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TNO report

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Final report: Cost-benefit analysis of options for certification, validation, monitoring and reporting of heavy-duty vehicle fuel consumption and CO_2 emissions

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Summary

A specific service request has been issued by the EC under Framework Service Contract CLIMA.C.2/FRA/2013/0007. The work under this contract, managed by TNO, has the objective to identify, define and assess options for Certification, Validation, and Reporting and Monitoring of fuel consumption and CO_2 emissions from heavy-duty vehicles.

The assessment of these options is needed regarding the quality, costs to the relevant stakeholders and stakeholder preference. This enables the EC to choose the best options for its goal: to be able to determine, monitor and positively influence the trends of CO_2 emissions of the EU fleet of heavy-duty vehicles and of individual vehicles. The Commission will ultimately utilize this work to support the development of future legislation to curb CO_2 emissions of heavy-duty vehicles.

The consortium assembled for the work consists of specialists from TÜV NORD Mobilität, the International Council on Clean Transportation (ICCT) and TNO.

A number of options has been defined and assessed for the certification of the CO_2 emission of heavy-duty vehicles and for the reporting and monitoring of the CO_2 emission. For certification, the focus was on methods for CO_2 determination, the checking of the conformity of production and the ex-post validation of the CO_2 emissions.

CO_2 determination ('D' Options)
For the CO_2 determination methodology 5 options have been identified and assessed. Option D1 (simulation and component testing, see the table below) seems to be the most promising approach from a technical point of view in terms of accuracy, repeatability, reproducibility and comparability. The stakeholder consultation revealed the preference of a large majority of stakeholders for options D1 and D2. The baseline option (D1, requiring more detailed component testing than option D2) was widely identified across the different stakeholder groups as the better option both in terms of expected quality of the results and general preference. Furthermore, option D1 (and D2) allows to determine CO_2 emissions of single vehicles for different mission profiles and payloads at a relatively low effort. Possibilities for the optimisation of the methodology in terms of the determination of actual component data instead of default data have to be further explored and assessed. The determination of the air drag by CFD simulations, which could address the issue of the large amount of body variations, which may be cumbersome to handle with the currently discussed approach (constant speed test), needs to be further investigated. Also more data is needed for some vehicle categories. Finally, it is worth mentioning that there can be differences between results from testing and simulation and the real world CO_2 emissions of the whole vehicle which could be tackled by either CoP or ex-post validation.

		Costs	Timeline	Comparability between vehicles	Technical feasibility	Accuracy	Stakeholder preference	Notes
D1	Simulation and component testing	Orange	Orange	Orange	Green	Green	Green	Preferred by both industrial and non-industrial stakeholders
D2	Simulation and reduced effort component testing	Green	Orange	Orange	Green	Orange	Green	Alternative for niche vehicles. Lowest total estimated cost.
D3	Chassis dynamometer testing	Orange	Red	Orange	Orange	Red	Orange	Alternative for ex-post validation due to better real world representation of whole vehicle. Fleet coverage is diminished in comparison to simulation options (D1, D2 and D5).
D4	On-road testing (PEMS / fuel flow meters)	Orange	Red	Red	Orange	Red	Orange	Alternative for ex-post validation due to best real-world representation of whole vehicle. Fleet coverage is diminished in comparison to simulation options (D1, D2 and D5). Least preferred option from industrial stakeholders.
D5	Simulation and transient engine testing	Red	Red	Orange	Green	Orange	Orange	Alternative for hybrids. Highest total estimated costs.

Green: lowest effort/costs, time line implementation EC is achievable (Certification Q3 2017, monitoring Q1 2018), good comparability between vehicles, generally technically feasible, most accurate, highest stakeholder preference, and/or no issues with regard to the criterion.
Orange: significant less performance on the criterion and/or existing issues with regard to the criterion, less preferred.
Red: least performance, serious issues with regard to the criterion, not preferred.
Hatched: not a relevant criterion for the option.
White: not addressed in the study.

CoP ('P' options)

The conformity of production (CoP) is a corner stone within the type approval process and shall ensure constant quality of the product, in this context a reliable CO_2 value (for each individual vehicle). The 2007/46/EC allows some freedom in defining CoP procedures. A CoP test does not need to be a repetition of the type approval test. Consequently, different options are possible as CoP test. The options developed are: component specific CoP, process specific CoP and vehicles specific CoP (see the table below). The results of the stakeholder consultation regarding the options for the validation of the simulated CO_2 values showed a difference in views between industrial stakeholders (who favour a component-specific approach to CoP with component testing) and all of the rest (who support both the process-specific and the vehicle-specific approach).

There are also clear differences in responsibilities between the options. Option P3, which includes vehicle testing, is the most costly.

		Costs	Timeline	Comparability between vehicles	Technical feasibility	Accuracy (depends on D option)	Stakeholder preference	Notes
P1	Component-specific CoP							Preferred option for OEMs and TAAs/technical services.
P2	Process-specific CoP							
P3	Vehicle-specific CoP							Preferred option for research bodies, consultancies and NGOs. Least preferred option for industrial stakeholders.

Ex-post validation
The ex-post validation could be an additional measure to show that the specification of the final vehicle in terms of fuel consumption / CO_2 emission is in line with the simulated values. On vehicle level, two approaches are in principle thinkable, which are: 1) simplified cycle testing and 2) testing under real driving conditions. The simplified cycle test has clear advantages in terms of repeatability, reproducibility and effort. Considering this test as CoP test would render an separate ex-post validation unnecessary.

Monitoring and reporting ('M' options)
During the project the stakeholders were consulted for their views on monitoring and reporting. This has lead to the definition of a baseline option which is tailored to the monitoring the CO_2 emission of heavy-duty vehicles and to further options on top of the baseline. The baseline option includes monitoring of individual HDV, extended data of different usage conditions of the vehicle and a new metric. To this baseline option an additional set of options has been defined for: 1) the amount and types of technical data of HDV that could be monitored on top of the data for the baseline, 2) different processes that can be followed, each of which involves different entities and responsibilities and 3) improvement of the data management.

There is a generally positive sentiment of stakeholders towards monitoring and reporting the CO_2 emissions from HDVs: both industrial and non-industrial stakeholders support the "extended" monitoring and reporting scheme (more parameters than currently covered in the CoC) as a means to improve transparency, and they call for a harmonised approach to data handling in order to reduce the additional administrative burden. It is recognized by the stakeholders that more data would be needed to follow the trends of HDV. Mentioned are data of different mission profiles, payload levels, addition of an alternative CO_2 metric and technical data that determines the utility of a vehicle which are therefore included in the baseline option M1. This M1option comes with responsibilities for the same entities (EC, Member State Registration Authorities and Vehicle OEMs) as for the monitoring of passenger cars and vans. The M3 options, which consider responsibilities for the monitoring for different entities, still need to be further discussed with stakeholders. The M2 options are about technical data to be monitored. M2.1 (VECTO data) is not supported by the vehicle OEMs. M2.2 (Multi-stage vehicles) and M2.3 (trailers) seem not to be feasible on a short term. For M2.2 it is recommended to further investigate the feasibility of the options to determine a representative CO_2 emission value for MSV. The M4 options (modernization) also seem to be not feasible on a short term. These options however, will in the end probably be less costly, as they could help to automate the monitoring process and on top of that, make the monitoring more transparent and robust.

		Costs	Timeline	Comparability between vehicles	Feasibility	Accuracy	Stakeholder preference	Notes
M1	Baseline monitoring: Member States+EC							Stakeholders generally positive towards this option regarding monitoring individual HDV and extended technical data
M2.1	Additional data input to VECTO							Confidentiality issues mentioned by vehicle OEMs
M2.2	Additional data MSV							Complex, time needed to further explore, assess issues
M2.3	Additional data trailers							Lack of harmonization for data collection
M3.1	Member States + vehicle OEM							To be further elaborated, explored and discussed with stakeholders
M3.2	Member States+Type Approval Authority							To be further elaborated, explored and discussed with stakeholders
M3.3	Vehicle OEM self-monitoring							To be further elaborated, explored and discussed with stakeholders
M4.1	Digitalization							Seen by some TAA and the EC as improvement for data transparency and accuracy but time is needed for implementation
M4.2	Use of (central) databases							Seen by some TAA and the EC as good solution in the long term for data handling and storage

Contents

1 Introduction

1.1 Background

Transport is responsible for approximately a quarter of EU greenhouse gas (GHG) emissions, with the road freight sector accounting for nearly 6%. While GHG emissions from other sectors have decreased by almost a quarter between 1990 and 2009, emissions from transport have increased by almost a third in the same period. In the future significant increases in total GHG emissions from transport – and in particular HDVs – are expected if no additional policies are implemented (AEA, 2010).

The long-term objective of the European Commission is a CO_2 reduction of 90% by 2050 for all sectors combined. For transportation the target is lower, around 60%.

In order to achieve this objective, the Commission is engaged with industry stakeholders and contractors on the subject of HDV CO_2 emissions since 2007. It commissioned the study 'Reducing Greenhouse Gas Emissions from Heavy-Duty Vehicles' (Faber Maunsell, 2008), in which GHG reduction potential and policy options were evaluated.

Since 2009, a number of projects have been initiated to further evaluate the CO_2 reduction potential for HDVs, as well as to explore policy options and the development of a certification procedure (see Table 1).

Table 1: EC projects on the topic of CO_2 reductions from HDVs

EC project	Description
LOT 1 project: 'Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles – LOT 1: Strategy'	The LOT 1 project provided an overview of the European truck manufacturing industry and an overview of possible policy and technical measures for reducing HDV energy consumption and CO_2 emissions. In 2011 TIAX carried out a study for the ICCT on the "European Union Greenhouse Gas Reduction Potential for Heavy-Duty Vehicles", which is available through the DG CLIMA website, and provides a more detailed assessment of costs and potentials of CO_2 reduction options for HD vehicles in 2030, a comparison to the results of the LOT 1 study, as well as a comparison between EU and US baseline trucks.
LOT 2 project: 'Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty vehicles, LOT 2, service contract N° 070307 /2009/548300/SER/C3	In LOT 2, the basis of the certification procedure was developed. Several options for a procedure were studied: Chassis dynamometer measurements On-road testing with PEMS Simulation tool & component testing The third option, the simulation tool, was chosen because it provides the most cost efficient, flexible and accurate basis to cover all truck models and the best incentive to improve all systems that play a role in the HDV energy consumption. These are the base truck including engine, gearbox and axle transmission, auxiliaries and tyres, the body (cargo) of the truck and the (semi) trailer. In the future, the simulation tool may also provide a good basis for individual fleet owners to

EC project	Description
	use to select truck types and configurations that would best serve their particular usage pattern.
LOT 3 project: 'Development and validation of a methodology for monitoring and certification of greenhouse gas emissions from heavy duty vehicles through vehicle simulation'; Service contract CLIMA.C.2/SER/2012/0004	LOT 3 provided a complete description of the CO_2 test procedure in the form of a technical annex for a regulation and the corresponding software together with a set of default values for those components were generic data is allowed instead of vehicle specific values. Within LOT 3, the test procedure will be validated first in a proof of concept phase on a sample of vehicles and components and later in a larger pilot phase. Additionally a method for verification of the CO_2 declaration values by the type approval authority will be developed. The entire test procedure will be elaborated and validated for at least three important HDV categories in LOT 3.

