

An integrated approach to road freight transport CO₂ reduction in Europe

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Abstract

We review and verify studies investigating CO₂ emissions reduction potential of road freight vehicles 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, with the support of ACEA. The aim of this study is to consolidate the collective knowledge of manufacturers and frame it in the context of an integrated approach to reduce CO₂ 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.

Abstract (French)

Nous examinons et vérifions les études portant sur le potentiel de réduction des émissions de CO₂ des véhicules de transport routier à travers une étude comparative de la littérature et une enquête avec les 6 plus grands fabricants européens de poids lourds: DAF, Daimler, IVECO, MAN, Scania et Volvo, avec le soutien de l'ACEA. Le but de cette étude est de consolider la connaissance collective des fabricants et l'encadrer dans une approche intégrée pour réduire les émissions de CO₂ du secteur du fret routier, en combinant les modifications de véhicules de nature technique avec les mesures à prendre par d'autres acteurs, comme les fabricants de pneus, les producteurs de carburants, les fournisseurs de services de transport, les gestionnaires de l'infrastructure routière et les législateurs.

Keywords: road freight vehicles, CO₂ emissions, emission reduction technologies, integrated analysis

1. Preamble

Several studies have been published over the past years on the topic of CO₂ 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.

Data on individual, technical and/or non-technical measures only provide so much insight. The combination of technical measures at vehicle level, way of use and policy driven measures, taking into account the “stackability” of reduction measures, give true understanding in the sector’s emission reduction potential.

We review, verify and summarize the information in these studies through a comparative literature study and a survey with the 6 largest European manufacturers of heavy goods vehicles (HGV). We combine the different types of emission reduction measures and consider the fleet turn-over dynamics to provide policy makers a comprehensive picture of the emission reduction potential of heavy duty vehicles in 2020. The focus lies on two specific operational profiles or “drive cycles”:

- The long haul cycle, which represents around 37% of Europe’s HDV CO₂ emissions, is a cycle covering 80-90% motorway driving at high speeds. Trips are at least 100km distance. The typical vehicle used in this cycle is a tractor-semitrailer combination on five axles, with a gross vehicle weight of at least 40 tonnes and a load factor of at least 70%;
- The regional delivery cycle, emitting 14% of CO₂, is a cycle of typically 20-50km distance, about half of which at motorway speeds. The reference vehicle for this cycle is an 18T rigid truck with a load factor of approximately 50%.

2. Approach

2.1 Literature review and stakeholder consultation

The main recent publications on CO₂ abatement technologies and policies were collected and reviewed, including AEA (2011), TIAX (2011) and TML (2010). These documents contained both general and specific information about various CO₂ emission reduction measures for heavy duty vehicles. Additionally we consulted sources with a focus on just one or a few types of measures. The results of the literature review are presented in the paragraphs on the respective technologies and policy measures.

The results of the literature review were later validated through a stakeholder consultation phase, which involved representatives of e.g. fuel producers, road infrastructure managers, transport operators, tyre manufacturers, road builders, etc.

2.2 Survey

The survey was set up to anonymously ask manufacturers of Heavy Goods Vehicles (HGV) 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 behavior over road management to government policy.
4. Effects of combinations of vehicle measures as a full vehicle package, a combination of all measures 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.

2.3 Definition of reference vehicles & fleet considerations

The reference vehicles mentioned in the survey are typical vehicles sold in the given years. They do not represent the average freight vehicle on European roads in those years. Indeed, the technical measures related to vehicle design apply only to newly sold vehicles, and their uptake – and thus their effect on overall CO₂ 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 database), split as follows:

