and Heavier Goods Vehicles - a Study of the Likely Effects if Permitted in the UK (2008)

Making abstraction of any demand or modal shift effects, if 1/12 of total tkm can be switched from standard HDV to EMS, the potential long haul CO_2 improvement is around 2%. In Sweden and Finland, the European countries with the longest history of EMS application, the tkm share of these vehicles is in the range of 70-90%. This would put the maximal theoretic CO_2 reduction potential at 17-22% for long haul.

For the contribution to the total emission reduction, we assume that a change in legislation will be approved to permit these vehicles in cross border transport, and that their market share will reach 8% by 2020, leading to a 2% reduction in long haul road freight fuel consumption.

Other remarks:

- While LHVs as a logistic concept could well be used in regional delivery transport too, the potential in that market cannot be assessed with currently available information. We therefore set it at 0.
- Other vehicles with increased dimensions are also being considered and tested, e.g. extra-long trailers in Germany and the UK; and even longer road trains up to 32m, 80t in Scandinavia.

3.5.3 Speed management

The current speed limit for HDVs on European motorways, where Long Haul and Regional Delivery vehicles spend a considerable amount of time, is fixed at 90 km/h; though in many countries the limit is set lower, at 80km/h.

Reducing this maximum speed, either by changing legislation or by choice of the vehicle operator, could lead to an important reduction of fuel consumption and CO_2 emissions. Indeed, limiting the speed of a HDV reduces the amount of aerodynamic drag. According to AEA (2010), the effect of lower maximum speeds on fuel consumption will be as shown in Figure 6.

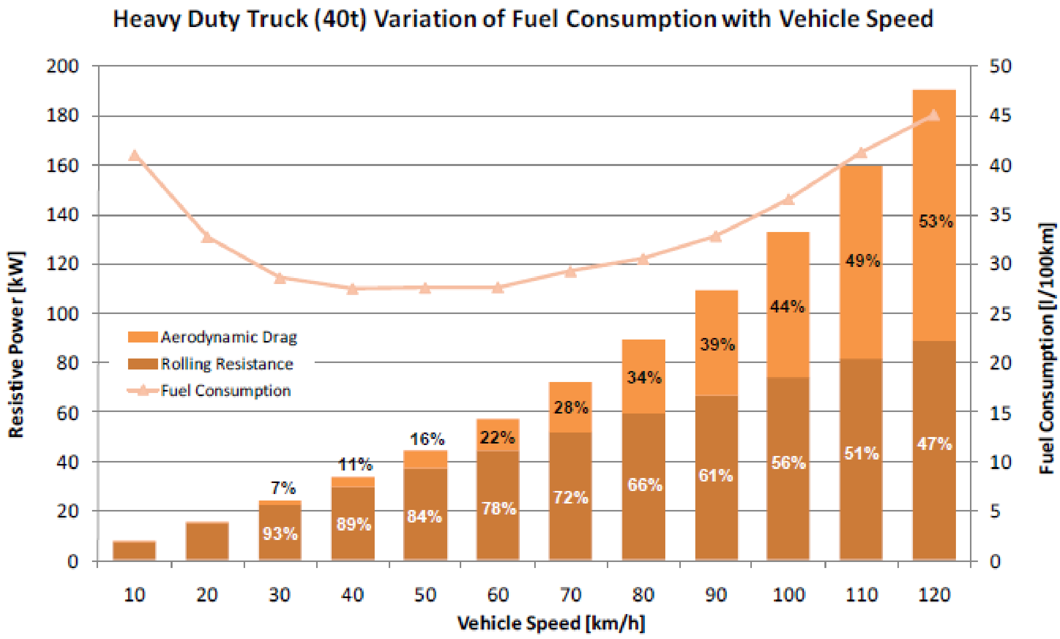

Figure 6: Fuel consumption as a function of vehicle speed

A speed reduction from 90 km/h to 80 or even 70 km/h could thus have significant effects on road freight CO_2 emissions. AEA (2011) quotes several sources, projecting reductions of 5% (TRB (2008)); 1.4% (Skinner et al. (2010)); and 2.6% (Faber Maunsell (2008)). Simulation with VECTO by the survey respondents suggests that these values are realistic, with answers averaging around 4% for 80 km/h long haul.

	Long haul	**Regional delivery**
80 km/h	-3.82%	-5.98%
70 km/h	-8.06%	-13.07%

This potential for improvement comes with a number of strong caveats.

The first is of technical nature. If HDVs are to be driven at lower cruising speeds, the powertrain of the vehicles will need retuning to optimise its power management. Additionally, lower vehicle maximum speeds also imply that measures to reduce aerodynamic drag stand to lose a part of their improvement potential.

Consideration will also need to be given to impact lower speeds will have on traffic flows and on the logistic chain.

While lower speeds may increase safety for HDVs, they also imply larger speed differences with passenger cars; these speed differences are an important reason for traffic accidents in merging and overtaking situations (note that the severity of accidents and the number of injuries and fatalities may in fact decrease)[14]. Average road speeds may also decrease for all road users due to the interaction between HDVs and cars, leading to time losses and economic damage.