Some relevant reports:
- HDV-CO_2 simulation tool: (ARES(2012)401058 "Development of a Heavy Duty Vehicle CO_2, Emissions and Fuel Consumption Simulation Tool", JRC Internal reference: IET/2012/F/08/03/NC;
- JRC "Proof of concept report", 03/02/2014;
- Marginal abatement cost curves for Heavy Duty Vehicles, Publication code: 12.4726.63, for the establishment of cost curves for packages of technical measures for CO_2 reduction (2012).

Most reports are available under:
http://ec.europa.eu/clima/policies/transport/vehicles/heavy/studies_en.htm

The LOT 1 project provided a solid overview of the European truck manufacturing industry, an overview of possible policy and technical measures for reducing HDV energy consumption and CO_2 emissions. In 2011 TIAX carried out a study for the ICCT on the "European Union Greenhouse Gas Reduction Potential for Heavy-Duty Vehicles", which is available through the DG CLIMA website, and provides a more detailed assessment of costs and potentials of CO_2 reduction options for HD vehicles in 2030, a comparison to the results of the LOT 1 study, as well as a comparison between EU and US baseline trucks.
In LOT 2, the basis of the certification procedure was developed. Several options for a procedure were studied:
- Chassis dynamometer measurements
- On road testing with PEMS
- Simulation tool & component testing

The third option, the simulation tool, was chosen because it provides the most cost efficient, flexible and accurate basis to cover all truck models and the best incentive to improve all systems that play a role in the HDV energy consumption.
These are the base truck including engine, gearbox and axle transmission, auxiliaries and tires, the body (cargo) of the truck and the (semi) trailer. In the future, the simulation tool may also provide a good basis for individual fleet owners to use to select truck types and configurations that would best serve their particular usage pattern. The accuracy of the simulation approach was assessed positively in the above-mentioned JRC "Proof of concept report' released in February 2014.

LOT 3 provided a quite complete description of the CO_2 test procedure in the form of a technical annex for a regulation and the corresponding software together with a set of default values for those components were generic data is allowed instead of vehicle specific values. Within LOT 3, the test procedure was validated in a proof of concept phase on a sample of vehicles and components. Additionally a method for verification of the CO_2 declaration values by the type approval authority will be developed. While the entire draft test procedure was elaborated and broadly validated for three important HDV categories in LOT 3, further testing is required under the new LOT 4 as well as improvements of the VECTO software that is still under development.

The subject of this service request includes the identification and analysis of options for the certification, validation, and reporting and monitoring of HDV fuel consumption and CO_2 emissions. It also includes a detailed costs analysis of what the options would mean for the main stakeholders.

1.1 Goal

A specific service request has been issued by the EC under Framework Service Contract CLIMA.C.2/FRA/2013/0007. This work under this contract, managed by TNO, has the objectives to identify, define and analyse options for Certification, Validation, and Reporting and Monitoring of fuel consumption and CO_2 emissions from heavy-duty vehicles and to determine the costs of these options to the relevant stakeholders. The Commission would ultimately utilize this work to support future legislation along with a full cost-benefit analysis, which will be needed to complement the Impact Assessment.

The consortium assembled for this task consists of senior and support staff from TÜV NORD, the International Council on Clean Transportation (ICCT) and TNO.

1.2 Structure of the report

Under section 2, this report describes the overall project methodology and structure of the work plan.

The work performed for certification ex-post validation is described in section 3, monitoring is discussed in section 4 and the stakeholder assessment and the cost analyses is discussed in section 5. Conclusions and recommendations are in section 6 of this report.

2 Methodology

2.1 Overall project methodology and structure of the work plan

The table below summarises the tasks that will be completed for this project and the main activities of each task. Also the respective task leaders are indicated. The tasks are schematically presented in Table 2 below.

Table 2: Description of tasks and task leaders

Task #	Task	Main activities
1	Certification ex-ante	- Identification, definition and assessment of certification options for HDV fuel consumption and CO_2 emissions, including a clear definition of tasks and responsibilities of the different stakeholders involved.
2	Ex-post: validation	- Identification, definition and assessment of validation options for HDV fuel consumption and CO_2 emissions, including a clear definition of tasks and responsibilities of the different stakeholders involved.
3	Monitoring & Reporting	- Identification, definition and assessment of options for a European monitoring and reporting system for HDV fuel consumption and CO_2 emissions. - Identification of tasks and responsibilities of the different stakeholders involved.
Parallel to the tasks	Stakeholders consultation	Stakeholders consultation for tasks 1-6: - Interviews and questionnaires - Workshop - Stakeholders include truck manufacturers, trailer and body manufacturers, key (driveline) parts suppliers, Technical Services, Approval Authorities, the European Commission and EEA
4	Costs of Certification	A detailed costs analysis of the (ex-ante) certification for the industrial stakeholders on these options for certification, validation and monitoring and reporting.
5	Costs of validation	A detailed costs analysis of the certification validation (ex-post) for the industrial stakeholders.
6	Costs of Monitoring & Reporting	A detailed costs analysis for a European monitoring and reporting system, including costs for Industrial stakeholders, for Technical Services, Approval Authorities and the Commission.

The stakeholder consultation will be performed in parallel with the other tasks throughout the project (Figure 1). It is necessary to involve the Stakeholders early in the project in order to introduce the project, its goals, and the Consortium (project team). It is also key to highlight the importance of the stakeholder's contribution and buy in. The earlier that the stakeholders are aware of their role and the fact that they will likely be called on to participate in the project though consultation, the higher the likelihood of fruitful Stakeholders discussions. A stakeholder consultation took place in the middle of the project (tentatively September 2014), upon completion of tasks 1, 2 and 3, yet prior to the start of tasks 4, 5, and 6. In addition to the mid-project stakeholder consultation, we planned a final presentation for briefing key stakeholders at the conclusion of the project.

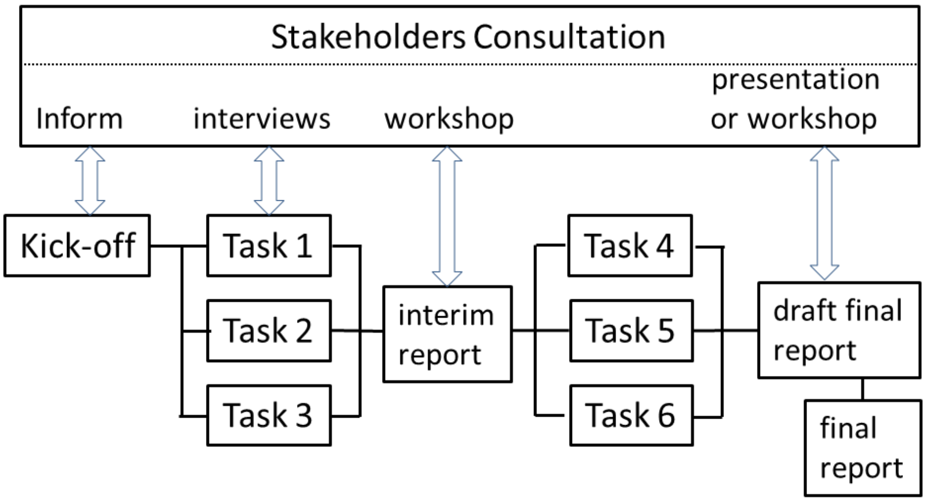

Figure 1: Schematic representation of the project

2.2 Assessment

On the basis of the proposal of technical options presented to the European Commission by TNO and TÜV Nord, a *stakeholder consultation* was carried out to gather the views of the different stakeholders regarding the technical merit, feasibility and expected costs of the different proposals. The consultation was supported by the responses to a comprehensive questionnaire (which was circulated to all stakeholders) and the outcome of a series of one-on-one interviews with a reduced number of key stakeholders.
Whenever possible, we also gathered cost estimates for task 4, 5 and 6 for the main cost items associated with the different technical options being considered. These data were coupled to commercially available European HDV market databases and various HDV industry sources to identify *cost structures* and estimate the costs that would be incurred by industrial stakeholders in the CO_2 monitoring scenarios underlying the technical options. We also provide a qualitative discussion of the benefits of monitoring CO_2 emissions from HDVs in Europe. The results of this cost/benefit analysis are presented by stakeholder type.
Each proposed option was evaluated on the basis of three dimensions:

1. *Cost:* This dimension comprises the costs borne by each stakeholder. Note that the questionnaires can only be used for qualitative/ordinal assessments (i.e. stakeholders can rank the different options in terms of cost). Quantitative cost estimates were gathered in ad-hoc text boxes in the questionnaire and also during the follow-up telephone interviews with selected stakeholders and complemented with desktop research activities during phase 2.

2. *Preference:* The preference of each stakeholder regarding the relevant options was gathered from both direct (stated preference) and indirect questions (inferred preference). To the extent possible, the preference is separated from cost considerations.

3. *Quality*: This dimension comprises aspects such as the technical merit of each option, its prospects for further technical development, etc.

Pro et contra
An elaborate qualitative assessment of the options comprises the assessment of the options against a list of relevant criteria in terms of pro et contra. This is done for the D, P, S and M options in the respective chapters next to the options. Besides costs most criteria are qualitative.

The options of tasks 1, 2 and 3 have been compared and assessed against the criteria which have been developed with the Commission at project kick-off.
Basic qualitative criteria are:

- *Risks and Reliability:* are there any risks for the long term CO_2 policy of the EU (e.g. loopholes, the design of the procedure and process needs to take account of this)? Risks for incorrect data? Risk for manipulation/fraud?
- *Comparability:* Could the resulting dataset be used for comparison of vehicles and or manufacturers?
- *Fairness*: Is the impact/burden of the introduction of the monitoring and reporting process even for the individual stakeholders?
- *Representativeness, accuracy, consistency:* How well is the real CO_2 emission performance and other parameters covered by the procedure/process and how reproducible and accurate is the CO_2 emission?
- *Confidentiality:* is data confidential and available for the process?
- *Timeline:* are there any issues with regard to the time of implementation (in Q1 of 2018 a monitoring system should be active).
- *Complexity, feasibility.* Are stakeholders equipped to deal with the process? Is learning time, additional communication or training required? Are additional investments needed?