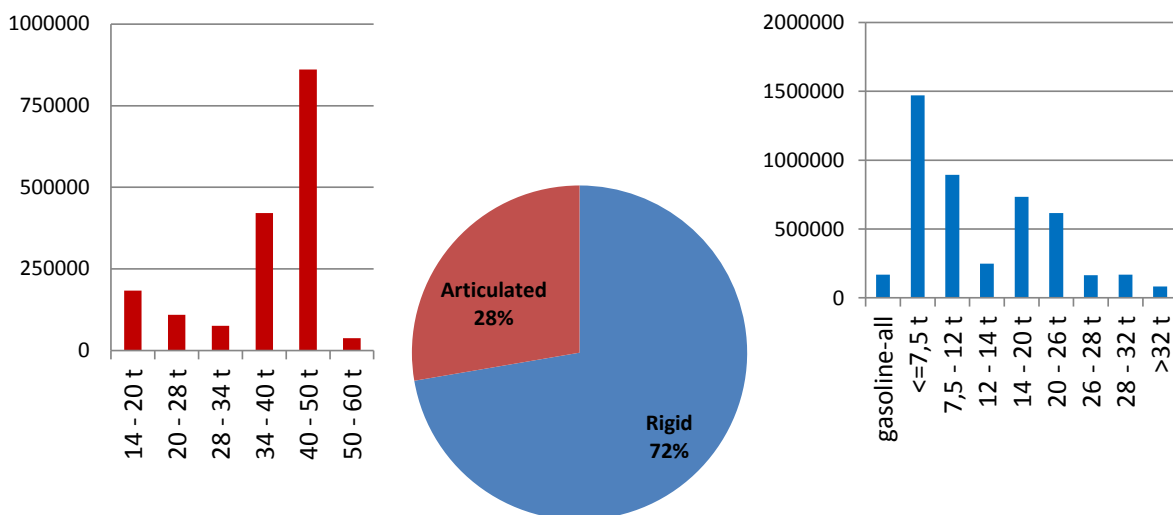


figure 1 EU heavy duty vehicle fleet composition by sub-type in 2010

Total EU sales of heavy and medium freight vehicles (>3.5t GCW) in 2013 amounted to 304,333 (source: ACEA statistics – excluding Bulgaria and Malta). 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 single 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.

3. Emission reduction measures

This section 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 data collected from the HGV manufacturers in the survey.

3.1 Background

Vehicle related measures were split into a number of packages, composed of individual measures of a similar nature. These packages account for the reduction potential of individual technologies, their “stackability” and their projected market share (a technology with a 10% reduction potential and a projected market share of 50% would have a 5% overall potential).

For each of the reference vehicles, a 2014 baseline fuel consumption value was determined using the EC’s new HDV CO₂ calculation tool VECTO. For the long haul cycle, the 2014 fuel consumption was at 32.5 l/100 vkm (1.69 l/100 tkm). For the regional delivery cycle, the baseline value is 22.7 l/100 vkm (5.16 l/100 tkm).

To properly identify responsibilities of market players, a further split was made between pure OEM measures and measures with at least a shared responsibility (e.g. on weight reduction and aerodynamics, trailer manufacturers also have an important role to play).

3.2 OEM-related vehicle measures

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.

Package 1: Conventional engine efficiency

Conventional diesel technology is likely to remain the dominant propulsion type in HGVs 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 reduction 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%.

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.

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 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.

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, and no value was attributed to this measure.

Package 6: Axles

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

3.3 Other vehicle measures

Outside of chassis construction, other vehicle parts like the body, the trailer and the tyres also impact fuel consumption but are manufactured 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 CO₂ emissions. For each, an indication will be given of the share of responsibility carried by each party.

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 cost. Wide single tyres could provide further improvements. The total benefit is estimated at **4%** for long haul and **3%** for regional delivery. These figures are based on the assumption of an 80%-100% market penetration of a mixture of class A and B tyres by 2020 on all new vehicles, which would be sensible from an economic point of view.

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 recent update of Directive

96/53/EC has removed some of these barriers, including derogations for the front of the cabin and the use of trailer tails.

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

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 realized by substituting steel for aluminum 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).

3.4 Summary of vehicle measures

The estimates of reduction potential from the packages per type of measure are shown in Table below. The reference year for these reductions is 2014.

Table 1 Vehicle related measures' reduction potential for new vehicles (top: OEM – bottom: other parties)

	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%
<i>Total OEM</i>	-9.67%	-9.38%
Tyres	4.00%	3.00%
Aerodynamics: fairings, tails, etc.	4.00%	3.00%
Weight reduction	0.50%	0.90%
<i>Total others</i>	-8.30%	-6.76%

By 2020, new vehicles and trailers will have the potential to be **15-17%** more fuel efficient than they were 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.

3.5 Reduction potential at fleet level, including non-vehicle tech measures

To estimate effects on the total fleet, vehicle replacement cycles and usage (annual and lifetime mileage) were taken into account to transform the values for new vehicles to the fleet

average values. Comparisons are possible between vehicle measures and actions taken by other parties to come to the integrated approach.

In this paper, we limit ourselves to a summary of the emission reduction potential of the relevant non-vehicle related measures. More details can be found in the full report.

Fuels

Biofuels are expected to be the main contributor to the realization of the Renewable Energy Directive and Fuel Quality Directive targets for 2020. If indeed 10% of all transport fuels (energy based) at that time are from a renewable source, and GHG reduction reaches the 6% FQD target, a significant improvement is achieved in comparison to a scenario with only fossil fuels. The targets will be challenging to meet (RED: 8.7% and FQD: 4.3% are projected). It is acknowledged that most of the remaining short term contributions to achieving these targets lie in the alternatives for gasolines rather than diesel. Based on these projections and the assessment of the fuel industry, the additional GHG reduction potential will be around **0.5%**. However, using a different, more theoretical calculation method, the improvement could also be estimated somewhat higher: a 2014 blend of 6% with a 35% GHG reduction should evolve to a 7% blend with a 50% reduction by 2020, which represents a CO₂ reduction of **1.4%**.

For gaseous fuels, the time horizon of 2020 is probably too short to achieve a significant CO₂ reduction, due to the need for an extensive network of refueling infrastructure and the low market shares of gas vehicles.