[14] See TML (2013): Ex-post evaluation of Directive 92/6/EEC on the installation and use of speed limitation devices for certain categories of motor vehicles in the Community, as amended by Directive 2002/85/EC

As journey times increase, logistic service providers also stand to suffer economic damage. On the one hand, lower fuel consumption leads to lower operational costs, as fuel consumption represents about 30% of a vehicle operator's overall costs. On the other hand, wage and depreciation costs will increase as more drivers and vehicles are needed to transport the same amount of goods. Logistic service levels drop as delivery times increase, and the supply chain as a whole would need to be reviewed. In TML (2006)[15], an assessment was made of the economic impact of lowering maximum HDV speeds in Belgium from 90 to 80 km/h. This measure would increase the cost of road freight transport by more than100 million € per year, equivalent to 3.7%. In a study within the same framework, VITO (2005)[16] estimated the reduction of CO_2 emissions between 5 and 10%.

3.5.4 Load factor & empty running

3.5.4.1 Improving load factor

The logistics industry represents an annual market volume of around €900 billion in the EU27, according to ProgTrans (2008)[17]. It covers the process of planning, organising, controlling and execution of freight transport and warehousing in the supply chain. Achieving maximal efficiency in every step of the process is key to creating added value for society. An important aspect of maximal efficiency for freight transport operations is maximising the load factor of the vehicles that are used.

Load factor is not a straightforward term: it refers to the percentage of the maximum payload that a vehicle has on board during a trip, but payload is often expressed in weight terms. This works for high density goods, but an important part of goods transported by road are low density, and the loading unit of the vehicle may run out of volume before the maximum payload weight is reached. However, the impact of the cargo on fuel consumption of the vehicle is through its weight only – with vehicle dimensions standardised as they are, volume has no impact.

The incentive to maximise the load factor of heavy duty vehicles is very strong: within the requirements for service levels (delivery dates/times), it is in the operators' best interest to have as much payload in their vehicles as possible as long as the revenue is higher than the incremental cost – which is basically the extra fuel cost (and the incentive becomes stronger as fuel prices increase). Still, data from EEA[18] indicates that load factors in road freight have gone down in most European countries between 1997 and 2006, which could imply that service level requirements have become stricter. If this came with a premium paid to transport operators, they may have been happy to sacrifice efficiency for higher profit.

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[15] TML (2006): Doorrekening met behulp van het TREMOVE model van de maatregel '80 km/u voor vrachtwagens'

[16] VITO (2005): 80 km/h maatregel voor vrachtwagens Wetenschappelijke screening van het effect op de uitstoot van CO_2 en schadelijke emissies

[17] ProgTrans (2008): Statistical coverage and economic analysis of the logistics sector in the EU (SEALS) http://ec.europa.eu/transport/themes/strategies/studies/doc/2008_12_logistics.pdf

[18] http://www.eea.europa.eu/data-and-maps/indicators/load-factors-for-freight-transport/load-factors-for-freight-transport-1

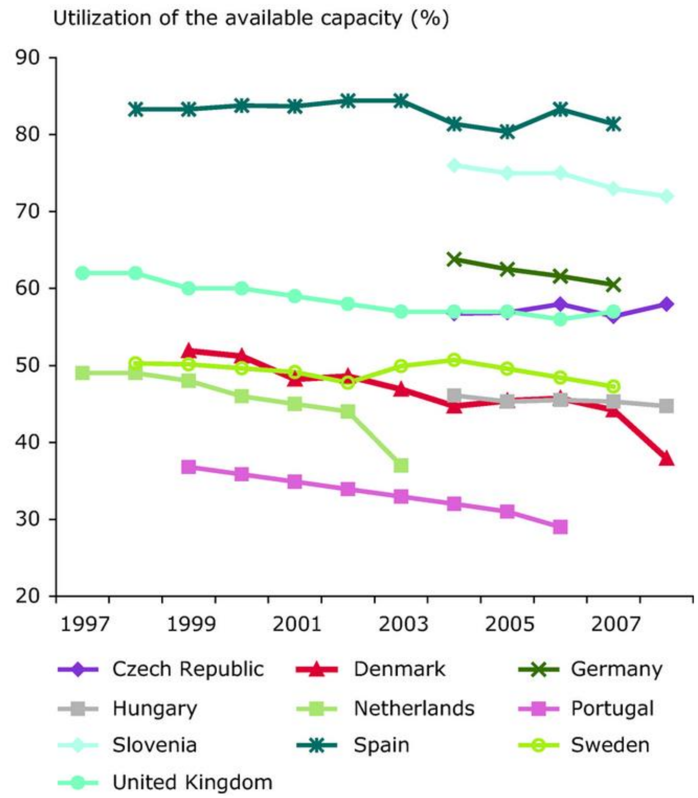

Figure 7: load factor of HDV in different countries[19]

Nonetheless, even in these circumstances the incentive to maximise efficiency is still present. In the improvement of operational conditions lies the key to increase load factors and fuel efficiency per tkm. IT supported logistics platforms are being developed all over Europe, and the European Commission is supporting these initiatives through several funding schemes. The key issue is to come to a harmonised system with as many transport stakeholders as possible getting involved. When that happens, the gains for the economy and the environment could be substantial.

