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Report on VECTO Technology Simulation Capabilities and Future Outlook

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Abstract

The European Commission is developing the Vehicle Energy Consumption Calculation Tool (VECTO) for Heavy Duty Vehicle CO_2 certification purposes. VECTO is a vehicle simulation tool tailored to estimate CO_2 emissions from heavy-duty vehicles of different categories, sizes and technologies. Further development and optimization of VECTO and the CO_2 certification methodology requires assessing their capacity to properly simulate specific vehicle technologies and gathering additional feedback on the possibility to capture future technologies which are expected to be deployed on heavy-duty vehicles in the years to come. In order to investigate the VECTO capabilities and performance a dedicated questionnaire was formulated and distributed to various stakeholders. The technologies under investigation were previously identified through a literature review. The feedback received clearly pointed out the technologies that can be properly simulated by VECTO, which constituted an important part of the initial technology list, pointing out that VECTO and the accompanying certification methodology have reached a good level of maturity. The responses provided also some initial feedback on the implementation approach for the technologies which are not properly captured at the moment. The latter were separated into three groups based on the type of work that is required for including them in the certification methodology which could relate either to the development of the VECTO software or further expansion-specialization of CO_2 certification methodology or a combination of the two. The current report presents the findings of the survey and outlines possible future steps for the further development of VECTO software and the accompanying certification methodology.

Executive Summary

The European Commission is developing the Vehicle Energy Consumption Calculation Tool (VECTO) for Heavy Duty Vehicle CO_2 certification purposes. VECTO is a vehicle simulation tool tailored to calculate CO_2 emissions from heavy-duty vehicles of different categories, sizes and technologies. Further development and optimization of the tool requires assessing its capacity to properly simulate specific technologies and gathering additional feedback on the possibility to capture future technologies which are expected to be deployed on heavy-duty vehicles in the years to come. In order to investigate the VECTO capabilities and performance regarding certain technologies a dedicated questionnaire was formulated and distributed to various stakeholders. The technologies under investigation were previously identified through a literature review. The current report presents the findings of this survey based on the respondents' feedback, the results of the literature review and outlines possible future steps for the further development of VECTO software and the accompanying CO_2 certification methodology.

The questionnaire focused on VECTO's capacity to properly capture the effect of each technology on CO_2 emissions, the current and future expected market penetration of each technology and additional comments on the potential improvement of the tool. The response rate was lower than expected, with 10 respondents completing the complete survey and another 8 partially completing it. Respondents' affiliations included research organizations, original equipment manufacturers (OEMs) and their associations. Vehicle manufacturers decided to respond also collectively through the European Automobile Manufacturer's Association (ACEA) the view of which is presented separately in the report.

The feedback received mostly focused on qualitative data with only limited answers providing quantitative data on the effect of each technology on CO_2 emissions and market penetration. However, the feedback received clearly pointed out the technologies that can be properly simulated by VECTO and provided information on the implementation approach for the ones that are not properly captured.

An important finding was that a large part of the technologies under investigation were already sufficiently captured by VECTO tool and the certification methodology. The remaining not covered or partially covered technologies were separated into three groups based on the type of work that is required for including them in the certification.

- Technologies which can already be covered and require work mostly on the certification methodology and minimal or limited interventions in VECTO software (short term interventions). Those could include: Improved alternator, Wide-base single tires, Tire pressure monitoring-automatic inflation systems, improved oil pumps and speed limiter.
- Technologies which require additional work to be done both at methodological level and software level (in some cases substantial) prior to implementation (mid-term interventions). Those could include: Predictive Cruise Control (PCC) – Advanced Driver Assist Systems (ADAS), Waste heat recovery, Electric hybrids, Electric turbocharger, A/C efficiency and refrigerant, Active flow systems, Trailer aerodynamic improvements, Dual Clutch Transmission and Neutral idle:
- Technologies for which no action is advised but should be reassessed in the mid-term future if more data become available. Those could include: Improved Cooling fan, Improved Air compressor, Vehicle body redesign, Adjustable fifth wheel, Continuous Variable Transmission, Hydraulic hybrids and ECU/Engine software optimization.

A detailed summary of the coverage of each technology and the proposed action can be found in Table 3 of the report (see Annex).

1 Introduction

The Vehicle Energy Consumption Calculation Tool (VECTO) is a simulation tool that is being developed by the European Commission (EC) in order to calculate CO_2 emissions from heavy–duty vehicles (HDV) and it is expected to be the backbone of the future European fuel consumption and CO_2 emissions certification procedure for HDVs in Europe. So far VECTO and the accompanying certification methodology have reach an established level of maturity with test results demonstrating their capacity to realistically capture the CO_2 emissions and fuel consumption of HDVs. Further development of VECTO requires assessing if certain established and fuel consumption relevant technologies are not being sufficiently simulated and whether new technologies that are expected to appear in the years to come should be implemented.

A list of potentially important technologies for the near future was compiled following a short literature review on the topic. Subsequently a questionnaire was formulated and circulated to various stakeholders requesting feedback on:

- the effect of each of the technologies on CO_2 emissions of different HDV vehicle types and over different operating conditions
- the level of market penetration of each technology now and in the future (5-10 years horizon)
- additional comments and feedback on the performance of VECTO with regards to the particular technology

The JRC distributed the questionnaire to seek expert opinion by addressing stakeholders such as OEMs, suppliers, relevant research organizations and European Automobile Manufacturers' Association (ACEA). Vehicle manufacturers decided to respond officially and collectively through ACEA the view of which is presented separately in the report. However certain experts affiliated to vehicle OEMs have also responded individually.

The current report presents the survey results and proposes possible actions for their implementation in future VECTO versions or future updates of the CO_2 certification methodology.

2 Identification of relevant technologies

A brief literature review was performed for identifying which technologies are likely to be introduced in the HDV market in the years to come for increasing the fuel efficiency of HDVs. The technologies considered in the study, their definition and their description are summarized in Table 1.

Table 1: List of technologies by category.

Engine	Aerodynamics	Tires	Axles and transmission
Turbochargers Intake/exhaust Waste heat recovery Internal friction reduction Engine efficiency Engine downspeeding Lubricant Engine Control Unit (ECU) optimization Cooling fan Alternator Water pumps Oil pumps	External grilles Active flow systems Mirror replacement Tractor cabin and trailer fairings Boat tails Vortex generators Adjustable fifth wheel Vehicle redesign	Wide base single tires Low rolling resistance tires Tire pressure monitor systems Automatic tire inflation systems	Automated Manual Transmission (AMT) Continuously Variable Transmission (CVT) Dual Clutch Transmission (DCT) Additional gear ratios Axle efficiency Lubricants
Hybrids	**Mass**	**Idling**	**Components and auxiliaries**
Hydraulic hybrids Full/mild electric hybrids Flywheel	Mass reduction	Stop-start systems Auxiliary power units Neutral idle	Electric hydraulic power steering LED lighting Air compressor A/C efficiency and refrigerant Reflective paint and glazing Predictive cruise control Advanced Driver Assistance Systems

A detailed account of the results of the literature review can be found in Table 2 (Annex). The number of sources found regarding the European market and the European HDV fleet was relatively limited. Many estimates were based on studies made for US vehicles and fleets and on information provided by the US Environmental Protection Agency (EPA) (EPA and Department of Transport 2015). Both the US market and fleet are distinctively different from the European ones. For this reason the results were collected and presented separately based on the origin of the study (US or Europe).

The feedback received from the questionnaire regarding the impact of each technology on fuel consumption/CO_2 confirmed, in most cases, the estimates which were found in the literature, particularly the ones focusing on European vehicles.

3 Questionnaire structure

The questionnaire was built on an online platform and stakeholders were invited by the JRC to provide their feedback. The questions were separated into categories to facilitate the respondents, who were initially prompted to select the ones corresponding to the field of their expertise. After this step, only questions under the selected categories were presented to the respondents.

The first question for each technology was whether the respondents considered that the effect of the technology was sufficiently captured by VECTO or not. In case they answered positively, no further questions appeared for this technology and the survey continued to the next technology. If the respondent answered negatively or "I don't know/I am not sure" then they were asked to provide some information about this technology based on their best knowledge. These questions involved fuel consumption reduction, current and future market penetration for the following heavy–duty vehicle classes:

- Rigid trucks
- Tractor – trailers
- Coaches
- City buses

The respondents were able to add their own comments if they wished on each question regardless of whether they considered the effect of the technology to be sufficiently captured or not. Finally, at the end of the survey they were allowed to add any additional general comments they sought suitable.

It is acknowledged that the provided answers reflect the opinions of individual experts and are not official positions of their respective affiliations.

4 Responses overview

The responses were collected during the period 23/3/2016 – 10/6/2016 and 10 respondents completed the survey, while an additional 8 respondents provided some feedback but have quitted the survey before answering all the questions in their respective categories.

The ACEA has replied to the questionnaire separately by providing a comprehensive overview of the inquired subjects. Due to the significance of the provided information, the ACEA response is examined and presented separately from the other respondents.

The retrieved information provided mostly qualitative data focusing on VECTO capabilities and little quantitative data that could be used for a statistical analysis. The number of respondents by category and also by respondent affiliation is presented in Figure 1.