3 CO_2 determination, certification and ex-post validation

3.1 Introduction

Within the activities of service contract CLIMA.C.2/SER/2012/0004 "*Development and validation of a methodology for monitoring and certification of greenhouse gas emissions from heavy duty vehicles through vehicle simulation*" a certification procedure related to the new methodology to provide robust data on the level of CO_2 emitted by the whole HDV including trailers and different bodies was developed.
In view of the vast number of variations and combinations possible in the construction and usage of HDVs it does not seem to be possible to determine the CO_2 emissions and fuel consumption through tests that are representative for a vehicle type, as it is done for light duty vehicles. Instead of such testing the simulation tool, "VECTO" has been developed. This working assumption of the Commission is however tested in the present report, which compares the simulation-based approach with other options.

VECTO can simulate the CO_2 emission and fuel consumption of each vehicle produced, based on input data of vehicle components. With that tool it seems appropriate that the CO_2 values per vehicle produced can be generated by the manufacturers of the vehicles themselves, taking into account the final specification of the vehicle by applying a downloadable and executable version of the VECTO simulation tool.
The aim of the certification procedure is therefore to ensure that the determined CO_2 and fuel consumption values are **comparable** between different manufacturers, **verifiable** by a third party and **monitorable** by the competent authorities (Commission and Member States). The certification process shall

- create a procedure to generate a robust CO_2 / fuel consumption value for each HDV produced and
- allow for recording and monitoring of such values

In a mid-term perspective the monitoring of CO_2 emissions shall generate knowledge of the CO_2 emissions of different vehicle segments, which could also be a basis for later regulation of CO_2 emissions.

For the development and assessment of options for certification, the legal implementation is also considered briefly in Appendix C. For this implementation the most obvious options are considered

The assessment of these options regarding the legal base to consider is <u>not</u> part of the present report. The way forward will be further discussed within the editing board that is being established by DG GROW.

The focus of this chapter (3) and the following (4) is the definition of options for:

- the determination of a specific CO_2 value / fuel consumption,
- the process of conformity of production (CoP),
- and an ex-post validation procedure that is being considered either independently, or as a cornerstone of CoP.

This is the basis for a comparative assessment and cost-benefit analysis that will be done for the options.

3.2 CO_2 and Fuel Consumption Determination Methodology

The methodology for the determination of the specific CO_2 emission and fuel consumption shall be as fair, robust, reliable, traceable and repeatable/reproducible as possible. Furthermore, the development and optimization of vehicle components that reduce the CO_2 emission shall be stimulated.

Below the options are summarized for the method of determination of the vehicle CO_2 emission and fuel consumption. Option D3 is more or less similar to the process of CO_2 determination for light duty vehicles, where the CO_2 emissions are determined by means of coast down tests and chassis dynamometer testing. The other options use VECTO, the simulation tool, as basis for the determination of the vehicle CO_2 emission. The options vary in the effort needed to determine the contribution of the components, from simulation to testing.

3.2.1 Option D1: Combination of component testing and simulation / VECTO (baseline option, Lot3)

A CO_2 and fuel consumption value shall be generated for each newly produced vehicle. The simulation by VECTO with component input values for each specific vehicle put on the road requires well defined procedures on how to establish these input values (described in the “Technical Annex”).
For the time being 17 vehicle classes (trucks only, buses and coaches to be integrated later) are defined. Besides the definition of the base vehicle also the bodies and trailer / semi-trailers are allocated to the vehicles, based on standard configurations (in a further step also individual bodies and trailers shall possibly be integrated). These configurations are finally allocated to the defined vehicle classes and corresponding driving profiles.
After the overall vehicle configuration is specified, the CO_2 and fuel consumption affecting parameters necessary as inputs for VECTO are determined by testing and verification. This part of the process is considered as *component testing*. In a very generic way the component testing activities can be summarized by the following:

- Air drag test; an additional assessment tool called the *CSE (constant speed test evaluation)* tool for the calculation of the air drag coefficient C_d is part of the *VECTO.*
- Transmission / Axle test; this covers the determination of the efficiency of the complete vehicle drive train, such as gearboxes, axles, transfer cases etcetera.
- Engine test; this test is necessary to describe the engine fuel consumption map as VECTO input.

As an option it is considered to describe default values (at least for the Axle, the transmission and with respect to few applications for the air drag), which can be used instead of values generated by testing. Those default values shall be set to ranges which are less attractive than values possible by state-of-the-art technologies in order to provoke the use of advanced components, using all the possibilities of simulation of VECTO with actual rather than default values.
Furthermore, some of the auxiliaries installed in the vehicle and on the engine are CO_2 and fuel consumption affecting components.

Unlike the testing specification indicated in the Technical Annex for the Air Drag, the Transmission / Axles and the Engine, specific testing provisions for such auxiliaries are not available so far. For that reason the power consumption of truck auxiliaries is considered within the CO_2 and fuel consumption calculation by adding a constant power demand to the engine load. In the present version of VECTO, power demand is defined (in tables within the Technical Annex) as a function of auxiliary type and can vary, dependent on the vehicle segment, the application and the specific technology.

The power consumption of the following auxiliaries shall be considered:

- Cooling fan(s)
- Steering pump(s)
- Electrical system/Alternator
- Pneumatic system(s)/Air compressor
- Air-Conditioning system(s)

For the time being these default values for the auxiliaries are only applicable to trucks. For buses and coaches (where auxiliaries may have a higher share of the total energy consumption) a more sophisticated approach is currently under development[1]. This is of particular importance for *HVAC* (heating, ventilation, and air-conditioning) systems for buses and coaches.

Another important VECTO input value is the *rolling resistance co-efficient (RRC)* of the vehicles tires. This value does not need to be determined separately within the CO_2 process since it is available via the tire manufacturer (considered as supplier to the vehicle manufacturer). For the tire labelling of Regulation EC 1222/2009 (EC 1235/2011) the RRC to be declared is already determined in accordance with ISO 28580. The applicable tire rolling resistance coefficient (RRC) for each of the tires installed on the vehicle is declared by the vehicle manufacturer. The general layout of the procedure is depicted in Figure 2.

[1] Quantify energy consumption of Heavy Duty Vehicle auxiliary components and their contribution to CO_2 emissions of buses and coaches. Integrate auxiliaries into the VECTO simulator and into the certification methodology for HDV CO_2 emissions. CLIMA.C.2/FRA/2013/0007

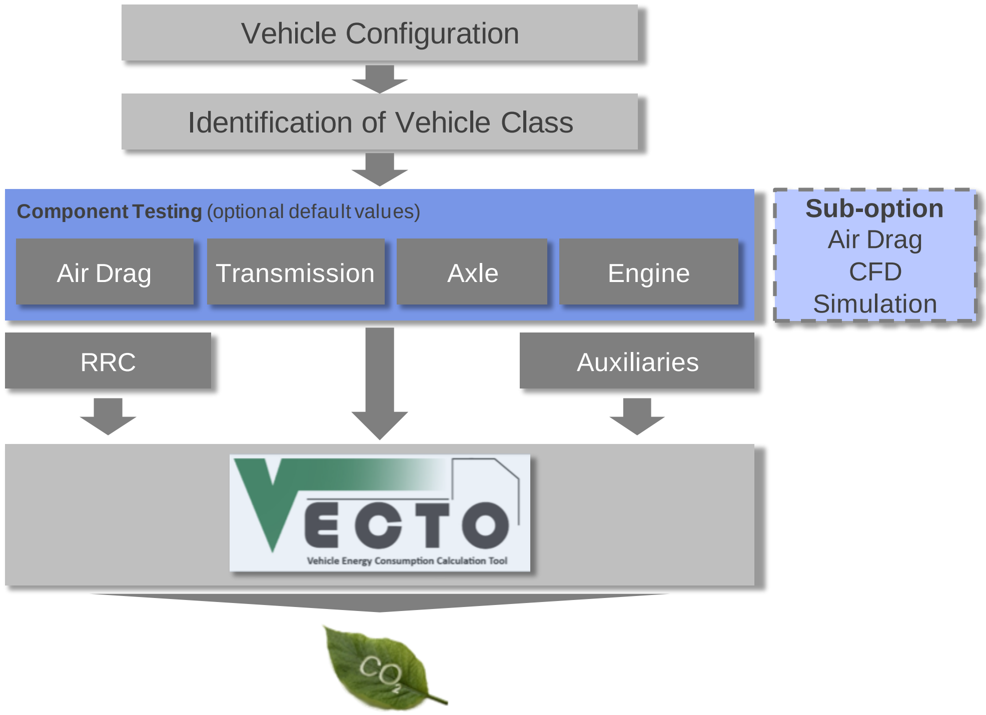

Figure 2: Process scheme of baseline option

Pros

- Compared to vehicle testing, of which it is assumed that families are needed to keep the testing effort and costs within an acceptable margin, the method is more accurate in the fact that it can cover more variation in vehicles at a lower effort. As such the tool can be used to determine the CO_2 emission for each individual whole HDV and if components are integrated well in the method, can become a technology driver for suppliers of components and for manufacturers in a sense that the most efficient components can be chosen.
- The CO_2 emission can relatively easily be determined for different mission profiles and payloads and include (variations of) road gradients and as such deliver more detailed information for the monitoring of the CO_2 emissions.
- The tool can be used by manufacturers to determine the most efficient (least fuel consuming, least CO_2 emitting vehicle) set up for their customers and tailor it to the specific needs of their customers, taking account of mission profiles, payloads and different combinations of components, this in a way that is transparent and harmonized between all manufacturers.
- Reproducibility and repeatability are assumed to be good, compared to complete vehicle testing where test conditions affect the test. However, for air drag testing, which is an optional part for D1, the issue with test conditions and reproducibility is still present.
- The driver is excluded as a factor of influence and thus the method makes vehicles better comparable.
- A high accuracy is possible, but it largely depends on the accuracy of the data of the individual components and the integration of their controls in the tool.

Cons

- There is a risk for a mismatch (deviation) between the simulated and the real CO_2 emission because not all parameters that affect the CO_2 emission may be included or integrated well. The CO_2 emission is a result from the simulation of a combination of all the data (either measured or default data) of the components and does not take completely into account the way the components are integrated in the vehicle powertrain and how the components work together in real world transient operation.
- For components, like engines, families may need to be defined. This would then still influence the accuracy of the method. For CO_2, smaller families may be needed, compared to the families as defined in legislation on pollutant emissions. This is because relative smaller differences in fuel consumption/CO_2 emissions between engines may have to be distinguished by the procedure.