The survey results suggest that the benefits of such an improvement could be major. A 10% increase in load factor in the Long Haul cycle would reduce fuel consumption per tkm by 6.5%. In the Regional Delivery cycle, it could be as high as 10%. Important to note is that the reference Long Haul vehicle has a load factor of 75%, while the Regional Delivery reference is only 50% loaded (weight based); the higher the load factor, the lower the per tkm gain for extra load.

Literature confirms this. Inter alia, Rizet (2012)[20] uses the ARTEMIS methodology to project a drop in fuel consumption at 80km/h from 2.1 to 1.2 l/100tkm for an articulated 34-40t HDV (more or less equivalent to the Long haul vehicle) going from 50% loaded to 100% loaded. For a rigid 14-20t (Regional delivery), the same increase in load factor drops consumption from 4.5 l/100tkm to 2.4 l/100tkm.

This is a measure with a very high potential, because of its important impact on the level of the individual vehicle, and more importantly, its effects cover the entire vehicle fleet. There are many

[19] The EEA site does not provide much insight in the reason for the large differences between countries.

[20] Rizet (2012): Reducing Freight Transport CO2 emissions by increasing load factor. http://ac.els-cdn.com/S1877042812027358/1-s2.0-S1877042812027358-main.pdf?_tid=7b3013d4-c495-11e3-b278-00000aab0f02&acdnat=1397563384_c3e7582bedbf422d73e4ad14823ff151

methods to improve load factor, but they differ depending on the type of goods, the distance class, the type of vehicle, the type of operator, etc. Load factors are also heavily dependent on economic activity. Freight transport volumes decreased up to 10% after the start of the crisis in 2008, and have only recently started to rise again. With such fluctuations that are uncontrollable by the road freight transport industry, the uncertainty about the realisation of this measure is great. It would therefore not be sensible to make assumptions about the projected autonomous improvement in load factor. Other measures, mainly targeting the price of transport, will stimulate logistic efficiency and could improve load factor.

3.5.5 Cabotage and avoiding empty running

The practice of cabotage, i.e. the transport of goods between two points in the same country performed by a vehicle registered in another country, is regulated by Directive 1072/2009/EC. This Directive relaxed the conditions for the operation of cabotage activities, driven by 2 main motives: (1) the creation of a European Single Transport Area; and (2) the reduction of empty running by road freight vehicles, and thereby improving economic efficiency and reducing fuel consumption. One of the important clauses in the Directive is that cabotage operations are more or less freely permitted, but with a maximum of 3 operations in a 7 day period.

The European Parliament's Commission for Transport & Tourism recently (2013)[21] published a study on the application of cabotage in the EU. This study found that empty running represented around 22% of vkm with freight vehicles in 2012, which causes a great amount of avoidable CO_2 emissions. Still, this was a decrease from 2005, when 25% of road freight vkm were empty.[22] Empty running is mostly higher in countries with lower wages, and far less predominant in international than in domestic trips (13% vs 25%).

[21] EP (2013): Development and Implementation of EU road cabotage http://www.europarl.europa.eu/RegData/etudes/etudes/join/2013/495854/IPOL-TRAN_ET(2013)495854_EN.pdf

[22] http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-07-117/EN/KS-SF-07-117-EN.PDF

UNIT: Millions of Vehicle-kilometre

TIME: 2012

GEO \ LOADSTAT	Total loaded and empty	Loaded	Empty
European Union (27 countries)	136,825	107,792	29,034
European Union (25 countries)	132,600	104,115	28,485
European Union (15 countries)	96,390	76,285	20,105
Belgium	1,722	1,722	:
Bulgaria	2,204	1,656	548
Czech Republic	4,788	3,894	895
Denmark	1,691	1,501	190
Germany (until 1990 former territory of the FRG)	29,106	23,024	6,083
Estonia	438	352	86
Ireland	1,307	869	438
Greece	2,142	1,358	784
Spain	16,468	12,332	4,136
France	18,022	13,488	4,534
Croatia	860	603	257
Italy	7,975	7,975	:
Cyprus	137	78	58
Latvia	963	729	234
Lithuania	1,789	1,441	347
Luxembourg	525	489	36
Hungary	2,937	2,316	622
Netherlands	7,645	5,993	1,652
Austria	2,512	1,742	769
Poland	20,480	15,311	5,169
Portugal	2,691	2,174	516
Romania	2,021	2,021	:
Slovenia	1,313	1,063	250
Slovakia	3,365	2,646	719
Finland	2,138	1,578	560
Sweden	2,445	2,040	405
United Kingdom	:	:	:
Norway	2,084	1,557	527
Switzerland	1,918	1,412	505

Cabotage operations could help reduce the amount of empty running, by allowing trips for profit after the initial loaded leg of the journey, to pass the time until a cargo for the return leg can be secured. Due to imbalances in trade flows, empty running cannot be avoided completely, but some decreases should be made possible. In 2011, cabotage operations represented around 1.7% of total tkm in the EU, up from 1.2% in 2006.