Driver training

According to McKinnon (2008), savings of up to 10% per vehicle are possible. At the fleet level in the UK, Faber Maunsell (2008) 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. The ECOeffect project did real world testing in a limited capacity, and found that immediate reductions of up to 20% were possible, dropping off to 7-10% later. In the GHG-TransPoRD study, the potential of ecodriving training for all of road transport is estimated at 10%. The same number is found by the Ricardo study for the UK. 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. From all of the consulted sources, a reduction potential of **7%** seems reasonable for the Regional Delivery cycle. For Long Haul, we estimate it at **6%**. The difference with the most common estimate of 10% is that we assume interaction effects with driver assistance systems built into the vehicle, which inevitably affect some of the same driving behavior driver training tries to improve.

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 was updated in 2015. 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 CO₂ 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) concludes that a reduction of CO₂ emissions of 12.45% per tonne-km is possible; other studies like ITF (2010) suggest that a reduction at the individual vehicle level of 11% is achievable.

For the contribution to the total emission reduction, we assume that these vehicles will be permitted to circulate freely on the main road network in cross border transport, and that their market share could reach 8% (of tonnes transported) by 2020, leading to a **2%** reduction in long haul road freight fuel consumption.

Speed reduction

A speed reduction from 90 km/h to 80 or even 70 km/h could have significant effects on road freight CO₂ 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.

Cabotage and reducing empty running

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 CO₂ can be saved in those 2 segments - 2.2% when considering only Long Haul and Regional Delivery applications:

- Long haul: 40.9% of HDV CO₂, saves 3% trips at 70% of normal consumption: $40.9 \cdot (1 - (3\% \cdot 70\%)) = 40.0\%$
- Regional delivery: 12.9% of HDV CO₂, saves 3% trips at 85% of normal consumption: $12.9 \cdot (1 - (3\% \cdot 85\%)) = 12.6\%$
- 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 an estimated 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, i.e. **0.55%** is a rough estimate.

Road infrastructure: rolling resistance

Rolling resistance occurs at the interaction of the vehicle and the road it drives on. At lower speeds, overcoming it is what most of the engine's power is used for, but even at higher speeds it remains an important aspect (though aerodynamic drag becomes more important). In the vehicle related measures, the rolling resistance of tyres was already assessed, with an estimated improvement potential of up to 4%.

According to Schmidt (2012), a rule of thumb is that a 10% reduction in rolling resistance could generate a fuel saving of about 3%. The responses to the survey are somewhat lower: 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 CO₂ reduction potential for Danish primary roads is around 3.3%, while VTI (2013) estimated that the use of concrete over asphalt could reduce fuel consumption by 5-7% (under specific conditions). With that, it should be noted that the material used for the pavement is not necessarily the determining factor; texture and roughness of the surface contribute more to the rolling resistance than the stiffness of the material. Descornet (1990) comes to a maximum difference in fuel consumption between different road types of 9%, which would represent a difference in rolling resistance of 47%.

Improved flow

Improving the flow of traffic can be done through a centrally managed system 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.

Estimates of the reduction potential for HDV CO₂ 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.

Road Pricing

Road user charging helps to promote efficient vehicle use, and thus also leads to reductions in CO₂ emissions. A lot depends on the tariff setting. According to ECMT (2007), the average CO₂ reduction in the countries that applied it (Switzerland, Germany, Austria) was 2.1% (range 0.2-3.5%). CE Delft (2009) estimates the CO₂ reduction for road freight at 0.4%, for a charge of 3.1 c€/km for 40t HGVs. In general, rates are a multiple of that (e.g. 12.8 c€/km in Belgium). 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 (2010), about 1/3 of that (**1%**) would be due to an increase in fuel efficiency.

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 is changing the driving conditions. A platoon of HGVs, one closely following the other in an organized and preferably centrally coordinated (using IT solutions) manner essentially forming a road train, could reduce drag, and CO₂ emissions, for all vehicles of the platoon. For the 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%).

The contribution of vehicle platooning to HGV CO₂ reduction depends mostly on the uptake. If we assume a penetration of 10% (of tonkm) by 2020, long haul CO₂ emissions could be reduced by **0.46%**.

3.6 Interaction between measures

The review above discussed the CO₂ reduction potential of measures of very different natures. Inevitably, some of these measures will rely on the same underlying processes to realize their potential, and it would not be correct to simply add up the contributions of individual 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 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. 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 conclusions in the next section include these assumptions. Where a clear evolution can be identified, the interaction is taken into account in the calculation of the total effect.

4. Conclusions

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

- The figures should be interpreted as the emission reduction that occurs when vehicles improve as described above versus a situation where they do not improve after 2014. This implies that the improvement compared to 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%. 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.
- 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%.
- The -0.5% contribution for biofuels reflects the assessment of the fuels industry; a theoretical calculation based on FQD target values gives a 1.4% reduction.
- 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 weight reduction of trailers are the other elements that make up the contribution of “other parties”.

Table 2 overview of HGV CO₂ reduction potential by 2020 (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%
	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 realize 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) CO₂ emissions – if at all.
- Driver training, low rolling resistance tyres and aerodynamic improvements provide the best cost-effectiveness of all measures.

5. Acknowledgements

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