Notes

- The issue of possible misuse can possibly be tackled by the introduction of an ex-post validation method.
- In the case default values are used for many components, the accuracy may decrease.
- If default values are to be used, the definition of worst-case default values in combination with optional testing could still help to drive technology as long as VECTO is also able to use real input values for the same components. It is to be questioned if this would be equally fair for large vehicle manufacturers and SME (such as bodybuilders), given the higher effort associated with the optional testing.
- The VECTO tool is not fully ready and still needs further refinement, checks and additional data is needed for some vehicle categories. Although for a few vehicle types the procedure seems able to perform within the desired margins of accuracy, it still has to be proven that the procedure and tool enables a fair comparison between vehicles and ranking of vehicles with regard to their CO_2 emission and is able to incentivise efficient technology.

3.2.2 Option D2: Simulation and Reduced Testing Effort (simplified baseline option)

The second option is mainly a simplification of the baseline option by reducing the testing effort. Testing is in this approach only done for the engine by generating a detailed fuel map. Transmission and axle efficiencies are based on technology specific default values /maps.
The air drag test can apply as in option D1, however the air drag can also be computed by a CFD simulation (sub-option as indicated in Figure 3), RRC values could still be taken from the measurements in accordance with ISO 28580 (to be performed by the tyre manufacturer and communicated between vehicle and tyre manufacturer). Auxiliaries are based on technology specific default values.

Effects of these options would be an appreciable reduction of costs and efforts for the vehicle manufacturer but in parallel loss of accuracy and a strong limitation on technology drivers for manufacturers and component suppliers. If CFD is used for the simulation of air drag for small variations in bodywork and hence decrease the family size, it could even lead to improvement of accuracy.

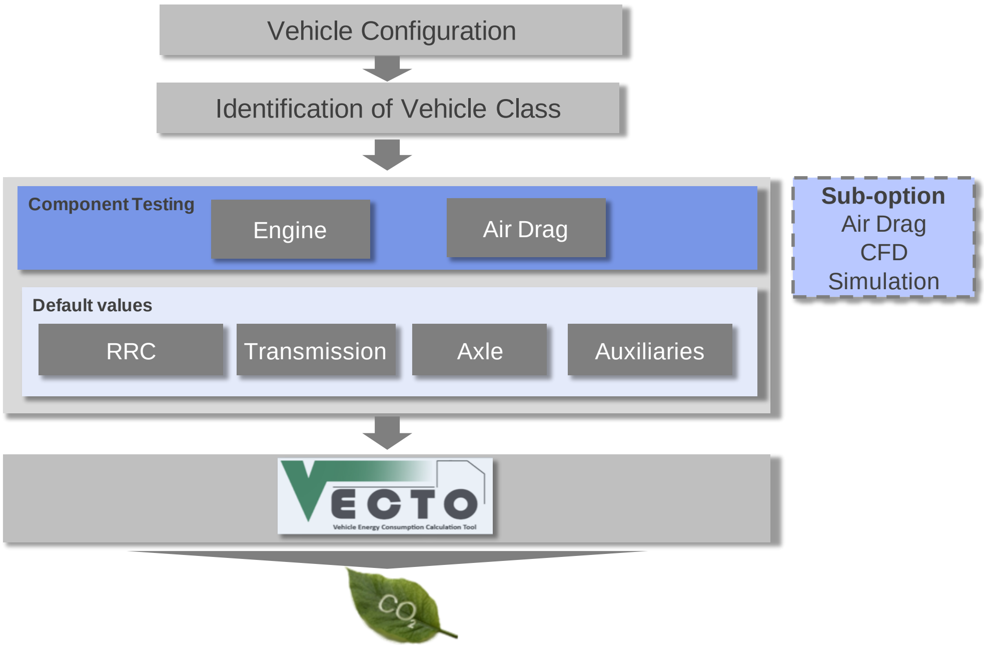

Figure 3: Process scheme for simplified baseline option

Pros

- Reduction of testing effort for the determination of axle and transmission efficiency.
- Reduction of testing effort for the determination of air drag (C_DxA) by using CFD calculation instead of an air drag test.
- Reduction of effort (costs), see the outcome of task 4, 5 and 6.

Cons

- (Slight) loss of accuracy for axle and transmission efficiency and auxiliaries.
- No discrimination of transmission and axle efficiency. Hence, no technology driver for manufacturers and component suppliers to optimize.
- The definition of worst-case default values in combination with optional testing could still help to drive technology. It is to be questioned if this would be equally fair for large vehicle manufacturers and SME given the higher costs associated with the optional testing.
- The approach gets closer to a family approach.
- This option could be considered for niche applications.

Notes

- Air drag simulation with CFD does not necessarily lead to a less accurate determination of air drag. If implemented and used well it could deliver air drag values for a wider range of variations of body work and air drag reducing measures under varying conditions (like wind yaw angle). On the other hand, it will probably be difficult to harmonize CFD calculations and if this would be required, at least some years of time would be needed to investigate and develop this option.

3.2.3 *Option D3: Chassis Dyno Test on a whole vehicle*

The third option for the determination of CO_2 emissions is based on chassis dyno tests. Because of the huge variety of commercial vehicle specifications with respect to cabin and drivetrain design, auxiliaries, add-ons, etc., it will not be possible to test each vehicle configuration on a chassis dyno. An option would be the building of families on basis of a worst-case approach with the result, that not every produced vehicle gets a specific CO_2 value in the first step. This could be overcome by generating technology specific compensations and therewith build the opportunity to label each vehicle with a specific value.
Nevertheless, driving resistances (air drag and rolling resistance) have to be measured as input data for the chassis dyno. This can be done either by the combination of constant speed tests and RRC values communicated by the tyre manufacturers or similar to passenger cars on basis of coast down tests (which was pointed out to be not accurate enough for simulations). An approach based on standard bodies/trailer/semi-trailers could be used, similar to option D1, to determine the driving resistance of the complete configuration.
Tests are finally performed on the chassis dyno, simulating defined payloads. Applications specific cycles could be used, similar to those defined in the baseline option.
The possibility and burdens regarding the definition of vehicle families have to be further assessed.

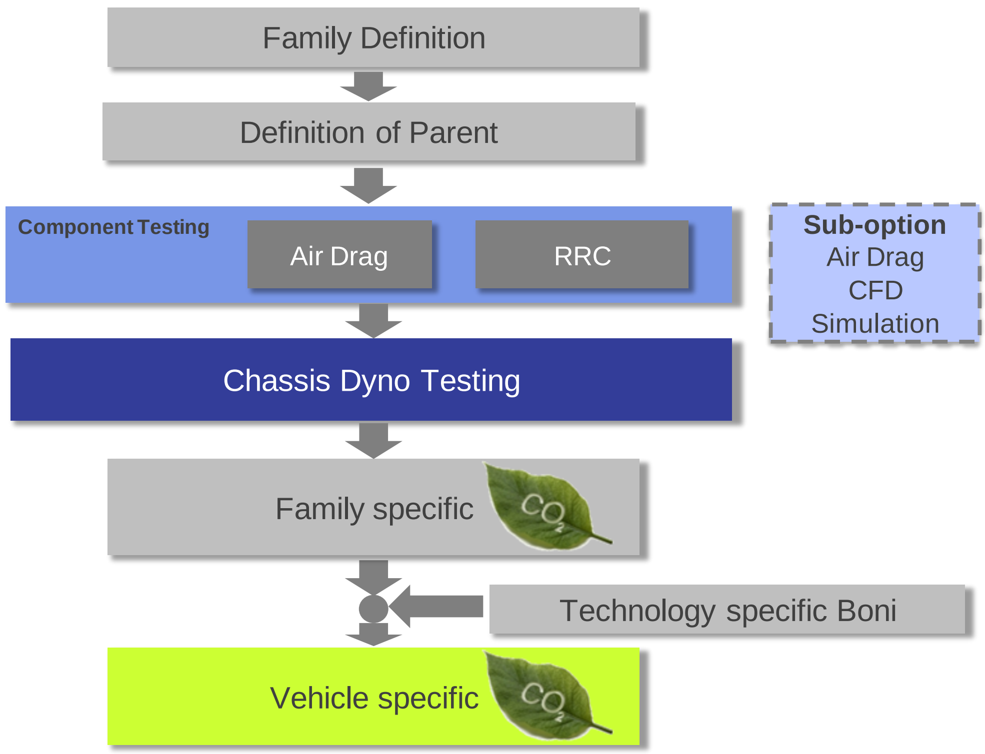

Figure 4: Process scheme chassis dyno testing

Pros

– Almost real operation of the whole vehicle, with all components working together, under relatively stable laboratory conditions.

Cons

- High testing effort. The effort increases if more information is needed, for instance for testing more payloads, mission profiles, more parents (of smaller families).
- Accuracy and reproducibility also depend on the road load determination and for the use of road load in principle the same issues rise as for option D1 and D2.
- Defining families (and testing parents) comes with the burden of the loss of accuracy because less variants are tested.
- Reproducibility and accuracy for testing CO_2 and fuel consumption of trucks on a chassis dynamometer are relatively bad. The effects are different from that of passenger cars on a chassis dyno due to the relative high load which is needed for trucks to be put to the drive axle to prevent abnormal slip between roll and tire. The effects of the tire/roll interaction and influence of tire temperature can cause variations of around 5% and higher if not controlled well. Also other variables can greatly affect the repeatability/reproducibility, like the driver driving the truck on the chassis dyno.
- This option would still require a considerable amount of time for the development of the test procedure.
- There are only few HDV chassis dynamometers in the EU.

Notes

- Technology specific compensations or corrections within families could increase the accuracy for individual vehicles and allow discrimination of certain technologies, herewith driving these technologies.

3.2.4 *Option D4: Fuel Consumption Measurement during Real Driving*

Another option would be the direct measurement of CO_2 or fuel consumption during real driving conditions on a similar basis as defined for the In-Service Conformity measurements according to 582/2011/EC (related to the measurement procedure, not the choice of vehicles).
In 582/2011/EC “the conformity of in-service vehicles or engines of an engine family shall be demonstrated by testing vehicles on the road operated over their normal driving patterns, conditions and payloads." The in-service conformity test shall be representative for vehicles operated on their real driving routes, with their normal load and with the usual professional driver of the vehicle. When the vehicle is operated by a driver other than the usual professional driver of the particular vehicle, this alternative driver shall be skilled and trained to operate vehicles of the category subject to be tested. Ambient conditions (temperature, wind, rain) have a significant impact on fuel consumption. Therefore a bandwidth for ambient conditions would need to be defined or/and a correction formula for ambient conditions would need to be developed.
Similar to option 3 (chassis dyno), vehicle families and parents could be defined to reduce test efforts and be tested on basis of application specific operating conditions. The boundary conditions for testing would have to be tightened because it is not measured against a limit with compliance factor (pass/fail criterion) but a specific value shall be generated.