Vehicles running empty consume about 30% (Long haul) or 15% (Regional delivery) less than the normally loaded reference vehicles. Should empty running by 2020 be reduced by an additional 3%, as it occurred between 2005 and 2012, about 1.2% of total HDV CO_2 can be saved in those 2 segments - 2.2% when considering only Long Haul and Regional Delivery applications:

- Long haul: 40.9% of HDV CO_2, saves 3% trips at 70% of normal consumption: 40.9*(1-(3%*70%))=40.0%
- Regional delivery: 12.9% of HDV CO_2, saves 3% trips at 85% of normal consumption: 12.9*(1-(3*85%))=12.6%
- Total: 40.9+12.9=53.8; 40+12.6=52.6; 53.8-52.6=1.2%

Cabotage is a useful instrument in achieving this 3% reduction in empty running, but will not suffice on its own to deliver this improvement. It also comes with a few caveats on safety and social dumping. Attributing a quarter of the 2.2% improvement is a rough estimate.

3.6 Road infrastructure management

Road infrastructure managers, often as part of a government institution, are in charge of both the construction and maintenance of roads and the day to day management of traffic flows. Their discretionary power with regard to the reduction of vehicle fuel consumption includes the type of pavement, the road slopes (to some extent), the implementation of advanced traffic management systems and the introduction of distance based road tolls.

3.6.1 Rolling resistance

Rolling resistance occurs at the interaction of the vehicle and the road it drives on. It mainly plays a role at lower speeds, but even at higher speeds, it remains an important aspect (though aerodynamic drag becomes more important in this case). In the vehicle related measures, the rolling resistance of tyres was already assessed, with an estimated improvement potential of up to 5%.

According to Schmidt (2012)[23], a rule of thumb is that a 10% reduction in rolling resistance could generate a fuel saving of about 3%. ICCT (2012)[24] claims however that the effect is more in the range of 1-2%, albeit for passenger cars. The responses to the survey are somewhat in the middle: for the Long haul cycle, a reduction of 2.5% per 10% RR reduction is achievable, while for Regional delivery, it is closer to 1.8%. Schmidt (2012) furthermore finds that the total CO_2 reduction potential for Danish primary roads is around 3.3%, while VTI (2013)[25] estimated that the use of concrete over asphalt could reduce fuel consumption by 5-7% (under specific conditions). Descornet (1990)[26] comes to a maximum difference in fuel consumption between different road types of 9%, which would represent a difference in rolling resistance of 47%.

As a cautious 2020 estimate, we project a reduction potential of 1% for low rolling resistance pavement on top of what can be achieved by low rolling resistance tyres. The great advantage of applying this measure is that improvements in fuel consumption will happen for all road users; they will be the greatest for heavy duty vehicles on heavily used regional roads with lower maximum speeds, but all road users will reap benefits. It is unclear how long it would take for the measure to reach its full potential, as pavement renewal rates tend to vary depending on the material that is used (much higher for asphalt than for concrete).

3.6.2 Reduced inclination

The slope of roads has an impact on engine loads. When it stays below a certain percentage (around 2%), there is little influence on fuel consumption, as the higher consumption during the uphill

[23] Schmidt, Dyre (2012): CO_2 Emission Reduction by Exploitation of Rolling Resistance Modelling of Pavements
[24] ICCT (2012): Influence of rolling resistance on CO_2
[25] VTI (2013): Measurement of fuel consumption on asphalt and concrete pavements north of Uppsala – Measurements with light and heavy goods vehicle
[26] Descornet (1990): Road Surface Influence on Tyre Rolling Resistance

phase are more or less offset by the lower emissions during the descent.[27] At higher gradients, the effect is non-negligible.

The ACEA drive cycles contain gradients up to 7%, but the extremes only occur in very limited quantities (no more than 1% of the total cycle). The survey asked for reduction percentages in cases road inclinations were limited to max 5%, 4%, 3.5% and 3% respectively. For long haul vehicles a small improvement was possible: around 0.2% for a reduction to max 5%, up to 5.5% for a reduction to max 3%. Regional delivery vehicles showed a much lower reduction potential, from just above 0% for a slope of max 5% to 2% at a slope of max 3%. While this measure certainly has some potential in the longer term, the 2020 horizon is probably too short to achieve any significant gains.

Remark: like rolling resistance, this measure will create benefits for the rest of the fleet as well. Even more so than for that measure though, it will take a long time to adapt the slopes of roads, as this would be a much more drastic modification to road infrastructure than just replacing the pavement, which could be a standard maintenance operation. In mountainous areas, it may even be impossible to do. The cost will also be very steep. A way of implementing the measure to some degree at a limited cost could be to push for the inclusion of lower upper limits to standard road inclinations as a best practice for road (re)construction.