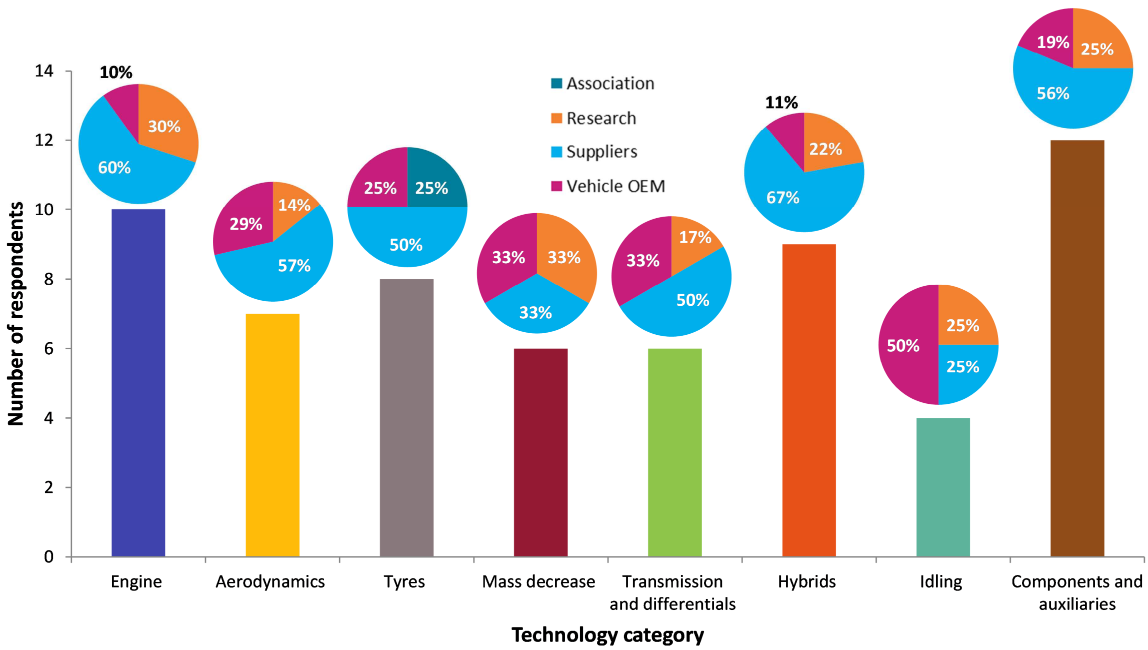

Figure 1: Number of respondents by technology category and breakdown by respondent affiliation

5 Results and Discussion

5.1 Simulated technologies overview

The analysis of the online survey results about VECTO capabilities investigated each technology individually. An initial approach separated the technologies into three categories, depending on the composition of the answers:

- **Simulated:** All respondents replied that the effect of the technology is sufficiently captured.
- **Not simulated:** All respondents replied that the effect of the technology is not sufficiently captured.
- **Contradicted:** Some respondents replied that the effect of the technology was sufficiently captured, while some others replied that it is not.

The "I don't know/I am not sure" answers were not taken into consideration at this stage. An overview of the results is presented in Figure 2.

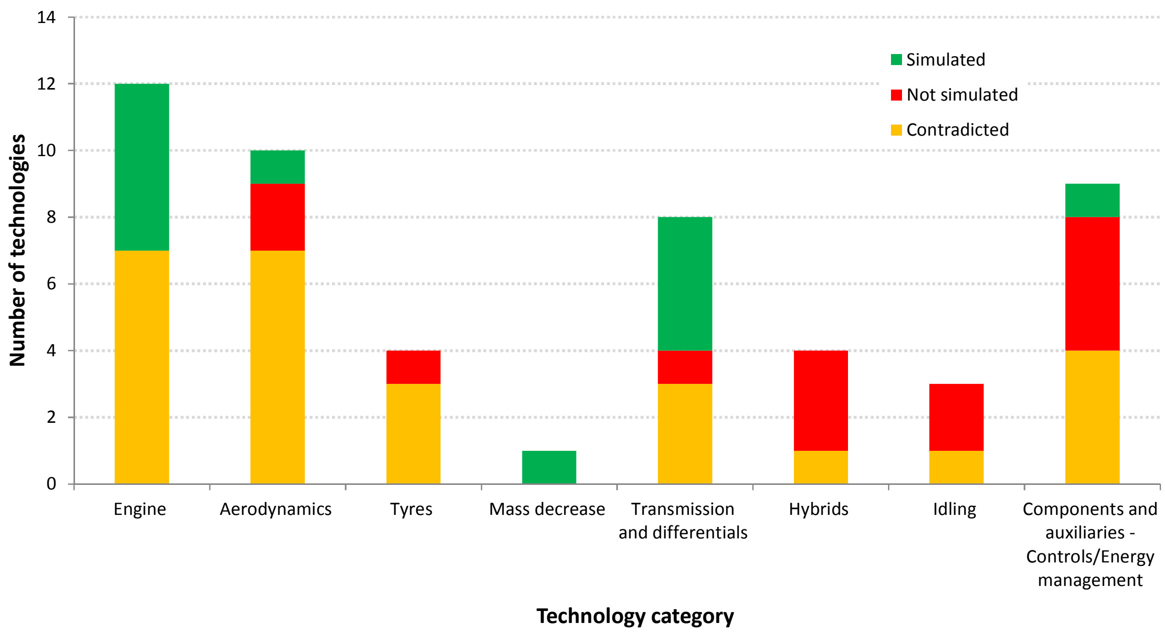

Figure 2: Individual technologies were separated into three categories depending on the simulation capabilities of VECTO.

ACEA provided feedback on the level of integration of each technology and commented on the possible simulation or tool implementation approach and it is presented in Table 3 in the Annex along with the respondents' feedback from the online survey. The table also includes a proposal for a suggested action for each technology based on a synthesis of all received feedback presented in this study. The classification used by ACEA is presented below.

- **Captured:** The effect of the technology is fully captured and is available on VECTO
- **Partially captured:** The effect of the technology is partially captured or models are readily available for implementation in VECTO.
- **Not captured:** The effect of the technology is not yet captured but model development and implementation work are in process.
- **Not covered/possible:** The effect of the technology is not possible to be implemented or there is no model development in process.

A detailed account of the feedback and the comments received for each individual technology can be found in Table 3.

5.2 Technology quantitative effect

Few respondents provided quantitative data about the effect on fuel consumption for some technologies, but as the number of estimates was limited to 1-3 per technology, it was not possible to conduct a statistical analysis. Nevertheless, as the replies reflect experts' opinion they can be considered to be highly significant and they are presented in Table 4 in the Annex. In addition, the table presents the effect on fuel consumption of each technology based on the values retrieved from a literature review. However, due to the diversity of the results, as the literature review covered also regions outside of Europe, the results were separated into EU and USA.

5.3 Market penetration

The feedback on market penetration was expected to indicate to which technologies VECTO should focus in future development. However the data was scarce with only one or two replies for some of the inquired technologies and is presented in Table 5. The data are reported as a starting reference point for future investigation on the issue.

Certain technologies were estimated to have an important penetration in the European market in a 5-10 years period from today (i.e. above 10% of the market). Those were: improved cooling fan, improved water pump, roof fairings, trailer mounted extensions, boat tails, mild electric hybrids, LED lighting, improvements in air compressor and predictive cruise control and other advanced driver aid systems. Most of the above can be captured by VECTO provided that the certification methodology is adequate for supporting such an inclusion – an issue which has to be further assessed. Additional feedback should be requested on the likely penetration rates of specific technologies which appear to offer important benefits such as waste heat recovery, electric turbocharging or full hybridization (for buses).

6 Conclusions

The survey retrieved information on VECTO's current capabilities and also some important feedback was provided on current feature improvement and implementation of other technologies.

The replies varied in some cases and several respondents could have entirely different opinions on whether a technology is simulated or not. However, in these cases the ACEA contribution provided a level of insight by pointing out some features which could not be captured and suggested a method to implement.

The quantitative data received was not enough for a statistical analysis but it is possible to use it as a general estimate of the fuel consumption reduction for some of the inquired technologies. Furthermore, it was expected that some insight on the technology penetration would be gained by receiving market information, but feedback was scarce. Further feedback in this case could assist in directing the tool development towards implementing technologies that are being deployed faster.

An important finding was that a large part of the technologies under investigation were already sufficiently captured by VECTO or can be relatively easily captured with limited simulation effort (e.g. addition of a generic factor) or by extending the certification methodology accordingly.

A synthesis of the retrieved information can be used to narrow down the technologies that could be implemented in the future. These technologies can be separated into three categories:

- Technologies which can already be covered and require work mostly on the certification methodology and minimal or limited interventions in VECTO software (short term interventions)
- Technologies that require additional work to be done both at methodological level and software level (in some cases substantial) prior to implementation (mid-term interventions)
- Technologies for which no action is advised but should be reassessed in the mid-term future if more data become available

The technologies are listed below, while a complete list with a proposal for each the investigated technology is presented in Table 3 in the Annex.