To finally generate vehicle specific data, similar to option 3 (chassis dyno), technology specific compensations could be defined and applied.

The possibility and burdens regarding the definition of vehicle families that are required under this option (testing is only possible on a small number of vehicles) have to be further assessed.

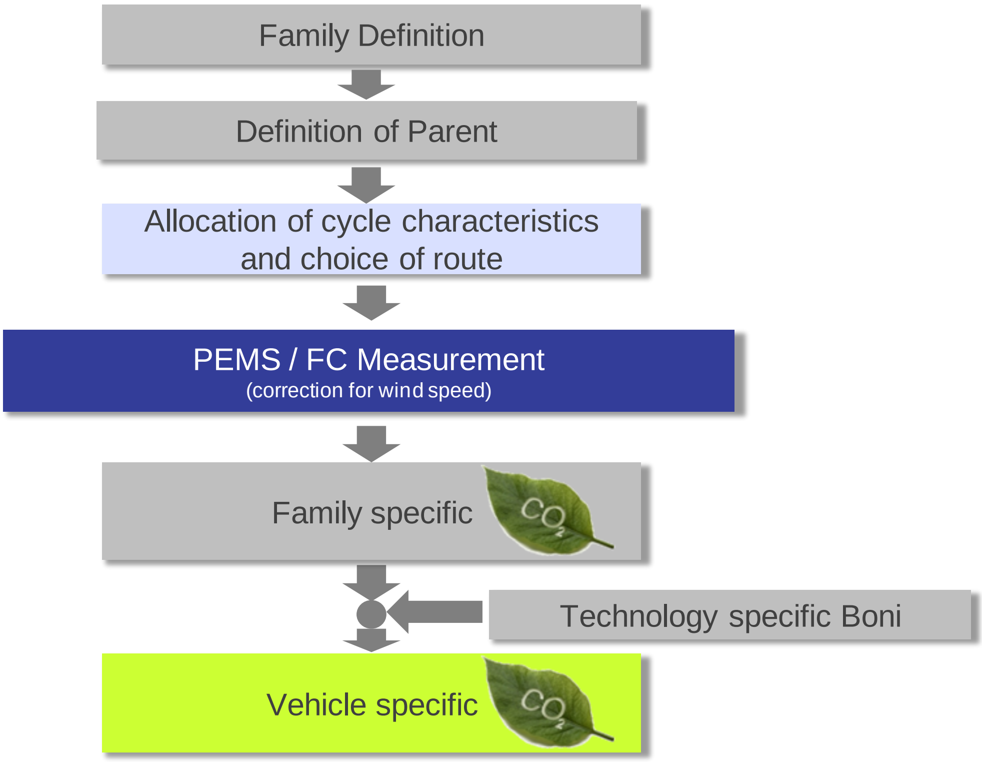

Figure 5: Process scheme FC real driving testing

Pros

– Real world operation of the whole vehicle, with all components working together, hence this option delivers a real world CO_2 value.

Cons

– Reproducibility is not good due to variations in test conditions that can't be controlled or can't be controlled well enough. Most important examples are ambient and weather conditions and the drivers influence. The effects can be compensated for by corrections to some extent, but an amount of uncertainty would remain.
– This option is still relatively expensive and a family definition would be required to lower the costs. Defining families (and testing parents) comes with the burden of the loss of accuracy because less variants are tested. Costs increase if more information is needed, for instance for testing more payloads, mission profiles, more parents (of smaller families).
– Although an on-road testing procedure has already been developed for in-service conformity of HDV with regard to noxious emissions, it is thought that still a considerable amount of time would be needed for the development of a test procedure which is dedicated for the best possible accurate determination of the CO_2 emissions.

Notes

- Technology specific compensations or corrections within families could increase the accuracy for individual vehicles and allow discrimination of certain technologies, herewith driving these technologies.
- Because the procedure produces real-world CO_2 emission it can optionally be considered for ex-post validation. However, a substantial margin is needed before non-conformity can be confirmed, given the low reproducibility, which is caused by the varying test conditions.

3.2.5 Option D5: Simulation and Transient Engine Test

A further option is the reversion of the baseline option. On basis of the specific vehicle, body/trailer/semi-trailer configuration and tested, simulated or default data related to air drag, rolling resistance, transmission, axle and auxiliaries, a simulation of the longitudinal dynamics within application specific cycles can be performed, similar to the baseline option. Different to the base line option, the fuel map of the engine is not measured and not part of the simulation tool. Based on the vehicle speed and the resistance forces, torque and speed at the wheels can be calculated and passed through axle and transmission to the engine. As the fuel map is not part of the simulation, the result is not a vehicle specific CO_2 or fuel consumption based on an engine fuel map, but a specific load and speed profile of the engine in a first step. This simulation can be performed for each vehicle configuration and therewith result in different load/speed profiles of the engine. The determination of fuel consumption, respectively CO_2 emission, is afterwards done by testing the engine on a transient engine test bench on basis of the before simulated and vehicle and application specific load and speed profiles. Advantage of this approach compared to the baseline option is the possibility of display the transient behaviour of the engine. Example of such an approach is the HILS methodology for heavy-duty hybrids.

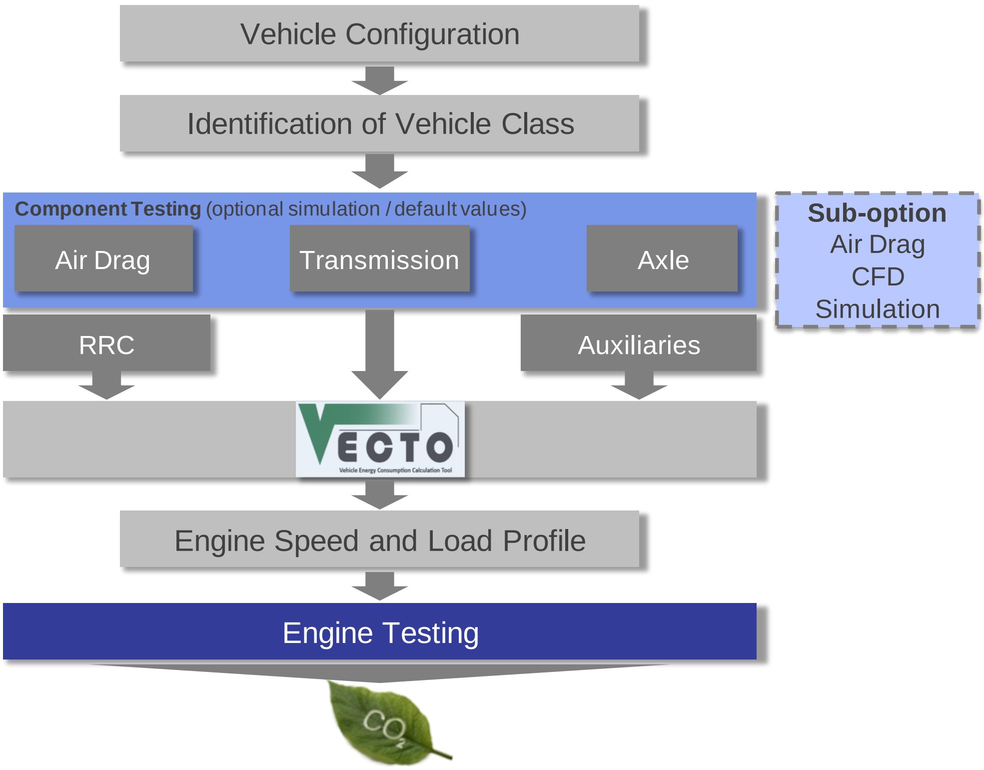

Figure 6: Process scheme simulation and engine test

Pros

– The test method itself is somewhat more accurate than D1 because it includes dynamic engine behaviour and engine behaviour as would occur for the given vehicle at give mission profile and payload, in contrast to option D1 where a static engine map is taken and a generic dynamic correction is made, based on WHTC data.

Cons

– For this option the effort will increase considerably compared to D1 because for each configuration and each parent a dynamic engine test needs to be calculated/determined and performed.
– Defining families (and testing parents) comes with the loss of accuracy of the whole method because fewer variants are tested. The effort increases if more information is needed, for instance for testing more payloads, mission profiles, more parents (of smaller families).
– Accuracy and reproducibility also depend on the road load determination and in principle, with regard to road load, the same issues rise as for option D1 and D2.

Notes

– Technology specific compensations or corrections within families could increase the accuracy for individual vehicles and allow discrimination of certain technologies, herewith driving these technologies.
– This option may be interesting for testing hybrid vehicles.

3.2.6 Sub-Option CFD

For all options a sub-option analysing the cost-benefit of the use of CFD simulations to examine the air drag instead of measurements will be assessed.

3.3 Conformity of Production (CoP)

CoP shall ensure that adequate arrangements have been made to safeguard that produced vehicles, systems, components or separate technical units conform to the certified product. In principle, three options how to test the conformity of production can be defined:

- Component-specific
- Process-specific
- Complete-vehicle test

The applicability of these options depends on the defined approaches of the determination of the CO_2 and fuel consumption value and the way it is implemented in legislation.

3.3.1 Option P1: Component-specific CoP

This options is related to the baseline option D1. It assumes the certified CO_2 value to be in conformity when the component specific CO_2 data matches the component values entered in the simulation. The component specific CoP tests could be done in accordance with the defined test procedures used for the determination of input data for the simulation. Tolerances or conformity factors have to be defined for each component / data set. Furthermore, a simplified test especially for components having more than one value to control (e.g. efficiency maps of transmission and axle or the fuel map of the engine) would be thinkable within this approach.