3.6.3 Improved flow

Improving the flow of traffic can be done through complicated process that revolves around the matching of the amount of vehicles, their speed and the road capacity at any given time. The goal is to avoid the occurrence of unwanted congestion, which entails both time losses and higher emissions, from driving at lower than optimal speeds, as well as start/stop actions.

Congestion cannot and should not be avoided completely – this would for example require too much expensive road capacity. The impact of congestion is generally lower on the primary network than on the underlying road system, which implies that long haul vehicles see lower than average congestion.

Estimates of the reduction potential for HDV CO_2 emissions are hard to come by. The survey responses as well are inconclusive, showing a wide range of answers. We set the improvement potential from congestion reduction at 2%, which is on the lower end of the range of answers. Road pricing, discussed in the following section is one of the systems that will help reduce congestion, in addition to a number of other effects.

3.6.4 Platooning

At higher driving speeds, aerodynamic drag is the biggest force to overcome. One way to reduce drag is to fit the vehicle with specific aerodynamic equipment, but another major area of improvement lies in changing the driving conditions. A platoon of HDVs, one closely following the other in an organised and preferably centrally coordinated (using IT solutions) manner essentially forming a road train, could reduce drag, and CO_2 emissions, for all vehicles of the platoon. For the

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[27] According to Antonaaci (2008): Influence of road gradient on emission factors, http://www.tfeip-secretariat.org/assets/Transport/Expert-Meetings/TFEIP-Meeting-of-Transport-Expert-Panel-2008-10-11-November-2008-Milan-Italy/20081111Antonacci.pdf

first vehicle, a reduction in fuel consumption of 0.5-1% is possible. The remaining vehicles' fuel efficiency could improve by 3-5%. This is significantly lower than what literature suggests (20-25%).

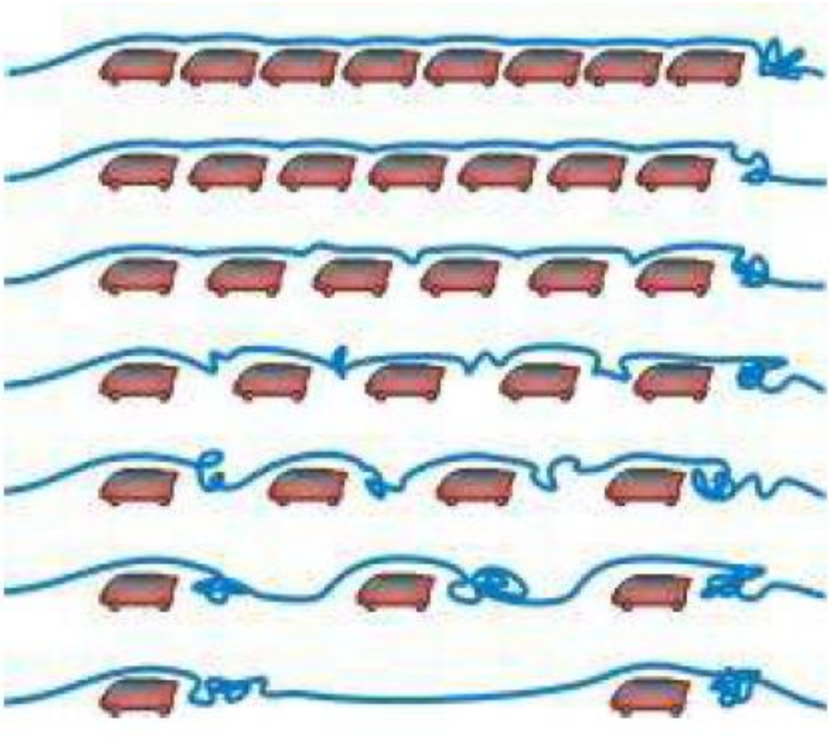

Figure 8: schematic view of the concept of vehicle platooning

This measure can be combined with longer, heavier EMS or EMS+ vehicles to further reduce the amount of space between vehicles. Survey results indicate that reducing the number of vehicles in the platoon by making them longer does not create synergies leading to better fuel efficiency. The main benefits come from using the extra-long vehicles and having them drive in a platoon, but their combination does not seem to generate additional improvement. The gaps that remain between the different loading units of the articulated vehicles are not necessarily smaller than those between two separate vehicles in a well organised platoon.

The contribution of vehicle platooning to HGV CO_2 reduction depends mostly on the uptake. If we assume a penetration of 10% by 2020, long haul CO_2 emissions could be reduced by 0.46%.

3.6.5 Road pricing

The practice of road pricing is regulated by Directive 1999/62/EC. It sets common rules for distance-related tolls and time-based charges for heavy goods vehicles for the use of certain infrastructure, with the aim of internalising some of the external costs caused by this form of transport. CO_2 emissions are of course an important externality of transport, but are not explicitly targeted by this directive; infrastructure (and sometimes congestion) is more commonly cited as the driver for this kind of tolling.