Technologies which can already be covered and require work mostly on the certification methodology and minimal or limited interventions in VECTO software (short-term interventions)*.*

- **Improved alternator:** Definition of certification procedure is required, which can be discussed with the European Association of Automotive Suppliers (CLEPA), ACEA and other relevant stakeholders. Expansion of the current generic list is possible if proven necessary.
- **Wide base single tires:** Can consider a generic improvement factor in vehicle aerodynamics for these tires but such a factor has to be quantified possibly by dedicated drag determination tests on vehicles equipped with such tires. No information regarding the actual market share of these systems was found. Additional feedback could be requested by ETRMA.
- **Tire pressure monitoring and automatic inflation systems:** Providing rolling resistance improvements can be contradictory. Vehicles are type approved based on the official rolling resistance coefficient of the tire. Operating with deflated tires is a

practice that increases the rolling resistance value, hence consumption. There are two options to promote these systems: **a**) make them mandatory as they offer real world savings (and possibly increase safety) **b**) increase the rolling resistance value used in VECTO by x% compared to its nominal value to account for real world rolling resistance deterioration and accept the nominal value only if the vehicle is equipped with the TPMS.

- **Improved oil pumps:** Can investigate further if there is an actual need to include these systems in a generic technology list. Additional feedback should be provided on the issue by engine OEMs.
- **Vehicle speed limiter:** Additional feedback could be requested from ACEA on the actual need of this technology and a possible implementation to proceed. ACEA claimed that a simple implementation is possible. No information was retrieved regarding the market penetration of such systems now and in the future.

Several technologies and require preparatory work and discussion with OEMs and other stakeholders and further development of the simulation process. These technologies are presented in the following list.

Technologies that require additional work to be done both at methodological level and software level (in some cases substantial) prior to implementation (mid-term interventions)*.*

- **Predictive Cruise Control (PCC) – Advanced Driver Assist Systems (ADAS):** Request additional feedback from stakeholders/ACEA on possible implementations. A clear definition is necessary that will define what exactly these systems are as the terms PCC and ADAS are too general and can include different implementations of not necessarily comparable systems. It is very important to discuss how these systems can be validated and how once could verify that the CO_2 benefits of such technologies are delivered in practice. These technologies should be implemented in VECTO only when consensus has been reached between vehicle OEMs and system suppliers regarding their definition, characteristics, simulation approach and validation methodology. Adopting a fixed CO_2 discount per individual technology (needs to be quantified) might make more sense particularly if viewed as a short term solution. Again an important aspect is how to prove that such a discount is realistic.
- **Waste heat recovery:** The potential of this technology and the extent to which is actually covered by present VECTO methodology (engine map) and simulator should be further investigated prior to any action. Issues relevant to certification and engine map measurement have to be solved prior to additional model development. A fix CO_2 discount in the order of 2-3.5% could be considered as a short-term solution but has to be supported by additional data or measurements demonstrating the benefit over different operating conditions and different vehicle categories.
- **Electric hybrids:** Addressing fully hybrid vehicles requires substantial developments in both the VECTO tool and the certification methodology (certification of hybrid components). A first solution along the lines proposed in the ACEA White Book can be investigated. A contract on the topic has already been launched by DG Clima. Fully capturing Electric hybrids might require in the future transition to a forward looking model which would require a complete redesign of VECTO software and has to be assessed separately.
- **Electric turbocharger:** Electrically driven turbocharges should be taken into consideration in future VECTO updates, especially if electric hybrid systems are

included. Additional feedback on the technology should be requested from respective OEMs. ACEA claimed that there are simulation models available for the specific technology.

- **A/C efficiency and refrigerant:** Can discuss the possibility to define a certification procedure for system efficiency starting from buses and coaches and later can extend VECTO bus auxiliaries' model to trucks if relevance is proven.
- **Active flow systems:** The inclusion of such systems in drag determination tests should be discussed. Alternatively these systems could be included in a generic technology list approach if their significance is proven.
- **Trailer aerodynamic improvements:** The inclusion of non-standard trailer bodies in the drag determination tests should be discussed and if necessary the methodology should be extended.
- **Dual Clutch Transmission:** The efficiency of the technology is captured but it is unclear why the shifting strategy should be much different from existing ones. This is a point where additional feedback on these systems can be requested from suppliers and OEMs, including also prediction on the market penetration. Can discuss the need to develop a shifting logic for this technology if possible. In general finding consensus on a common shifting logic can be very time consuming.
- **Neutral idle:** Re-assess the need and the way to capture this technology after the implementation of automatic transmission which is essential prior to any such development.

Technologies for which no action is advised for the time being but which should be revisited in the mid-term future:

- **Cooling fan:** Possibly consider following a cooling fan operating approach similar to that of bus auxiliaries in the future, if proven necessary. Generic cooling fan energy consumption values could be revised in the future if new data become available
- **Air compressor:** Can consider extending the coverage of specific technologies in the future if those are verifiable. Can discuss the possibility to extend part of or the complete bus auxiliaries' module to trucks if proven necessary.
- **Vehicle body redesign:** Consider possible revision of standard bodies for drag determination procedure in the future.
- **Adjustable fifth wheel:** Possible need to revisit drag determination test (constant speed test) once the technology becomes widely available in Europe.
- **Continuous Variable Transmission (CVT):** Can discuss the addition of this technology in the future if it becomes relevant for the European market. The possibility that it is already, or will be soon, relevant for markets outside Europe can be discussed and solutions for the implementation of CVT could be investigated at a global level if it is necessary.
- **Hydraulic hybrids:** Little information collected on the technology. Can request additional feedback from stakeholders in the framework of the Hybrids contract launched by DG Clima regarding the significance. Any need for implementing such technologies in VECTO should be clearly demonstrated.
- **ECU/Engine software optimization:** It is very difficult to describe and validate such a technology. Maybe consider in the future as part of a VECTO-SILs upgrade if a software in the loop approach is deemed necessary for certification purposes. Validation methodologies should accompany any such inclusion.

Finally, it is interesting to present some key points on the VECTO capabilities based on the comments provided by the respondents. It should also be noted that most of the feedback focused on trucks, whether rigid or tractor-trailers, while there was little information on city buses and coaches.

- The map approach is considered sufficient for the effect of many engine, axle and transmission technologies for steady driving conditions, but it is argued in some cases on whether is sufficient in transient driving. Implementation of more sophisticated technologies such as waste heat recovery should take into consideration such conditions.
- Many emerging technologies are not captured by the current version of VECTO, especially the ones that relate to energy recuperation and storage and several respondents point out the need to implement, as the tool is being developed to include hybrid powertrains. The interest in energy storing includes several applications such as hydraulic, electric hybrids and flywheel.
- An issue that is highlighted is the design of the electrical paths especially in the case of handling restored energy. Better design and implementation of electrical paths is needed to simulate hybrids and also in order to properly simulate electrically controlled/operated components such as electrical turbochargers, air compressors and fans.
- Electrically powered/controlled component options are not adequately simulated compared to the mechanical counterparts.

Annex

Table 2: Literature review of technologies reducing fuel consumption in heavy-duty vehicles.

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
Engine	Turbochargers	3-5%	(EPA and Department of Transport 2015)	USA	Use of twin turbo	A typical mechanical turbocompound utilizes turbine that is driven by the pressure of the exhaust gases. Improvements in turbo charging systems with the use of twin turbo or variable geometry turbochargers (VGT) offer wider operational range and can increase engine efficiency. The use of two turbos instead of one have less turbo lag and while one of the turbos can be activated/deactivated depending on the needs. In VGTs only one turbocharger is used whose geometrical features (turbing blade opening, movable walls, nozzle opening, etc.) are readjusted to optimize the turbocharger's operation. Turbochargers enable also engine downsizing. Current research is focusing also on electric turbo compounds, where the turbine is driven by an electric motor.	The most common problem of a mechanical turbo compound is the turbo lag that occurs when there is not sufficient exhaust gas pressure due to low engine speed and load. Electric turbocompounds do not have this problem, but this technology requires power that can be provided quickly to drive the turbine. The utilization of supercapacitors is a solution to this issue, but the mass of the vehicle is increased as a charging system is also required (e.g. regenerative braking). To gain benefits, this needs to be used with accessory electrification or electric hybridization.
		2.5-4%	(Baker et al. 2015)	USA	For mechanical turbocompound		
		3-10%	(Baker et al. 2015)	USA	For electrical turbocompound		
		1.3-2.5%	(Duleep 2011)	USA	For mechanical turbocompound		
		2.5-5%	(Duleep 2011)	USA	For electrical turbocompound.		
	Intake/ exhaust	1.40%	(EPA and Department of Transport 2015)	USA		A combination of improvements on engine design such efficiently designed air paths for the intake-outtake of the air in the engine and variable valve actuation systems can improve performance and fuel consumption depending on the needs. Also, EGR systems with higher efficiency can reduce frictional pressure loss and maximize thermal air control	
	Internal friction reduction		(EPA and Department of Transport 2015)	USA		Improvements in pistons, bearings and valve trains with proper coating and improved water and oil pumps reduce parasitic and friction in the engine.	Friction reduction must ensure that there are no durability or performance capability issues.
		1-1.5%	(Duleep 2011)	USA			
	Increase in engine efficiency	11% FE	(Gao et al. 2015)	USA	50% peak engine efficiency	Increased compression ratio, higher peak cylinder pressure, reduced friction losses, improved air-handling, reduced heat losses, high efficiency combustion strategies	Temperature of exhaust gases decreases and could affect the effectiveness of emission control systems, heating and waste heat recovery.