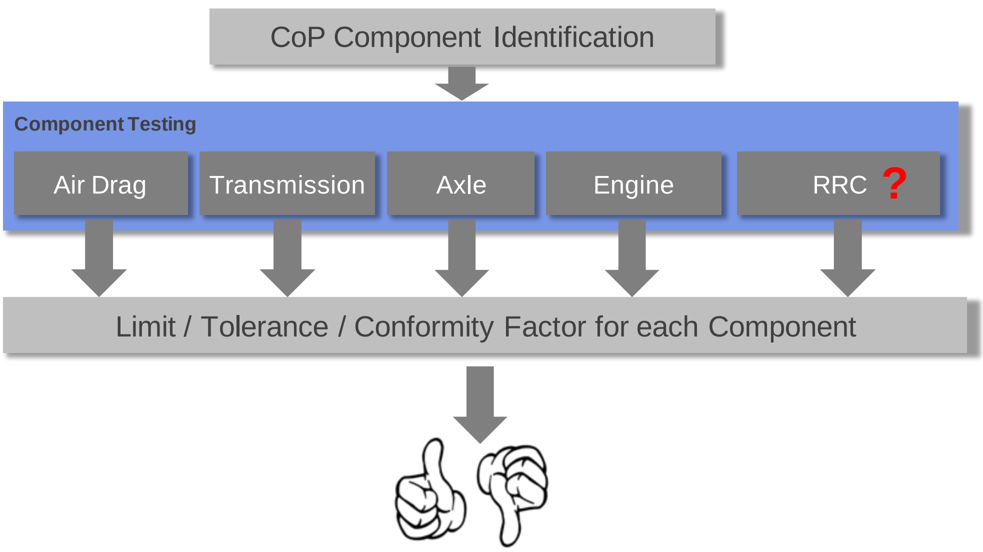

Figure 7: Component-specific CoP

Pros

- This process is straightforward and allows a direct quality control on component level, respective input data level.

Cons

- There is a lack of control over the rest of the process, including the simulation. Due to this, also the relation with the final result (CO_2 emission) is lost/not present and thus not under control.

Notes

- Distribution of responsibilities over the component suppliers, but there is no responsibility for the vehicle manufacturer.
- CoP on component level is only possible if the component is type-approved.
- Performance criteria (e.g. tolerances) are needed for each component. For instance, for the efficiency/fuel map of the engine, tolerances are needed for each measured point.

3.3.2 *Option P2: Process-specific CoP*

The process specific CoP includes a complete repetition of the process, from the component testing to the simulation of the final, vehicle and application specific CO_2 and fuel consumption value. Therewith, the certified and retested/simulated CO_2 values can be directly compared. If deviations are found, the component(s) causing it has/have to be identified and further investigations need to be carried out.

Pros

- As the title suggests, this options covers the whole process. The CoP result and the certified CO_2 value will be easy to compare.

Cons

- A higher effort than P1 as the whole process is repeated.
- Without tolerances and CoP requirements for components, the effect of a deviation of component data between CoP and certification can compensate each other if the deviations have opposite effects on the CO_2 emission / fuel consumption and thus it may be hard to find the cause.
- In the case of non-conformity, further investigations to identify the component(s) causing the deviation are necessary. These further investigations can become very intensive since it is very hard to isolate the component causing the non-complying.

Notes

- Without tolerances and CoP requirements for components, the control over the input data would need to be arranged by the vehicle manufacturer because he is responsible for the overall CO_2 value.

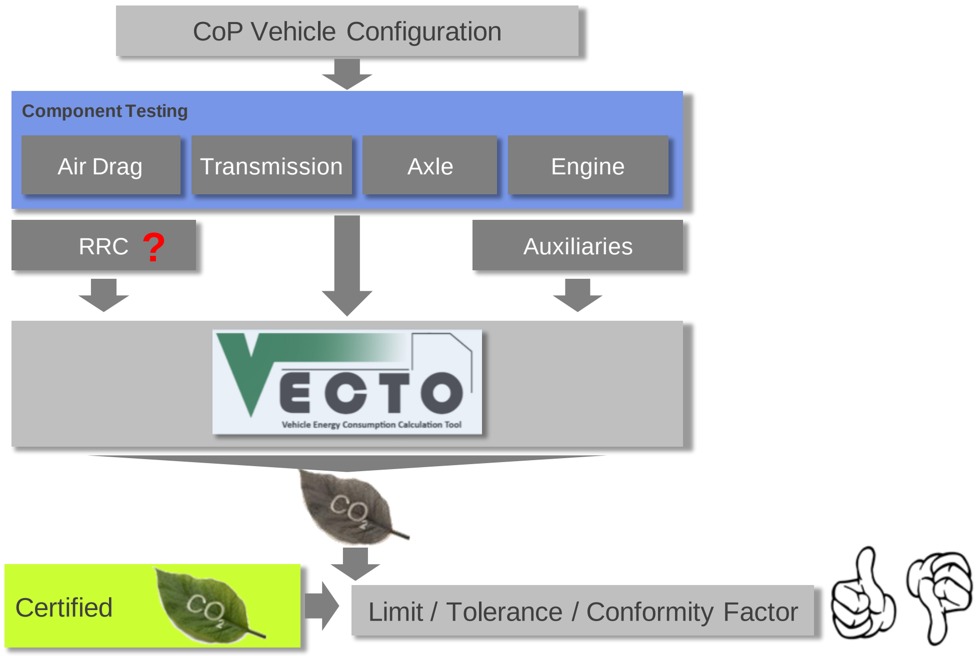

Figure 8: Process-specific CoP

3.3.3 *Option P3: Vehicle - specific CoP*

3.3.3.1 *Simplified Short Cycle Test (baseline option)*

This ex-post validation option is based on a simplified test cycle consisting of constant speed and acceleration/deceleration events to be driven on a test track measuring the fuel consumption. During the certification of the vehicle, which is based on the approach combining component testing and simulation, the CO_2 value / fuel consumption within this simplified cycle is simulated in parallel to the later registered CO_2 / fuel consumption value based on the realistic, application specific cycle. Therewith, the simulated CO_2 / fuel consumption value for the simplified cycle can be compared to the measured one on the test track during CoP.

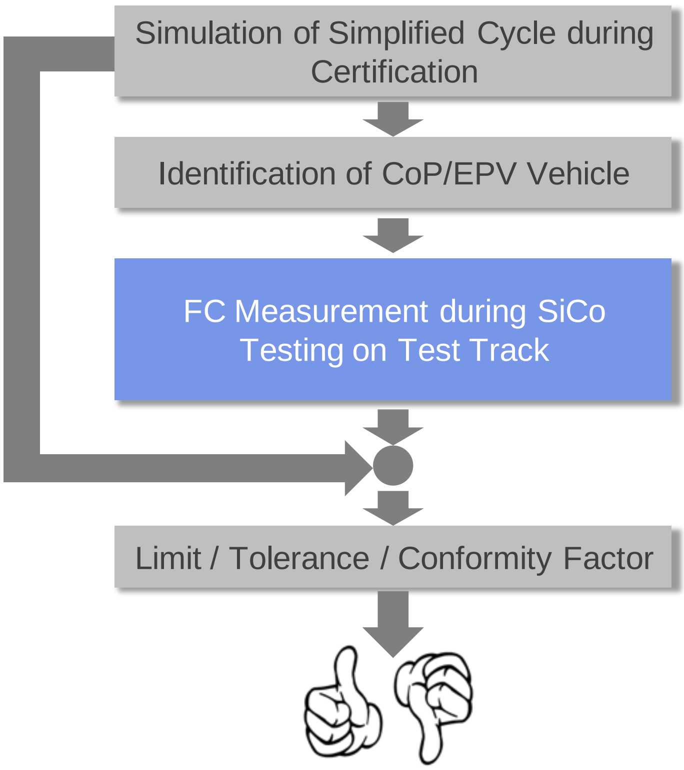

Figure 9: Vehicle specific CoP – SiCo

Pros

– Real-world validation of the simulated CO_2 emission value.

Cons

– The relation between the simulation and real world is not fixed. Fundamental differences between the methods may cause certain deviations between the two methods, which in turn would require wider tolerances to be defined.
– Not all conditions can be checked

3.3.3.2 PEMS or fuel meters

Another option would be the direct measurement of CO_2 or fuel consumption during real driving on a similar basis as defined for the In-Service Conformity measurements according to 582/2011/EC (related to the measurement procedure, not the choice of vehicles).
In 582/2011/EC “the conformity of in-service vehicles or engines of an engine family shall be demonstrated by testing vehicles on the road operated over their normal driving patterns, conditions and payloads. The in-service conformity test shall be representative for vehicles operated on their real driving routes, with their normal load and with the usual professional driver of the vehicle. When the vehicle is operated by a driver other than the usual professional driver of the particular vehicle, this alternative driver shall be skilled and trained to operate vehicles of the category subject to be tested.”

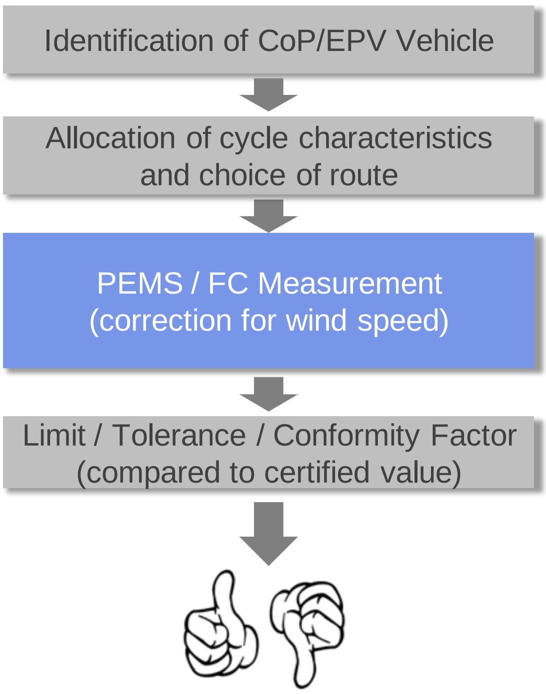

Figure 10: Vehicle specific CoP – Real Driving

Pros

- Real-world validation of the simulated CO_2 emission value.

Cons

- The relation between simulation and real world is even less clear than for the Simplified Short Cycle due to the effects of test conditions that vary and fundamental differences between vehicle simulation and testing. This would probably require wide tolerances and/or corrections.
- Reproducibility is low (repeatability is 5% at best if controlled well and reproducibility (lab-to-lab) typically worse and more in the order of 10% or higher).

Notes

- The risk for a short fall (between the certified CO_2 emission value and the real world CO_2) could be tackled in an ex-post validation. An option is mentioned to make a reverse check, i.e. put the real PEMS trip in the simulation tool. This would require a very robust tool or again tolerances. This is probably not well repeatable (see PEMS and cons) repeatable and therefore the tolerances are assumed to be wide.