Nonetheless, road user charging helps to promote efficient vehicle use, and thus also leads to reductions in CO_2 emissions. A lot will depend on the tariff setting. According to ECMT (2007)[28],

[28] ECMT (2007): Cutting transport CO_2 emissions

the average CO_2 reduction in the countries that applied it (Switzerland, Germany, Austria) was 2.1% (range 0.2-3.5%). CE Delft (2009)[29] estimates the CO_2 reduction for road freight at 0.4%, for a charge of 3.1 c€/km for 40t HDVs. TML (2009)[30] made projections for Flanders for several rates:

Table 4: effects of road pricing scenarios from TML (2009)

Average rate per km (c€)	CO_2 reduction
2	Close to 0
3.4-14.4	-1.7%
8	-1.95%
10-15.5 (Maut)	-3%
29	-9.23%

Especially the scenario with an average charge of 0.29€/vkm is interesting, as this represents a full internalisation of external costs, and can be seen as the theoretical maximum rate and its reduction of 9.23% as the upper bound to the potential for this measure. Note that this measure will likely interact with some others, such as improved logistics and avoidance of empty running. The assumption is that a 3% total reduction can be achieved, as was projected for the Maut. According to De Jong et al. (2010)[31], about 1/3 of that (1%) would be due to an increase in fuel efficiency.

3.7 CO_2 legislation

At a higher level than road infrastructure managers, governments can create a framework for CO_2 reduction measures aimed at improving the knowledge in the sector and generally providing an all-encompassing market structure in which transport users are held liable for the externalities they cause. Ideally, this would be applied to the entire sector, including all transport modes.

3.7.1 Declaration of fuel efficiency

A declaration of fuel efficiency is currently mandatory in the EU for passenger cars, a sector where a lot of progress has been made in terms of efficiency of newly sold vehicles. However, much of this progress has been theoretical, as the design of the NEDC test cycle has become less and less representative for real world driving conditions. An additional very important contribution to the (theoretically) increased efficiency of passenger cars, is the fact that mandatory efficiency targets have been set for vehicle manufacturers. It is highly likely that the latter aspect is by and far the main driver behind the increased fuel efficiency, rather than the improved quality of information. The concept of consumer myopia, whereby only a small part of the future benefits in fuel costs are taken into account, probably also plays a role.

Aside from the criticism to the method of measurement, a declaration of fuel efficiency is a very useful measure to allow market forces to work, especially in the professional transport market, where consumer myopia should not occur as much, or at all. If the ambiguity about the precise fuel efficiency of vehicles can be removed or reduced, cost-minimising behaviour from vehicle buyers

[29] CE Delft (2009): Effecten van verschillende milieu-differentiaties van de kilometerprijs voor vrachtauto's, bestelauto's en autobussen

[30] TML (2009) Effecten van een kilometerheffing voor vrachtwagens

[31] De Jong et al. (2010): Price sensitivity of European road freight transport – towards a better understanding of existing results. A report for Transport & Environment.

should stimulate competition and improve the innovative potential of the market. The development of the VECTO tool, applied by survey respondents in other parts of this study, is a big step in the standardisation process. A standardisation for the full vehicle, a very complicated process, could be preceded by a labelling at the level of vehicle parts with a great impact on fuel efficiency, e.g. tyres, trailers,…

While it may not have a direct effect on emissions itself, a fuel efficiency declaration should speed up the development of new technologies, both by pulling (looking for the most efficient vehicle) and pushing (more sales for the most efficient technologies mean lower pay-periods for R&D efforts). For example, between 2002, the year when HDV fuel efficiency standards were implemented in Japan, and 2009, HDV fuel efficiency increased by almost 7%. In the 5 year period between 2005 and 2010, European manufacturers improved fuel efficiency by 5.4% for long haul vehicles and 3.4% for regional delivery vehicles, a very similar improvement. The EURO NCAP classification for vehicle safety is a similar kind of information improvement measure that can stimulate the functioning of market forces.

3.7.2 Purchase tax differentiation

Purchase tax differentiation is a government intervention aimed at promoting vehicles with certain properties, while dissuading the choice for vehicles with other, supposedly less desirable properties such as high fuel consumption.

The effectiveness of such measure depends greatly on the specific market conditions: the rate and structure of the tax, the difference in standard purchase price between vehicles that are differently taxed, the projected usage profile of the vehicle. This last aspect will greatly determine the effect of the tax. The higher the value of the differentiation, the more vehicles will be attracted with lower average mileages, and the lower the effect of the policy. Ideally, the tax should be set at the level where the value of the lower CO_2 emissions (the externality targeted by the tax) is just compensated by the tax. Clearly, this also requires high quality information about the fuel consumption of the vehicle and its projected lifetime usage – the risk of over- or undertaxation is significant. Another issue is the lack of coordination of these taxes at a European level. Rates currently vary widely between member states, which is hard to justify is this instrument is to be used as measure to reduce CO_2 emissions.