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
	After treatment system optimization	0.5-2%	(EPA and Department of Transport 2015)	USA		Increased aftertreatment efficiency lead to better combustion system optimization with higher cylinder pressure and injection optimization. SCR: Better engine calibration and lower use of the EGR, although more efficient combustion can form increased NO_x emissions, which can be treated with an SCR system. Improvements in SCR systems, such cell density and catalyst material optimizations, are required as they add weight to the vehicle and some additional CO_2 emissions can be produced due to the carbon content and oxidation of urea. DPF: Reduce of backpressure through further development of the aftertreatment systems, such a thinner DPF, reduced fuel consumption during filter regeneration and improved aftertreatment flow.	
			(McCarthy, Korhumel, and Marougy 2009)	USA	Fuel consumption reduction		
	Waste heat recovery		(EPA and Department of Transport 2015)	USA		The principle is to utilize exhaust heat from various sources, such EGR cooler and the exhaust gas, to vaporize a working fluid that passes through a turbine to generate electrical or mechanical power. The power can be directed to the engine power shaft (mechanical) or to produce electricity to power auxiliaries and to charge a battery in hybrid vehicles.	The efficiency of the waste heat recovery is reduced as engine efficiency increases, because less heat is available in the exhaust system. The installation of the system adds extra mass to the vehicle.
		5% FE	(Daccord, Darmedru, and Melis 2014)	USA	In trucks		
			(Vaja and Gambarotta 2010)	EU			
			(Macián et al. 2013)	EU	15% in break specific fuel consumption		
		3%	(Dünnebeil et al. 2015)	EU	The study uses changes in energy consumption, as it tests different fuels. Value is for diesel. For Semi-trailer in long haul cycle		
		4.1-4.7%	(Reinhart 2015)	USA	Water Based Bottoming cycle		
		2.6 - 2.8%	(Reinhart 2015)	USA	R245 Refrigerant-Based Bottoming Cycle. Cycle has lower efficiency due to lower working		

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
					temperature		
		2% FE	(Gao et al. 2015)	USA			
	Engine downspeeding	3% FE	(Volvo 2016)	USA	Improvement for 200 rpm reduction	The engine is running at lower RPM and the vehicle maintains speed and performance by faster gear ratios.	The faster gear ratio generates higher torque stress on the drivetrain materials that could reduce their lifetime. Several innovations should be adopted such as more capable primary gear with wider gearing face and tooth length, rigid gear mounting to eliminate joint loosening and more capable input shaft, pinion splines and bearings to ensure material endurance.
		1% FE	(Nieman 2014)	USA	1% per 100 rpm reduction		
		2-3%	(Trucking Efficiency 2015c)	USA			
		2-4%	(Reinhart 2015)	USA			
	ECU /Engine software optimization		(EPA and Department of Transport 2015)			Advanced software management ensures that powertrain components (engine, transmission, and axle) are efficiently working together. To achieve the best optimization it is required that individual component manufacturers collaborate together or that all powertrain components are made be the same manufacturer. Software management and hardware optimization in this sense it is also required to achieve better engine downspeeding results.	
	Cooling fan		(EPA and Department of Transport 2015)	USA		Cooling fans that are electrically controlled adjust on the cooling requirements and pose a lower load compared to a system that is ran directly from the combustion engine.	
		2-3%	(Duleep 2011)	USA			
	Water pumps		(Duleep 2011)		Reduction in fuel consumption	Improvements in water and oil pumps. Water pumps: Efficiency improvements, variable pump speed and activation/deactivation controls. Oil pumps: Variable displacement, piston/ring/liner friction reduction.	
	Oil pumps		(Duleep 2011)		Reduction in fuel consumption		
	Low viscosity	3-5% FE	(EPA 2015)	EU	EPA. European study	Lubricants with low viscosity are easier to pump, therefore requiring less energy, while	

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
	lubricant	1.8% FE	(Total Lubricants 2016)	Canada		they offer better component coating and protection. Lubrication is required for the engine, transmission and differentials.	
		0.7 - 1.1%	(Taylor et al. 2011)	EU	Higher improvement for 10t truck, lower for 40t		
		1.3-6.4% FE	(Total Lubricants 2015)	EU			
Aerodynamics	External grille shutter	0.6-1.4%	(EPA and Department of Transport 2015)	USA	Drag improvement	Active grille shutters at the front of the vehicle can readjust automatically depending on the needs to provide the required air and limit at the same time the air drag by effectively directing the air flow to the rear of the vehicle.	
	Active flow control	9% FE	(ATDynamics 2011)	USA	Active flow systems are not optimized yet	Active flow control is a system that actively pressurizes the lower pressure-vortex or vacuum that develops behind the trailer. The technology has not been tested enough.	Additional research is required to increase efficiency of the motor and the blower package.
		7%	(T&E 2010)	EU			
		10%	(Seifert et al. 2016)	Israel	For highway operation of large trucks, busses and tractor trailers		
	Mirror replacement.	1%	(EPA and Department of Transport 2015)	USA	Drag improvement	Replacement of OEM mirrors with cameras.	In the case of replacing mirrors with cameras there are regulation issues, driver adjustability and the need for alternative means in case of failure.
	Tractor cabin mounted extensions	Effect on air drag, see paper	(EPA and Department of Transport 2015)	USA		Roof fairings on the tractor cabin reduce air stagnation at the front of the trailer, while accelerating and better controlling the air flow to the rear of the vehicle.	The installation of aerodynamic add-ons increase the mass of the vehicle, but the use of lightweight materials can minimize the effect. Inflatable boat tails can also contribute in limiting the additional weight.
			(Patten et al. 2012)	Canada		Bumper with under bumper valance, halogen headlights with aerodynamic design and visor designed to direct the air over the cab. Roof, cab and side fairings and less clearance between the road and the vehicle (rubber skirt under steps) prevent the air entering the under body of the vehicle.	
		9-17%	(Mohamed-Kassim and Filippone 2010)	EU	Cab rood and side fairings.		
	Trailer-mounted	3-7%	(Patten et al. 2012)	Canada	Widely adopted in Canada	Trailer fairings around the wheel/bogie and side skirts prevent the air from entering the under	

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
	extensions	10-15% drag	(Patten et al. 2012)	Canada		body area that would increase turbulence. The use of gap fillers limits the low pressure area between the tractor and the trailer.	
		7.2%	(Surcel, Provencher, and Michaelsen 2009)	Canada	Trailer skirts		
		3.9%	(Dünnebeil et al. 2015)	EU	Side, underbody panels and boat tail. For tractor-trailer in long haul cycle		
		19.9 - 26.3% Drag reduction	(Landman et al. 2011)	USA	Side skirt for rigid truck. Depends on speed		
		7-10%	(Mohamed-Kassim and Filippone 2010)	EU	Trailer front fairings		
	Boat tails/extension panels		(Patten et al. 2012)	Canada	See also page 77 for charts	Panels at the rear of the trailer assist in the pressure equilibrium between the front and the rear of the vehicle facilitating the air flow and reducing the air drag.	
		5.6%	(Surcel, Provencher, and Michaelsen 2009)	Canada	Boat tails		
		5-10% drag decrease	(Buresti, Iungo, and Lombardi 2007)	EU			
		3-8%	(T&E 2010)	EU	Depends on the type of the cavity. Inflatable tails can be used to reduce weight		
	Vortex generators	<1%	(Patten et al. 2012)	Canada		Vortex generators are placed on a surface to create a vortex of air to prevent air flow separation across the surface. The technology has not been tested adequately.	Fuel savings could be really low compared to the required cost for development.