3.4 Certification related issues

3.4.1 Non-standard bodies/trailers/semi-trailers and Multi-Stage Vehicles

HDVs are often individual vehicles produced by more than one manufacturer in several stages (e.g. base vehicle produced by manufacturer A, completed with a super-structure by manufacturer B). A rigid tipper truck is a typical example of such a vehicle, where the tipper body is installed by manufacturer B onto a base vehicle of manufacturer A.

Within the type approval framework a so-called multi-stage approach is described to cover the type approval of vehicles completed in more than one stage.

The methodologies considered above for the certification of HDVs CO_2 emissions foresee neither a certification of non-standard bodies/trailers/semi-trailers nor a multi-stage approach. Currently, incomplete vehicles are to be completed with defined standard bodies, vehicle combinations are to be certified with standard trailers/semi-trailers. Vehicles equipped with others than standard bodies/trailers/semi-trailers are therewith not covered within the procedure so far. As the CO_2 labelling approach should also push the improvements within the body/trailer/semi-trailer industry, a corresponding legislative basis in matters of a second stage of certification **could** be developed. Therewith the first stage of certification (“first-stage-certification”) is directly done by the OEM of the vehicle for vehicle with default bodywork, an optional “second-stage-certification” **could** be introduced to give the possibilities to body/trailer/semi-trailer manufacturers to get a certification for their product which may differ from and be better than the vehicle with standard body/trailer/semi-trailer.

In principle, two options for an integration into the actual methodology are conceivable:

Option S1: Simulation of further stages with VECTO
After the certification of the complete vehicle on the basis of a standard body/trailer/semi-trailer any further certification (multi) of the complete vehicle with a non-standard body/trailer/semi-trailer can be performed by the corresponding body/trailer/semi-trailer manufacturer by running through the complete simulation again with the changed relevant data (air drag and mass to be measured by manufacturer B).

Pros
- This option results in more realistic CO_2 values for MSV.
- It would also allow SME/bodybuilders to determine a more optimal configuration with regard to the CO_2 emission and fuel consumption.
- Certain improved technology/components, which are built onto the vehicle by a bodybuilder, can be included in the CO_2 determination. This would enable to drive also these technologies.

Cons
- SME as well as large OEMS need to work with the tool. The burden would be unequally high for large OEMs and SME and probably it would be expensive for SME to determine final C_DxA when based on measurement.
- If the CO_2 value should be certified, this option adds some complexity to the processes for Member States, Technical Services, Type Approval Authorities and Final stage manufacturers/bodybuilders, bearing in mind however that the intention is to make this option optional (non-mandatory).
- Given the complexity implementation issues are expected, for instance harmonization of legal processes across MS is needed. Obviously, this would also come with issues for the timing.
- Control over the certified value probably needs to be arranged at the local Technical Service.

Notes
- This process raises confidentiality issues regarding data transfer / black box models from manufacturer A to manufacturer B, which have to be intensively discussed and solved beforehand.
- If this option would be considered, it requires at least further investigation into the actual processes of the involved stakeholders and an assessment of what is needed to make this work reliably and as efficient as possible.
- Exemptions for small series or SME could be considered. Of course this makes monitoring less accurate.

Option S2: Table based calculation
For this second option the influence of a defined bandwidth around the measured air drag and mass on the fuel consumption and CO_2 emission has to be simulated with VECTO. For the second or any further stage of the certification with non-standard bodies/trailers/semi-trailers the corresponding CO_2 emissions and fuel consumption can be calculated on basis of the **actual** air drag and mass by manufacturer B and the corresponding table values from stage 1. Any possible issues regarding data confidentiality are therewith solved. This however requires an air drag value to be calculated (air drag test or CFD calculation) which may be costly.

Pros
- More realistic CO_2 values based on the actual vehicle, but less accurate than re- simulation as it uses tables or simplified functions to make a correction.

Cons
- The option, like S1, adds complexity to the process for several stakeholders, see S1. This complexity is somewhat less than for S1 in the fact that the CO_2 determination would be easier for the bodybuilder.

Notes
- Exemptions for small series or SME could be considered. Of course this makes monitoring less accurate.
- If this option would be considered, it requires at least further investigation into the actual processes of the involved stakeholders and an assessment of what is needed to make this work reliably and as efficient as possible.

3.4.2 Families
Families within the different options may need to be implemented on different levels. While for simulation-based approaches (D1, D2, D5) families can be defined on component level (engine, transmission, axle, air drag), whole vehicle families have to be defined for approaches related to vehicle testing (D3, D4). The implementation of a family concept can help to maintain costs at a reasonable level. This at the cost of accuracy for individual vehicles, as in this case there would be a single value by vehicle. Due to the huge variety of bodies/trailers/semi-trailers, a family approach is necessary for the “first-stage-certification” for all options.

Notes
The possibilities and burdens to identify/define those kinds of families need to be intensively discussed within the editing board.

The effects regarding the loss of accuracy for single vehicles have to be analysed and compared with the objectives set by the COM.

3.5 Ex-post validation

A random verification of the VECTO calculated fuel consumption and CO_2 emission versus real on-road measured fuel consumption and CO_2 emissions is considered necessary as additional measure, for a very small number of vehicles. The recent status stipulates certain measures for this verification. The simulated CO_2 value for a certain vehicle can be checked by applying real-world testing to vehicles equipped with fuel flow measurement devices[2]. The real-world fuel consumption can then be checked against the VECTO fuel consumption / CO_2 value calculated for a correlative simplified and partial driving profile, (see option P3.1). Additionally, the above described options related to the vehicle specific CoP should be considered also as possible ex-post validation of the certified CO_2 value.

Options within this sections and the corresponding assessment of those will be further detailed and described within the final report.

Simplified Short Cycle Test
As described for the CoP process the SiCo–test can be based on a simplified cycle on which a defined vehicle configuration equipped with fuel measurement equipment or PEMS is tested on a test track under defined conditions. The measured fuel consumption / CO_2 emission is then compared with a value simulated during the type approval (parallel to the certified value based on the realistic driving profile) based on the simplified cycle.

Real Driving
Another option for the ex-post validation beside the SiCo-Test is the measurement of fuel consumption or CO_2 emission under realistic driving conditions based on representative route characteristics as for example performed within the In-Service Conformity test for EURO VI HDV.

The pro et contra of these options can be taken from the respective chapters dealing with the same measurement principles.

[2] Similar to Euro VI PEMS testing

4 Monitoring and reporting

4.1 Introduction

Monitoring is defined as the activity to follow the values and trend of the CO_2 emissions and fuel consumption of the EU heavy-duty vehicle (HDV) fleet (for newly registered vehicles), while reporting is defined as the activity to collect the data needed for the monitoring and to report it to the European Commission.

In the EU, the monitoring and reporting of CO_2 emissions is in place for passenger cars and light commercial vehicles (Regulations (EU) No 1014/2010 and (EU) No 293/2012). These regulations have prescribed methodologies for reporting and monitoring the CO_2 emissions of the given group of road vehicles of EU vehicle class M1 and N1 ((with a reference mass not exceeding 2610kg) and to vehicles of category N1 to which type approval is extended.)

The short-term action of the EC with regard to HDVs is now focussed on certifying, monitoring & reporting of fuel consumption and CO_2 emissions. The primary objective of the EC is the release of HDV CO_2 certified emissions values for each vehicle put on the market and annual reporting of the fuel consumption and CO_2 emissions for the newly registered HDV, per HDV manufacturer and per EU Member State, to be able to track the development of the fuel consumption and CO_2 emission of the EU fleet of HDV.

For HDVs the situation is different than for passenger cars and most LCVs. HDVs are used in different configurations such as tractors with different type of semi-trailers, rigid trucks with different bodies and rigid trucks with or without trailers. Like for the group of Multi-stage Vans (MSV), rigid trucks are often constructed in more than one stage and into many configurations, meaning that more parties than the base vehicle manufacturer are involved in the process of construction of a completed vehicle. Also different ways of (type) approval are used: national small series, whole vehicle type approval, individual type approval. This means that information regarding the specific CO_2 emission of a completed vehicle has to be made available in all these instances so that the specific CO_2 value can be registered in the Member State vehicle registration. For MSVs, a method for measuring and monitoring CO_2 emissions was already developed and implemented in EU regulation (carried out by TNO). The importance of MSV in the EU fleet is small however (about 7% of N1), and as such an approach which is based on a ‘default added mass’ keeps the system for CO_2 measuring and monitoring simple, cost effective. I.e. the reference (test) mass of the base vehicle is increased by a default added mass representative of the completed vehicle in order to deliver a value for the specific CO_2 emission that is representative for the completed vehicle but may be reported in the CoC of the base vehicle. In that case the vehicle manufacturer knows the CO_2 emission value of his product already at the moment of production.

For HDV, the situation is somewhat comparable to MSV, especially given the typical distributed market of production of completed HDV by either the vehicle manufacturer, or through stages of production, including a base vehicle manufacturer and further stages where small to large bodybuilders add bodywork.

There are however several differences. With HDV, the trucks are used in very different applications (such as distribution, long haulage, construction, etc.), which results in entirely different driving patterns (mission profiles) and entirely different bodies & (semi)trailers. For the monitoring this difference seems mostly relevant for the further aggregation of data at the reporting stage. I.e. depending on the use of the data, it may or may not make sense to lump together HDVs with different missions, masses and applications.

A technical way to reduce the fuel consumption and CO_2 emissions of HDV is to optimise the body/trailers and accessories. However, in that case it would be necessary to measure and attribute CO_2 emissions not only to the (base) vehicles, but also to the (semi) trailers (see sub-option on second stage certification). This would help to ensure that technical options to decrease fuel consumption and CO_2 emissions are used to the full potential. This however would increase the complexity of the system of measuring, monitoring and reporting and also divides responsibilities over different stakeholders.
The focus of this work on options for reporting and monitoring is therefore on vehicles with default bodywork or (semi-) trailers.

In the LOT2 report, the market shares for the different bodies were estimated by TNO. In Table 5, these market shares are given for rigid trucks.

4.2 Current status of the method for the determination of CO_2 emission of HDV

The current most promising method for ‘measuring’ fuel consumption and CO_2 emissions for HDVs (with the tool named VECTO) is a model based approach and can, in principle, handle a wide variety of vehicle types and technical variations. As such, already early in the process the CO_2 value can be calculated, if the total set up of the vehicle produced or to be produced is known.

For certification and monitoring & reporting system, the vehicle segmentation proposed by ACEA (Table 3) can be involved in the options. The segmentation is based on the axle configuration. Additionally to this a number of standard bodies were defined, indicated by B1 thru B9 for rigid trucks and ST1, ST2, T1 and T2 for (semi) trailers. Refer to Table 4 for an overview and the Lot 3 report. It should be noted however, that in practise there are substantial variations in bodies or mounted accessories and not all body types are covered.
The estimated market shares of different body types of rigid trucks is included in Table 5.