In general however, purchase tax differentiation on CO_2 emissions is not ideal, and much better and easier methods exist, like excise duties and ETS, covered in the next sections.

3.7.3 Excise duties

Fuel excise duties are a much simpler and effective method to target CO_2 emissions from transport, given the 1-to-1 ratio of fuel consumption and CO_2 emissions. Increasing this tax to reduce carbon emissions effectively comes down to the most accurate form of charging for CO_2 emissions. As such, the effects of an increase in excise duties by a certain percentage are to a great extent comparable to that of a highly differentiated road charge.

For example, an increase in excise duties of 10 c€/l would imply that a long haul vehicle, with an average fuel consumption of 32.5l/100vkm would pay an additional 3.25c€/km. This would lead to a reduction of CO_2 from these types of vehicles by around 1%, based on Table 4. If it is assumed that current excise duties contain no internalisation of external costs of CO_2, a 10c€/l increase for that represents a CO_2 cost of around 38€/tonne, about 7 times current market prices (€5.43/tonne CO_2 on 02/05/2014 according to the Intercontinental Exchange Group)[32].

Another approach to estimating the effect of an increase of excise duties is through price elasticities. According to De Jong et al. (2010), the fuel consumption elasticity with regard to fuel price is between -0.2 and -0.6, with a best guess at -0.3. If we assume diesel price to be €1.3/l, adding €0.1 would mean an increase of 7.7%. The resulting decrease in fuel consumption by the sector would be 2.3%. Part of that would also come from a decrease of tkm by 0.77% (elasticity= -0.1) and of vkm by 1.5% (elasticity= -0.2).

3.7.4 ETS

Market prices for CO_2 are determined in the EU ETS (Emission Trading Scheme) for CO_2. The inclusion of HDV into this scheme in some capacity is a price measure that could be applied to reduce HDV CO_2 emissions.

Several options could be considered for the setup of a scheme, with different liable parties:

- Vehicle manufacturers
- Vehicle users
- Fuel suppliers
- Transport buyers

Only in the case of fuel suppliers would it make sense to apply an ETS scheme. For vehicle manufacturers, there would be too much uncertainty about the actual vehicle use and CO_2 emitted to have a sufficiently clear and effective price signal – much like purchase tax differentiation. For vehicle users and transport buyers, a clear price signal can be given. The problem arising for both options is the number of liable parties – if each of the vehicle users or transport buyers would have to go through the process of registering for, calculating and paying the tax, the burden of the administrative costs could be higher than the value of the tax. The only situation that creates an acceptable compromise between number of tax payers and effective price signal is to make fuel suppliers liable to pay the tax. In this case, the effects would be much like that of an excise duty increase – as the costs would be passed on to fuel buyers, i.e. vehicle users/transport buyers - , with an identical range of projected effects.

[32] https://www.theice.com/emissions.jhtml

4 Conclusion: towards an integrated approach for CO_2 reduction

The review above discussed the CO_2 reduction potential of measures of very different natures. Inevitably, some of these measures will rely on the same underlying processes to realise their potential, and it would not be correct to simply add up the contributions of individual measures. As was done for the creation of packages of technical vehicle measures, in this section we will describe the interaction effects between different types of measures.

4.1 Interactions between measures

Interactions occur at different levels. Whenever two measures act on the same force, e.g. aerodynamics, load factor improvement, etc., their combined effectiveness will be lower than the individual improvement potential of each. For some combinations, it is possible to come to a quantitative estimate of the interaction effect. For others, it depends a lot on the combined implementation of the measures.

- Measures acting on the reduction of aerodynamic drag can be at the vehicle level or at the vehicle use level. As shown in Figure 6, aerodynamic drag represents 39% of the force (and emissions) generated by the engine at 90 km/h, but only 34% at 80 km/h. This means that a speed reduction in that sense would reduce the effectiveness of aerodynamic improvements to the vehicle by 13%.
- Improving load factor is a way to make transport less expensive. This can be sufficient stimulus on its own, but often it is or has to be induced by measures that make transport more expensive, like road pricing or fuel taxation.
- Interactions between measures at the vehicle level only, e.g. different measures to improve engine efficiency, were assessed in the survey by manufacturers using the VECTO tool.

Estimating lower efficiency due to interaction effects requires many assumptions on the exact modalities of implementation. A mixed approach was taken in processing the need for assumptions. The next paragraph discusses these assumptions. Where a clear evolution can be identified, the interaction effect is accounted for in the calculation of the total effect.

4.2 Assessment of total CO_2 reduction potential for heavy duty freight vehicles

The combined effect of all measures is displayed in Table 5 below.

- The figures should be interpreted as the emission reduction of an average vehicle in the fleet of 2020 versus the 2014 reference vehicle. This implies that the improvement versus the 2014 fleet average will be higher than what is shown. The effect of increased demand for road freight transport is not accounted for; between 2015 and 2020, the European Commission expects an increase of road freight demand of almost 6%.
- The effect of road pricing is assessed solely on its potential to improve efficiency. Effects on transport demand, which represent about 2/3 of the total reduction potential of the measures, are omitted from the overview.