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
	Adjustable fifth wheel	3% FE	(Patten et al. 2012)	Canada		An adjustable fifth wheel can decrease the gap between the cabin and the trailer, which is a low pressure area that causes disturbances in the smooth airflow around the vehicle significantly increasing the drag.	
	Complete vehicle redesign	17%	(Patidar, Gupta, and Bansal 2015)	India	Bus, for 30% drag improvement at 60 km/h		
			(EPA and Department of Transport 2015)	USA	Two cases claim 10.7 and 13.4 MPG	New vehicle design that has lower aerodynamic coefficient and cabin designs that could differ from current box-like shapes and maintain safety standards. The new design can significantly increase safety by lowering the risk of accident, while in case of accident they can reduce the damage to be caused.	Vehicle cab length must increase a little bit for better results, which is not permitted by the current legislation.
		3.2-5.3%	(T&E 2012)	EU	Air drag reduction of 12% for a long haul lorry		
	Full airflow package	8%	(Volvo Trucks 2016)	EU	Roof deflector, side deflectors and chassis skirts	Full airflow package includes a combination of various aerodynamic improvements.	Vehicle mass increase.
		6%	(Dünnebeil et al. 2015)	EU	For tractor- trailer in long haul cycle		
		17% FE	(Gao et al. 2015)	USA	Information simulations. Side skirts, fairings, air dams, etc. are considered		
Tires	Wide base singles	6-13%	(EPA and Department of Transport 2015)	USA		Single wide based tires are used to replace dual tires on the tractor and/or on the trailer, leading rolling resistance and weight reduction. Additionally, they may reduce air drag at higher speeds.	The damage on the tire is greater if it is not inflated properly compared to a dual set up. Tread wear could be irregular and re-treading could be more difficult. It is also possible that the tire has a slightly smaller surface area than duals, which makes it more sensitive to overload. Also, some cases reported increased damage to the road infrastructure. Roadside failures can result in the vehicle being immobilized.
		Reduction	(Holmberg et al. 2014)	EU			
		3%	(NACFE 2010)	USA			
		4% FE	(Cummins n.d.)	USA			
		6%	(Dünnebeil et al. 2015)	EU	For tractor-trailer in long haul cycle		
		7% FE	(Gao et al. 2015)	USA			

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
	LRR tires	3%	(Park 2014)	USA		Tires with low rolling resistance have lower rubber hysteresis and less energy is lost due to tire deformations.	
			(Michelin Trucks 2012)	EU			
		5%	(Bridgestone Tires 2014)	EU			
		3%	(Goodyear 2012)	EU			
		2%	(Holmberg et al. 2014)	EU	For 10% RRC reduction		
		3.7-5.6%	(Dünnebeil et al. 2015)	EU	Depends on the No of A tires. For tractor-trailer in long haul cycle		
		1.4% FE	(Schubert and Kromer 2008)	USA	Straight truck		
		5%	(Hausberger et al. 2011)	EU	Motorway, LRR tires on trailer. More info for urban routes		
		3.2 - 4.6%	(LaClair and Truemner 2005)	USA			
		8%	(Zhao, Burke, and Miller 2013)	USA	For 20% RRC reduction		
	Tire pressure systems		(EPA and Department of Transport 2015)	USA		Tire pressure systems monitor (TPMS) the pressure of the tires and provide information to the driver.	
	Automatic inflation system		(Continental 2015)	EU		Automatic tire inflation systems (ATIS) maintain the tires up to the optimum operational pressure.	
			(NACFE 2013)	USA	FC increase by 0.5-1% per 10 psi below the recommended. Use of pressure control systems can avert this effect		

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
Axles and transmission	AMT		(EPA and Department of Transport 2015)	USA		Automated Manual Transmission comprises of a standard manual gearbox, but the clutch is removed from the driver and gear shifting is done automatically. Optimized shifting can improve fuel consumption, while AMT also enables engine downspeeding that lead to further fuel savings.	
		3-10%	(Reinhart 2015)	USA	NHTSA		
		4-8%	(Baker et al. 2015)	USA			
	DCT		(EPA and Department of Transport 2015)	USA		A dual clutch transmission (DCT) gearbox utilizes two clutches that one engages odd gears and the other the even ones. When a gear is selected, the next gear is also preselected by the second clutch offering fast shifting and smooth accelerations without torque interruption.	
	CVT	19%	(Burtt 2007)	EU	For a 11t midi-bus, compared to 5-speed AT	Continuously Varying Transmission (CVT) is a gearbox that deploys two conical pulleys connected with a belt, chain or a cogwheel offering an infinite number of gear ratios. The use of the CVT can ensure that engine is running most of the time at optimal RPM that promote fuel savings.	
	Axle efficiency		(EPA and Department of Transport 2015)	USA		Increase axle efficiency by reducing mechanical and spin losses. Mechanical losses: Reduce friction by improving surface finish of the gears. Limit the distance the gears are sliding against each other. Spin losses: Reduce the area the gears are churning through lubricant by limiting the volume of the lubricant in the sump.	
	Additional gear ratios		(EPA and Department of Transport 2015)	USA		Gear size and the sequence they engage is the gear ratio. Optimized gear ratio depending on the intended use during vehicle design. Dual speed axles can be deployed to switch to higher axle ratio during transient driving conditions.	
		0.5%	(Dünnebeil et al. 2015)	EU	For tractor-trailer in long haul cycle		
	6x2	1-3%	(EPA and Department of Transport 2015)	USA		6x2 configurations offer savings compared to 6x4 due to reduced mass and friction losses on the axle. In cases of slippery conditions and loss of traction a system with an enhanced 6x2	

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
		2% FE	(Trucking Efficiency 2013)	USA		configuration can transfer more loads to the powered axle.	
	Enhanced 6x2	2%	(EPA and Department of Transport 2015)	USA			
	Disconnect 6x4 axle	2.50%	(EPA and Department of Transport 2015)	USA		Automatically or manually disconnect 6x4 axle depending on the needs effectively reducing friction losses when switching to 6x2 mode. There are fewer benefits compared to a 6x2 configuration, since there is no mass reduction from the removal of differentials.	
	Low viscosity lubricants	0.5-2% FE	(EPA 2015)	USA	Synthetic lubricant in transmissions and axle	Lubricants with low viscosity are easier to pump, therefore requiring less energy, while they offer better component coating and protection. Lubrication is required for the engine, transmission and differentials.	
		1-4%	(EPA 2015)	EU	EPA. European study	Lubricants with low viscosity are easier to pump, therefore requiring less energy, while they offer better component coating and protection. Lubrication is required for the engine, transmission and differentials.	
Hybrids	Hydraulic hybrid		(EPA and Department of Transport 2015)	USA		Hydraulic hybrid vehicles store energy in a cylinder by compressing a gas by recovering energy during deceleration. The compressed gas expands to provide additional power during acceleration.	This technology provides benefits only if there are many start and stops, e.g. in an urban/regional route.
		5.30%	(Midgley, Cathcart, and Cebon 2013)	EU			
		12-25%	(Baker et al. 2015)	USA	For cycles with many stops. There are 3 sources included in the document, here it is presented IEA's value		
		19-52% FE	(Lammert et al. 2014)	USA			
		22.20%	(Bender, Bosse, and	EU	For refuse trucks for the transfer cycle. For the		

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
			Sawodny 2014)		collection cycle the benefits are ~19%		
		30.00%	(Van Batavia 2009)	USA	For regional delivery		
		15-25%	(de Oliveira et al. 2014)	Brazil			
	Electric hybrids		(EPA and Department of Transport 2015)	USA		Electric hybrid vehicles deploy a conventional combustion engine and an electric engine. The electric engine is powered by a battery, which is recharged by recovering energy during braking or by the excess loads of the combustion engine. This system enables the combustion engine to run more time on the most efficient RPM and when additional power is required it is provided by the electric engine. The range of hybridization of a vehicle (mild to full hybrid) varies depending on the technologies deployed and the amount of contribution of the electric motor on the propulsion of the vehicle. **Mild hybrids:** In this case there is no additional electric motor, but a more powerful starter and a battery with larger capacity. The improved starter is required, as a stop-start system is deployed. It can also provide some additional power to the combustion engine, but there is no propulsion an exclusive electric mode. **Full hybrids:** The vehicle has an internal combustion and an electric motor and can run exclusively on any of the two modes or in a combination of the two.	The cost is high and depends on the range of the hybridization and battery capacity. The additional powertrain and battery increases the mass of the vehicle that can decrease the total payload capacity.
		5-7% FE	(Gao et al. 2014)	USA	In long haul trucks for mild hybrids		
		17%	(Zhao, Burke, and Miller 2013)	USA			
		6%	(Lajunen 2014)	EU	Depends on the route, but there are benefits even for constant speed		
		6-7% FE	(Duleep 2011)	USA	For highway use		
		25-35% FE	(Duleep 2011)	USA	For urban and suburban use		
		7% FE	(Gao et al. 2015)	USA			
	Flywheel application for energy savings	34%	(Brockbank and Greenwood 2009)	EU	Bus with CVT gearbox	The energy is stored in the form of mechanical energy in a spinning flywheel, which is held in a frictionless environment (vacuum, levitating flywheel) to prevent energy loses. The stored energy can be used to provide mechanical work or generate electricity by coupling the flywheel to the system. Modern coupling systems are	
		25%	(Boretti 2010)	EU	Over the NEDC adapted for HDV		

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
		20%	(Ricardo 2009)	EU	Combined with AMT for a bus	using magnetic coupling to prevent friction loss and material wear.	
Mass	Mass reduction	5%	(EPA and Department of Transport 2015)	USA	Per 10% of mass reduction	Weight reduction can be achieved primarily by switching to lightweight materials and/or component redesign to use less material. Lightweight materials, such high strength steel, aluminium, magnesium and composite materials can be also used for manufacturing various aerodynamic add-ons which reduce air drag, but contribute to mass increase.	Lightweight materials and new component design must ensure that they deliver the same safety and performance standards as the materials they replace.
			(EPA and Department of Transport 2015)	USA	FC reduction		
		1%	(Hill et al. 2015)	EU	Data value presented here is an average for potential reduction in 2020		
		5-10%	(EPA, n.d.)	USA	For every 10% drop in weight		
		0.70%	(Dünnebeil et al. 2015)	EU	For 400 kg reduction, for a tractor-trailer in long haul cycle		
		1-2%	(Trucking Efficiency 2015a)	USA	For 1800 kg reduction		
		2% FE	(Gao et al. 2015)	USA	For 10% weight reduction.		
Idling	Auxiliary power units (APU)		(EPA and Department of Transport 2015)	USA	On board installations for reduced fuel consumption while parked. Infrastructure for plugging in while parked	Use of alternative source during parking instead of the main engine, such as Auxiliary Power Units (APUs) and connecting the vehicle to the grid to provide electricity for cooling/heating, auxiliary use. APUs could be additional batteries or electric generators that are not used to vehicle propulsion, but to power the vehicle's auxiliaries.	Technologies can be competing each other, such APUs and truck stop electrification. Market penetration and user acceptance is not quite known yet.
		60-85%	(Storey et al. 2003)	USA	For the use of APU and Direct Fire Heater during stops		
			(Brodrick et al. 2002)	USA	Hydrogen fuel cell APU		
			(Agnolucci 2007)	EU	SOFC fuel cell APU		

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
			(Rahman et al. 2013)	USA	Truck stop electrification		
		5% FE	(Trucking Efficiency 2015b)	USA	Optimize programmable parameters related to idling (e.g. engine speed)		
	Stop-start		(EPA and Department of Transport 2015)	USA		The engine stops working during idling and accessories usage rely on batteries. Vehicles deploying stop-start technologies require higher capacity batteries or supercapacitors.	
	Neutral idle		(EPA and Department of Transport 2015)	USA	Torque in automatic transmission	Automatic transmission applies torque during idling, unless the driver switches into neutral. Neutral idling technology disengages the clutch when the vehicle is at a complete stop and the brakes are applied, effectively switching to neutral automatically.	
Components and auxiliaries	A/C system efficiency		(EPA and Department of Transport 2015)	USA			
	Solar reflective paint and glazing		(EPA and Department of Transport 2015)	USA		Reflective paint and glazing limits the amount of solar infrared radiation to the cabin and reduce cooling needs. Reflection depends also on colour selection.	
			(Lustbader et al. 2014)	USA	7.3% reduction in A/C load for switching from white colour instead of dark colours		
	Electro-hydraulic power steering		(EPA and Department of Transport 2015)	USA		Steering assistance is provided by an electric driven motor that runs the hydraulic pump. This is an on-demand energy system, which means that a torque sensor detects steering needs and activates the electric motor. The hydraulic system currently deployed in most vehicles is continuously driving the hydraulic pump by the engine regardless of the steering needs.	
	LED lighting		(Schoettle, Sivak, and Fujiyama 2008)	USA		Typical halogen headlights can be replaced by more efficient LED lighting. The efficiency of LED relies on the lower power requirements and the output light direction. The light can be directed exactly where needed, limiting the use	

Category	Technology	Effect (FC reduction if not specified otherwise)	Source	Region	Comments	Description	Caveats
						of deflectors and wasting less light compared to typical halogen lights.	
Controls/ Energy management	Predictive cruise control	2%	(EPA and Department of Transport 2015)	USA		Intelligent cruise control systems can utilize GPS data to predict slope grade and adjust gearshifting properly.	
	Advanced Driver Assistance Systems (ADAS)		(WABCO 2016)			Advanced Driver Assistance Systems (ADAS) assist the driver in controlling the vehicle contributing to traffic safety and reducing fuel consumption. The systems provide feedback about traffic and road conditions and can actively adjust vehicle speed and steering.	
	Vehicle speed limiter		(EPA and Department of Transport 2015)	USA		A speed limiter can be used to limit the vehicle's speed into the most fuel efficient engine operation band.	
		3.4%	(Dünnebeil et al. 2015)	EU	Set to 80 km/h for tractor-trailer in long haul cycle		

Table 3: Summary of the VECTO capabilities based on respondent feedback and proposed action.

Category	Technology	Respondents - Online survey	ACEA	Respondent feedback/Suggestions	Proposed Action
Engine	Turbochargers	Contradicting Views	Partially captured / Models available	**Overall:** Mechanical turbochargers are captured sufficiently. Further work is needed in electric paths design to implement electrical turbocompounds. **ACEA** suggests that electrical path can be captured by a recuperation model (adaptation of a future hybrid model).	The case of electrically driven chargers could be taken into consideration in future VECTO updates particularly if hybrid systems are considered for inclusion. Additional feedback should be requested from OEMs.
	Intake/Exhaust	Contradicting Views	Simulating	**ACEA**: considered in fuel map.	No action
	Waste heat recovery	Contradicting Views	Model work necessary prior to implementation in VECTO	**Overall:** Energy recovery model is required and can be implemented through a fuel map approach, although a steady fuel map approach could overestimated savings (due to the high thermal inertia of the WHR systems). Mechanical WHR covered by fuel map. A respondent claimed that backward simulation is not adequate for capturing the effect of this technology. Respondents mentioned inadequacies also in the engine certification procedure. Putting the potential of WHR in the steady state BSFC map might be misleading. **ACEA:** Fuel map approach generally suitable NO_x / PM certification definition necessary, they estimate fuel savings at 2-3% depending on cycle.	The potential of this technology and the extent to which is actually covered by present VECTO methodology and simulator should be further investigated prior to any action. Issues relevant to certification and engine map measurement have to be solved prior to additional model development. A fix CO_2 discount in the order of 2-3.5% can be considered but has to be supported by additional data or measurements.
	After treatment system optimization	Simulating	Simulating	**Overall:** All but one respondent consider the technology captured. The respondent who disagrees, states that NO_x and CO_2 are measured separately and there is no link between the CO_2 calculation and the actual NO_x test. A respondent noted that the dependency on thermal conditions of the aftertreatment system is not fully covered.	No action, WHTC factors considered by VECTO. Can consider linking ex-post test to PEMs results for NO_x emissions compliance.
	Internal friction reduction	Simulating	Simulating		No action
	Increase in engine efficiency	Simulating	Simulating		No action
	Engine downspeeding	Simulating	Simulating	**ACEA:** Fully captured but additional verification of the shifting strategy may be required.	No action. Possibly verify shifting strategy in the future.
	Low Viscosity Lubricant	Simulating	Simulating	**Overall:** Technology captured in the steady state engine map. However only the lubricant used in Engine testing is considered. No possibility to assess different lubricants without test.	No action
	ECU /Engine software optimization	Contradicting Views	Not possible / not reasonable	**Overall:** Cannot be captured by a generic driver/gearshifting model. ECU optimization and intelligent controllers are difficult to implement in current VECTO. Possibility to include Software In the Loop is mentioned. **ACEA** believes it is not covered and estimates a fuel consumption benefit of 1%.	No action right now as it is very difficult to describe and validate such a technology. Maybe consider in the future as part of a VECTO-SILs upgrade.

Category	Technology	Respondents - Online survey	ACEA	Respondent feedback/Suggestions	Proposed Action
	Cooling fan	Contradicting Views	Simulating	**Overall:** Covered. Effect is captured through a technology list with generic values. One respondent noted that in current VECTO cycles, the fan remains off most of the time. So it's difficult to demonstrate savings. Current approach (adding to the driving power fan losses as constant value for each technology) is sufficient, but if we want to become more accurate in the future fan control strategies and the engines' cooling circuit needs to be added in VECTO somehow. Other respondent commented that VECTO should allow the activation on demand and different power levels during simulation, dependent on status of other vehicle systems. The need for forward looking model is mentioned.	No action right now. Review generic cooling fan energy consumption values in the future if data become available. Possibly consider following a cooling fan operating approach similar to that of bus auxiliaries in the future, if proven necessary.
	Alternator	Contradicting Views	Model work necessary prior to implementation in VECTO	**Overall:** Some participants claim that it is covered. Others ask for an extension of electric auxiliary technology list and determination of a certification procedure. **ACEA**: States that the technology is not fully captured yet but the technology list can be extended only after a certification test procedure for alternator efficiency is defined. Estimates the benefit in the order of 0.5%.	No action on modelling side. Definition of Alternator certification procedure can be discussed also with CLEPA members. Savings reported by ACEA appear to be low.
	Water pumps	Contradicting Views	Simulating	**Overall**: Most respondents consider the effect of this technology captured in the engine map. Some users note the lack of transient operation (currently it is captured via a Steady State map).	No action. The WHTC correction partly compensates the lack of transient operation.
	Oil pumps	Simulating	Partially captured / Models available	**ACEA:** The technology can be captured either by a fuel map approach or through a technology list approach combined with generic power demands.	No action on modelling side. Can investigate further if there is an actual need to include these systems in a generic technology list.
Aerodynamics	External grille shutters	Contradicting Views	Partially captured / Models available	**Overall:** There are contradicting views on the actual benefit of the technology. Its effect can be quantified during the air drag test. **ACEA**: The effect can be captured either by air drag tests at 0° yaw angle if the system is mounted on the tractor during the test or by generic values in a technology list combined with an average generic improvement.	No action. Benefit can be demonstrated by constant speed test air drag test.
	Active flow systems	Not simulating	Partially captured / Models available	**Overall:** The technology is not captured by the methodology particularly regarding trailer mounted systems but there are possibilities to test. One user notes that the aerodynamic drag of trailers is largely contributing in the total drag of the complete vehicle. The low hanging fruit solutions are present at the trailer side. Active flow control is a promising technology but requires energy which is a cost compared to passive devices. Therefore the penetration within 5-10 years will be low. **ACEA**: The effect can be captured either by air drag tests at 0° yaw angle if the system is mounted on the tractor during the test or by generic values in a technology list combined with an average generic improvement.	No action on modelling side. Need to decide on the inclusion of non-standard trailers in the certification process. Can discuss the possibility to assess these systems in the constant speed test or potential inclusion in a generic list of technologies that offer aerodynamic drag reduction. In the latter case need to quantify the benefit and clearly define the technology.