- Where interaction effects could be estimated with a sufficient degree of certainty, they are processed as such in the table. This includes interactions within the vehicle level and interactions between driver training and driver assistance systems, but not the interaction between speed reduction and aerodynamics.
- The vehicle level effects are derived from Table 2.
- There was significant disagreement between manufacturers about the uptake level of hybrid technologies. For that reason, their effects could not be reflected in the overview. At the vehicle level, full hybrids could reduce emissions by 7 to 10%.
- Half of the aerodynamic measures are assigned to OEMs and half to "other parties" in the overview below. They are also the main reason of the difference between Long Haul and Regional Delivery, due to the higher speeds in the former cycle.
- Tyres, aerodynamic trailers and half of weight reduction are the other elements that make up the contribution of "other parties".

Table 5: overview of HGV CO_2 reduction potential by 2020 via an integrated approach (reference year= 2014)

		Long haul	*Regional delivery*
Vehicle	OEM	-2.75%	-2.68%
	Other	-2.36%	-1.93%
Vehicle Total		**-5.05%**	**-4.56%**
Alternative fuels	Gaseous fuels	0.00%	0.00%
	Biofuel	-2.50%	-2.50%
Alternative fuels total		**-2.50%**	**-2.50%**
Vehicle operation	Driver training*	-5%	-5%
	EMS	-2.00%	0%
	Speed management*	-3.82%	-5.98%
	Improve load factors	No reliable estimates found	
	Cabotage	-0.55%	0%
Vehicle operation total		**-10.95%**	**-10.68%**
Road infrastructure management	Rolling resistance pavement	-1%	-1%
	Reduced inclination	0.00%	0%
	Improved flow	-2%	-2%
	Platooning	-0.46%	0%
	Road pricing (HDV only)*	-1%	-1%
Infrastructure total		**-4.39%**	**-4.00%**
CO_2 legislation		Can strengthen market forces but does not create gains itself. Best option = fuel tax.	
Integrated effects		**-21.18%**	**-20.22%**

*: see comments above

4.3 Identification of high-priority measures

The measures described in the present study vary greatly in their pathway to CO_2 reduction, technological maturity and maximum technical reduction potential. In some cases, significant quick wins can be made, while other measures would take large efforts and investments with little potential.

Quick wins:

- One of the most prominent candidates for a quick win is driver training. At a minimal cost, the potential reduction is as high as 5%.
- Low rolling resistance tyres can be retrofitted to any vehicle at little to no extra cost and provide fuel efficiency improvements of up to 5%.

High potential at a cost

- The development of more efficient engines is not cheap, but the potential is still significant.
- Aerodynamic modifications to the cab and trailer can combine for the highest reduction at the vehicle level, but their full potential can only be realised with amendments to legislation on vehicle dimensions. Some of the changes can be retrofitted (like tails), but others with great potential will be part of the vehicle replacement cycle.
- The highest technical potential of any measure lies in the use of renewable energy sources (90-100%). However, it is unlikely that much of it will be realised by 2020. The great uncertainty with regard to the evolution of technology, the land available for feedstocks and crude oil prices should not be overlooked.

Small contributions

- Transmission improvements are not likely to provide much more improvement. Intelligent driving strategies built into vehicles are the natural next step.
- Electrification of auxiliaries can each provide small improvements, but are relatively expensive.
- Weight reduction is not expected to go beyond 1 tonne, and the material substitution is expected to be costly.
- Road charging as a measure to reduce fuel consumption adds little value. A fuel tax, direct or in the form of ETS, is a more direct manner of internalising the external cost of CO_2. The effects of such an internalisation depend greatly on the value attributed to a tonne of CO_2.
- Cabotage can help reduce empty running, but cannot eliminate it. Furthermore, empty running already occurs far less in international transport than on average.

Difficult measures

- Some of the measures require changes to legislation before their effects can materialise. These include vehicle aerodynamics, EMS and vehicle platooning. Their potential is large, but so is the uncertainty.
- Lower maximum speeds may be an effective manner to reduce fuel consumption, but they are disruptive to logistic processes, could affect road security and the costs may outweigh the benefits.
- Through road construction with lower slopes and pavement renewal reducing rolling resistance, some gains in fuel efficiency can be made. Particularly for road inclination, the cost is probably excessive. The effects go beyond the road freight transport sector though, as other road users will also benefit from this.

Useful, but in other drive cycles mainly

- Hybridisation can provide benefits in the Long Haul and Regional Delivery cycles, but this measure is far more effective in drive cycles with a larger share suitable for electric driving.

- Shifting to gaseous fuels decreases dependency on crude oil, but still requires the construction of a refuelling network throughout Europe. In more local transport, a single refuelling point can supply an entire fleet.
- Congestion mainly affects freight vehicles in urban environments, Measures to improve traffic flow will have a small impact on the Long Haul and Regional Delivery cycles, but other road users will also gain from it.

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