Category	Technology	Respondents - Online survey	ACEA	Respondent feedback/Suggestions	Proposed Action
	Mirror retraction/ replacement, component replacement.	Contradicting Views	Simulating	**Overall**: The effect can be captured during the constant speed test for air drag determination.	No action
	Tractor cabin mounted extensions	Contradicting Views	Simulating	**Overall:** Captured, one respondent claims that the constant speed test doesn't capture sidewinds so the potential of the technology cannot be captured.	No action
	Trailer mounted extensions	Contradicting Views	Not possible / not reasonable	**Overall:** The effect is not captured as only standard body types are considered in the air drag determination. Respondents mention the possibility to gain high savings if these technologies are applied at trailer level. **ACEA** suggest a 3% CO_2 benefit from this technology.	No action on modelling side. Need to decide on the inclusion of non-standard trailers in the certification process. Can discuss how to address trailer aerodynamics in the future.
	Boat tails/extension panels	Contradicting Views	Not possible / not reasonable	**Overall:** The effect is not captured as only standard body types are considered in the air drag determination. These systems are expected to increase after a change in the weights and dimensions legislation. **ACEA** suggest a 3% CO_2 benefit from this technology.	
	Vortex generators	Contradicting Views	Not possible / not reasonable	**Overall:** The effect is not captured as only standard body types are considered in the air drag determination. **ACEA** suggest a CO_2 benefit in the order of 0.5% from this technology.	
	Adjustable fifth wheel	Contradicting Views	Partially captured / Models available	**Overall:** Can be captured by constant speed test, one respondent claims that the constant speed test doesn't capture this technology. **ACEA** claims it can be captured by the constant speed test and alternatively proposes list of generic air drag reduction value**.**	No action for the time being. Possible need to revisit constant speed test once the technology becomes widely available in Europe.
	Vehicle redesign	Contradicting Views	Simulating	**Overall:** Can be captured by constant speed test, two respondents disagree claiming that the constant speed test doesn't capture side wind effect and thus underestimate the potential of this technology. **ACEA** claims it can be captured.	No action for the time being. Possible need to revisit constant speed test in the future.
Tires	Wide base single tires	Contradicting Views	Partially captured / Models available	**Overall:** The effect on rolling resistance is captured however the effect on aerodynamics is not captured as drag determination is realized with standard tires.	No action on modelling side. Can consider a generic improvement in vehicle aerodynamics for these tires but the improvement has to be quantified (possibly by constant speed tests).
	Low rolling resistance tires	Contradicting Views	Simulating	**Overall**: The effect of rolling resistance is considered to be captured, although questions are raised on the fraction of low rolling resistance tires sold in Europe.	No action
	Tire pressure monitor systems	Contradicting Views	Partially captured / Models available	**Overall**: The effect can be captured by a technology list approach as a generic impact on rolling resistance. **ETRMA**: suggested mandatory TPMS for HDVs at a later stage in order to help uptake this technology.	No action on modelling side. Providing rolling resistance improvements can be contradictory. Vehicles are type approved based on the official rolling resistance coefficient of the tire. Operating with deflated tires is a practice that increases the rolling resistance value, hence consumption.

Category	Technology	Respondents - Online survey	ACEA	Respondent feedback/Suggestions	Proposed Action
	Automatic tire inflation systems	Contradicting Views	Partially captured / Models available	**Overall**: The effect can be captured by a technology list approach as a generic impact on rolling resistance.	There are two options to promote these systems: **a**) make them mandatory as they offer real world savings (and possibly increase safety) **b**) increase the rolling resistance value used in VECTO by x% compared to its nominal value to account for real world rolling resistance deterioration and accept the nominal value only if the vehicle is equipped with the TPMS. In the latter case the magnitude of the increase needs to be quantified, 5% could be first estimate.
Axles and transmission	Automated Manual Transmission (AMT)	Contradicting Views	Simulating	**Overall:** All but one respondent consider the technology captured.	No action
	Continuously Variable Transmission (CVT)	Not simulating	Model work necessary prior to implementation in VECTO	**Overall:** The technology is not captured and appears to be not relevant for the near future. One gearbox OEM responded that they will not offer CVTs for HDVs in the near future. One respondent noted that CVT definition should comprehend all CVT and IVT architectures.	No action for the time being. Can discuss this improvement in the future if it becomes relevant. Can investigate the possibility that it is relevant for markets outside Europe.
	Dual Clutch Transmission (DCT)	Contradicting Views	Partially captured / Models available	**Overall:** The efficiency of this technology is considered to be captured but differences in shifting logic and shifting duration are not covered. A gearbox OEM mentions that these systems can be simulated as AT powershifts.	Although it is unclear why the shifting strategy should be much different from existing ones, this is a point where additional feedback on these systems can be requested, including also prediction on the market penetration. Can discuss the need to develop a shifting logic for this technology if possible. In general finding consensus on a common shifting logic can be very time consuming.
	Additional gear ratios	Simulating	Simulating	**Overall:** Consensus that the technology is covered. One manufacturer states that disengageable axle drive is not offered.	No action. Can discuss the significance of disengageable clutches.
	Axle efficiency	Simulating	Simulating	**Overall:** Effect captured in efficiency map (if measured).	No action
	Lubricants	Simulating	Simulating	**Overall:** Effect of transmission lubricant included in transmission efficiency map test method (options 2-3).	No action
Hybrids	Hydraulic hybrids	Contradicting Views	Model work necessary prior to implementation in VECTO	**ACEA:** Hydraulic hybrid solutions not (yet) available in the ACEA white book.	No action for the moment. Can request additional feedback from ACEA in the framework of the Hybrids contract launched by DG Clima.
	Full/mild electric hybrids	Not simulating	Partially captured / Models available	**Overall**: The energy recuperation and storage system should be developed. Mild hybrids are should be captured as they will gain significance in urban applications. Should investigate the electrification of auxiliaries in addition to powertrains.	Addressing fully hybrid vehicles requires substantial developments in both the VECTO simulator and the certification methodology (certification of hybrid components). A first solution along the lines proposed in the ACEA White Book can be investigated. A contract on the topic has already been launched by DG Clima. Lack of studies in Europe makes it difficult to quantify the technology based on literature.
	Flywheel	Not simulating	Partially captured / Models available	**ACEA**: the effect of the technology is not covered yet in VECTO but ACEA recommends an implementation approach in their 2016 White Book.	

Category	Technology	Respondents - Online survey	ACEA	Respondent feedback/Suggestions	Proposed Action
Mass	Mass reduction	**Simulating**	**Simulating**		No action
Idling	Stop-start systems	**Contradicting Views**	**Simulating**	**Overall:** Consensus that the technology is covered. One respondent expressed the opposite view.	No action
	Auxiliary power units	**Not simulating**	**Model work necessary prior to implementation in VECTO**	**Overall:** The technology is not captured. **ACEA:** Overnight engine idling in Europe very exceptional. Estimated effect 0.1%	No action unless proven that overnight engine idling is not insignificant in Europe.
	Neutral idle	**Not simulating**	**Model work necessary prior to implementation in VECTO**	**Overall:** Currently not captured. **ACEA**: The effect is not captured as automatic transmission modelling is still under development. Estimated effect 0.4%	Re-assess the issue after the AT modelling is finalized.
Components and auxiliaries	Electric hydraulic power steering	**Simulating**	**Simulating**		No action
	LED headlights	**Contradicting Views**	**Simulating**	**Overall**: Most participants claim that technology is covered. Respondents who disagree did not provide justification.	No action
	Air compressor	**Contradicting Views**	**Simulating**	**Overall:** The technology is sufficiently captured although not all the technologies are covered. VECTO sufficiently covers mechanically driven compressors and related technologies. VECTO should also consider electrically driven compressors. One respondent mentions that in the future VECTO should also consider the pneumatic consumers (brake, gearshift, air suspension) for truck and trailer, to cover the efficiency of these systems. **ACEA**: Several technologies captured (the ones that are easily verified at truck level).	No action for the moment. Can consider extending the coverage of technologies in the future if those are verifiable. Can discuss the possibility to extend part of or the complete bus auxiliaries' module to trucks.
	A/C efficiency and refrigerant	**Not simulating**	**Model work necessary prior to implementation in VECTO**	**Overall**: Mostly covered for buses and coaches but not trucks. **ACEA**: A/C efficiency can be captured by extending the auxiliary list if a certification test procedure for the system efficiency is determined.	No action on modelling. Can discuss the possibility to define a certification procedure for system efficiency starting from buses and coaches. Can extend VECTO bus auxiliaries' model to trucks if relevance is proven.
	Reflective paint and glazing	**Not simulating**	**Partially captured / Models available**	**ACEA**: The effect is not captured for trucks but it could be captured within the HVAC auxiliary model for buses and coaches.	No action unless relevance for trucks is demonstrated. Buses and coaches are covered.

Category	Technology	Respondents - Online survey	ACEA	Respondent feedback/Suggestions	Proposed Action
Controls / Energy management	Predictive cruise control	**Not simulating**	**Partially captured / Models available**	**Overall**: The effect is not fully captured in VECTO. One vehicle OEM considers these systems covered. **ACEA** recommends an implementation approach in their 2016 White Book.	Request additional feedback from ACEA on possible implementation. A clear definition is necessary that will define what exactly these systems are as the terms PCC and ADAS are too general and can include anything. Need to discuss with stakeholders the possibility to actually validate and check that CO_2 benefits of such technologies are actually delivered. Implement VECTO models if possible and if consensus has been reached on their characteristics in order to avoid very long process. Adopting a fixed CO_2 discount (needs to be quantified) might make more sense.
	Advanced Driver Assistance Systems	**Contradicting Views**	**Partially captured / Models available**	**Overall**: Some active control functions -that they do not require driver interaction- are included, such as Eco-Roll, but the available technologies should be extended. ACEA considers that the effect is not captured in VECTO but recommends an implementation approach in their 2016 White Book.	
	Vehicle Speed limiter		**Partially captured / Models available**	**ACEA**: Not captured in present VECTO simple implementation is possible.	Request additional feedback from ACEA on possible implementation. Implement if possible.

Table 4: Effect on fuel consumption by technology type based on respondents' replies.

Category	Technology	Vehicle type	Effect on fuel consumption reported in questionnaire			Number of estimates	ACEA estimate on fuel consumption
			Median	Highest	Lowest		
Engine	Waste heat recovery	Rigid trucks	-3.5%	-5.0%	-2.0%	1	-2.0%
		Tractor-trailers	-3.5%	-5.0%	-2.0%	1	-3.0%
		Coaches	-3.0%	-4.0%	-2.0%	1	-2.0%
	Engine software management optimization	Rigid trucks	-3.5%	-5.0%	-2.0%	1	-1.1%
	Improved cooling fan	Rigid trucks	-0.5%	-1.0%	0.0%	2	
		Tractor-trailers	-0.5%	-1.0%	0.0%	1	
	Improved alternator	Rigid trucks	-0.4%	-0.5%	-0.3%	1	
		Rigid or Tractor-trailer					-0.3%
	Improved water pumps	Rigid trucks	-0.8%	-1.0%	-0.5%	2	
		Tractor-trailers	-0.8%	-1.0%	-0.5%	1	
Aerodynamics	Active flow control	Rigid trucks	-2.0%	-15.0%	-1.0%	3	
		Tractor-trailers	-2.5%	-20.0%	-1.0%	3	
		Coaches	-2.5%	-12.0%	-1.0%	3	
	External grille shutter	Rigid trucks	-0.5%	-1.0%	0.0%	1	
		Tractor-trailers	-1.0%	-1.5%	-0.5%	1	
	Roof fairing design	Rigid trucks	-13.0%	-16.0%	-10.0%	1	
		Tractor-trailers	-16.0%	-22.0%	-10.0%	1	
	Wheel/bogie fairings	Rigid trucks	-3.5%	-5.0%	-2.0%	1	

Category	Technology	Vehicle type	Effect on fuel consumption reported in questionnaire			Number of estimates	ACEA estimate on fuel consumption
			Median	Highest	Lowest		
	and side skirts	Tractor-trailers	-4.5%	-5.0%	-4.0%	1	
		Coaches	-1.5%	-2.0%	-1.0%	1	
	Trailer-mounted extensions	Rigid trucks					-3.0%
		Tractor-trailers					-3.0%
	Boat tails/ extension panels	Rigid trucks	-3.5%	-4.0%	-3.0%	1	-3.0%
		Tractor-trailers	-3.5%	-4.0%	-3.0%	1	-3.0%
		Coaches	-4.5%	-5.0%	-4.0%	1	-2.0%
	Vortex generators	Rigid trucks	-0.5%	-1.0%	0.0%	2	-0.5%
		Tractor-trailers	-0.5%	-1.0%	0.0%	2	-0.3%
	Complete vehicle redesign	Rigid trucks	-2.5%	-3.0%	-2.0%	1	
		Tractor-trailers	-5.0%	-7.0%	-3.0%	1	
		Coaches	-5.5%	-8.0%	-3.0%	1	
Axles and Transmission	AMT	Rigid trucks	-0.5%	-1.0%	0.0%	1	
		Tractor-trailers	-0.5%	-1.0%	0.0%	1	
		Coaches	-0.5%	-1.0%	0.0%	1	
Hybrids	Hydraulic hybrid	Rigid trucks	-3.5%	-5.0%	-2.0%	1	-7.0%
	Full electric hybrids	Rigid trucks	-6.0%	-8.0%	-4.0%	1	
	Mild electric hybrids	Rigid trucks	-2.0%	-3.0%	-1.0%	1	

Category	Technology	Vehicle type	Effect on fuel consumption reported in questionnaire			Number of estimates	ACEA estimate on fuel consumption
			Median	Highest	Lowest		
Idling	Idle control technologies	Rigid or Tractor-trailer					-0.1%
	Neutral idle	Rigid or Tractor-trailer					-0.4%
Components and auxiliaries	A/C system efficiency	Rigid or Tractor-trailer					-0.2%
	High efficiency exterior lighting	Rigid trucks	-0.4%	-0.5%	-0.3%	1	
	Air compressor	Rigid trucks	-0.4%	-0.5%	-0.3%	1	

Table 5: Technology market penetration. Expected market share change is highlighted

Category	Technology	Current market penetration	Expected market penetration in 5-10 years	Responses
Engine	Electrical turbocompound	Innovation <3%	Low 3-10%	1
	Improvements in Intake/outtake system	Innovation <3%	Low 3-10%	1
	Waste heat recovery	Innovation <3%	Low 3-10%	2
	ECU optimization	Low 3-10%	Low 3-10%	1
	Cooling fan	Developing 11-30%	Standard ≥61%	1
	Improved alternator	Developing 11-30%	Established 31-60%	1
	Improved water pump	Low 3-10%	Developing 11-30%	2
		Established 31-60%	Standard ≥61%	
Aerodynamics	Active flow control systems	Innovation <3%	Innovation <3%	1
	External grille shutters	Innovation <3%	Low 3-10%	1
	Roof fairings	Established 31-60%	Standard ≥61%	1
	Trailer mounted extensions	Low 3-10%	Developing 11-30%	1
	Boat tails	Innovation <3%	Developing 11-30%	1
	Vortex generators	Innovation <3%	Innovation <3%	1
	Complete vehicle redesign	Innovation <3%	Low 3-10%	1
Axles and transmission	AMT	Established 31-60%	Established 31-60%	1
	CVT	Innovation <3%	Innovation <3%	1
Hybrids	Hydraulic hybrid	Innovation <3%	Innovation <3%	
	Full electric hybrid	Innovation <3%	Low 3-10%	2

		Buses: Low 3-10%	**Buses: Developing 11-30%**	2
	Mild electric hybrid	**Low 3-10%**	**Developing 11-30%**	1
Components and auxiliaries	LED lighting	**Developing 11-30%**	**Established 31-60%**	1
	Improvements in air compressor	**Developing 11-30%**	**Established 31-60%**	1
	Predictive cruise control	**Developing 11-30%**	**Established 31-60%**	1

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List of abbreviations and definitions

A/C	Air conditioning
ACEA	European Automobile Manufacturers' Association
ADAS	Advanced Driving Assistance Systems
AMT	Automated Manual Transmission
AT	Automatic Transmission
BSFC	Brake Specific Fuel Consumption
CLEPA	European Association of Automotive Suppliers
CVT	Continuously Variable Transmission
DCT	Dual Clutch Transmission
ECU	Engine Control Unit
ETRMA	European Tyre & Rubber Manufacturers' Association
FC	Fuel Consumption
FE	Fuel Economy
HDV	Heavy-Duty Vehicle
HVAC	Heating Ventilation Air Conditioning
IVT	Infinite Variable Transmission
JRC	Joint Research Centre
LED	Light-Emitting Diode
OEM	Original Equipment Manufacturer
PCC	Predictive Cruise Control
PEM	Portable Emissions Measurement
PM	Particulate Matter
RRC	Rolling Resistance Coefficient
TPMS	Tire Pressure Monitoring System
TUG	Technical University of Graz
VECTO	Vehicle Energy Consumption Calculation TOol
WHR	Waste Heat Recovery
WHTC	World Harmonized Test Cycle

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