Table 3: Vehicle segmentation proposed by ACEA for vehicles with a GVM >=7.5t

ACEA proposal Vehicle segmentation trucks ≥ 7.5 t													
	Identification vehicle configuration			Class	Cycle allocation Vehicle configuration / weight / axle loads								
	Axle configuration	Chassis configuration	weight	Vehicle Class	Long haul	Regional delivery	Urban delivery	Municipal utility	Construction	Standard Bodies (B)	Standard Trailer (T)	Standard Semitrailer (ST)	National specific variation (N)
2 axles	4x2	Rigid + (Tractor)	7.5t - 10t	1		R/W	R/W			B1			
		Rigid + (Tractor)	> 10t - 12t	2	R/W	R/W	R/W			B2			
		Rigid + (Tractor)	> 12t - 16t	3		R/W	R/W			B3			
		Rigid	> 16t	4	R+T/W	R/W		R/W		B4	T1		
		Tractor	> 16t	5	T/W	T/W						ST1	
	4x4	Rigid	7.5t - 16t	(6)	exclude all-wheel-drive vehicles 4x4 (sales volume < 1%)								
		Rigid	> 16t	7					R/W	B5			
		Tractor	> 16t	(8)	exclude all-wheel-drive vehicles 4x4 (sales volume < 1%)								
3 axles	6x2/2-4	Rigid	all	9	R+T/W	R/W		R/W		B6	T2		
		Tractor	all	10	T/W	T/W						ST1	
	6x4	Rigid	all	11					R/W	B7			
		Tractor	all	12					T/W			ST2	
	6x6	Rigid	all	(13)	exclude all-wheel-drive vehicles 6x6 (sales volume < 1%)								
		Tractor	all	(14)									
4 axles	8x2	Rigid	all	(15)	exclude 8x2 (very low sales volume < 1%)								
	8x4	Rigid	all	16					R/W	B9			
	8x6/8x8	Rigid	all	(17)	exclude all-wheel-drive vehicles (sales volume < 1%)								

T = tractor + semi-trailer, R+T = Rigid + Body + Trailer, T+T = tractor + semi-Trailer + Trailer
R = Rigid + Body, D = 2-axle Dolly for semi-trailer

Table 4: Overview of standard body types with formally defined dimensions. Source Lot 3 report

Truck	Reference body type	Reference body	GVM (tonne) (1)
2 Axle 4x2 rigid truck	Hard shell box	B1 B2 B3 B4	10 12 16 19
2 Axle 4x2 rigid truck	Tipper for sand/cement	*B5*	19,5 – 20.5
3 Axle 6x2 rigid truck	Hard shell box	B6	27
3 Axle 6x4, 6x6	Tipper for sand/cement	*B7*	33 – 34,5
4 X axle 8x2 rigid truck	Construction	*B8*	all
4 Axle 8x4, 8x6	Tipper for sand/cement	*B9*	43 – 46
Semi-trailer	Hard shell box Tipper sand/cement	ST1 *ST2*	27
Trailer	Box body	T1 = T2	18

(1) Indicative numbers, precise mass varies between countries

Table 5: Estimated market shares for body types for rigid trucks (source: LOT2 report)

Truck type	Config	GVW	Rigid	Bodywork rigid truck				
				Box	Bulk/ tank	Container/Swap body	Tipper	Other
Truck 2axl	4x2	7,5 - 10						
		10 - 12	36.7%	19%			6%	12%
		12 - 16						
		18 - 19	20.0%	10%	0.5%	4%	2%	4%
		all						
	4x4	7,5 -16	1.5%				0.5%	1.0%
		18 - 19	1.6%				0.6%	1.0%
		18 - 19						
Truck 3axl	6x2/2-4	24 - 26	19.4%	10%	2%	4%	1%	3%
		all						
	6x4	24 - 26	7.8%				3%	5%
		all						
	6x6	24 - 26	1.6%				0.6%	1.0%
		all						
Truck 4axl	8x2	30	0.5%				0.2%	0.3%
	8x4	30	10.2%				3.5%	6.7%
	8x6/8x8	30	0.7%				0.2%	0.5%
Total			100.0%	39.0%	2.0%	7.5%	17.5%	34.0%

For special non-standard bodywork build on HDV, the same issue arises as for MSV; the use of a 'default approach' may be desirable but the choice for such a method depends on what CO_2 emission should exactly be monitored; the real CO_2 emission of a complete(d) vehicle, the CO_2 emission of the half product (base vehicle) from vehicle manufacturers or of a default vehicle? E.g. compared to MSV N1 vehicles, the default approach for HDV is intended to provide a CO_2 value that is representative for the vehicle on the road.

The design of the monitoring process and thus its complexity and costs will likely depend on what exactly should be monitored.

4.3 Goal of task 3

The aim of the work in task 3 is to identify, define and assess the options for the monitoring and reporting of HDV fuel consumption and CO_2 emissions, to gain more information to enable a better statistical evaluation of the fleet and trends with regard to the CO_2 emission and the attributes which affect the CO_2 emission of HDV.

In this task the work from LOT3, the technical procedure to measure fuel consumption and CO_2, the options for certification and validation of task 1 and 2 of this study and the options for monitoring and reporting, should be brought together, taking account of:
- the current market situation of construction and certification of HDV and its consequences for the possibilities regarding monitoring and reporting, and
- the (experience with) current procedures in place for monitoring and reporting the CO_2 emissions of passenger cars and vans.
- the Commission's long term goals regarding policies to reduce fuel consumption and CO_2 emissions from HDVs.

4.4 Approach for task 3

The definition of options for monitoring and reporting will build further on the options for certification of task 1 as well as previous experience gained from the monitoring and reporting for passenger cars and vans. Interaction with task 1 of this Service Request is required as task 1 delivers the options and a comparative assessment of the options for certification of HDVs. For these options the various stakeholders taking part in the certification process and their roles were identified (task 4). For the definition of the final options for monitoring and reporting it was be necessary to have consulted the stakeholders for their experience with monitoring and reporting CO_2 emissions of cars and vans to take note of their views.

The options on the table should be in principle the simplest processes delivering the most accurate information and should allow a robust monitoring and reporting. It should be noted that more complex processes may be needed, depending on the preferred options developed in task 1. The options may include, in discussion with the Commission, alternatives to the current methodology.

4.5 Current reporting and monitoring for light duty vehicles

The monitoring and reporting principle for light duty vehicles is that the specific CO_2 emission of each vehicle registered in a certain year in an EU Member State will be taken into account for the calculation of the ‘average specific CO_2 emissions’ for a given manufacturer for that given year.

The vehicle registrations of one year are reported by each EU Member State to the EEA (European Environment Agency), the body that keeps the register of the data on behalf of the Commission. The provisional detailed specific CO_2 data is sent to the manufacturer for checks and after the data has returned, the Commission, supported by the EEA, calculates and confirms for each manufacturer the final average specific CO_2 emission. This confirmed value is then compared with a target value, the ‘specific emission target’, set for each individual manufacturer. The target CO_2 emission is related to the vehicles’ average mass in running order, which compensates manufacturers of either lighter or heavier than average vehicles with regard to the absolute level of CO_2 emission to be reached. In this case, the responsibilities are clear. A vehicle manufacturer can, taking account of lead time, technically improve his complete product portfolio to achieve an ‘average specific CO_2 emission’ which is at or below the ‘specific emission target’.

Once the new vehicle is sold and is registered by a MS, it enters the national registration database. For passenger cars and vans the collection of this data, the method and the format for the monitoring and reporting are defined.

The information is mostly taken from the Certificate of Conformity (CoC) (Annex IX of 2007/46/EC) but some Member States also collect the data from Type Approval data/documents.

After the calendar year the Member State has to report the information to the EEA:

From 2007-46-EC: “*…The certificate of conformity is a statement delivered by the vehicle manufacturer to the buyer in order to assure him that the vehicle he has* *acquired complies with the legislation in force in the European Union at the time it was produced. The certificate of conformity also serves the purpose to enable the competent authorities of the Member States to register vehicles without having to require the applicant to supply additional technical documentation. For these purposes, the certificate of conformity has to include: (a) the Vehicle Identification Number; (b) the exact technical characteristics of the vehicle (i.e. it is not permitted to mention any range of value in the various entries)…"*

From 2013-297-EC:"*…The detailed data referred to in point 1 shall be taken from the certificate of conformity of the relevant passenger car or be consistent with the certificate of conformity issued by the manufacturer of the relevant passenger car. Where the certificate of conformity is not used, Member States shall put the necessary measures in place to ensure adequate accuracy in the monitoring procedure*…"

As such the CoC can be a good <u>source</u> for information from the vehicle and could also for HDV serve as data carrier for the monitoring data throughout the process from production to registration. Therefore, the current status of the CoC, including the entries/parameters needs to be assessed with regard to its suitability to serve as basis for reporting and monitoring CO_2 emissions of HDV.

For passenger cars and vans, monitoring is done for each individual vehicle registered in a calendar year in an EU Member State taking into account the following data parameters:
An example of detailed monitoring data of vans:
- Manufacturer name— EU standard denomination
- Manufacturer name— Manufacturer denomination
- Manufacturer name— National Registry denomination
- Type approval number and its extension(s)
- Type
- Variant
- Version
- Make
- Category of vehicle type-approved
- Category of vehicle registered
- Total number of new registrations
- Specific emissions of CO_2 (g/km)
- Mass (kg)
- Technically permissible maximum laden mass (kg)
- Wheelbase (mm)
- Track width steering axle (mm)
- Track width other axle (mm)
- Fuel type
- Fuel mode
- Capacity (cm_3)
- Electric energy consumption (Wh/ km)
- Innovative technology or group of innovative technologies code

Table 6: Flow scheme of current system in place in the EU for monitoring and reporting of the specific CO_2 emissions of passenger cars, as regulated by Regulation (EU) No 1014/2010 (latest amended by 396/2013)

For light duty vehicles: Specific CO_2 value measured according to Regulation 715/2007 and implementing acts.
Specific CO_2 value and detailed data of the vehicle recorded at the time of 1st registration and taken from the COC or type approval documentation
End of calendar year: Specific CO_2 value and detailed data from MS registration to MS report.
End of February: Report with specific CO_2 value and detailed data from MS to the Commission, i.e. to central register (kept by EEA /public).
By 30 June Commission provisionally calculates: - average specific CO_2 emissions - specific emission target for the preceding calendar year - The difference between the average specific emissions in the preceding year and the specific emission target for that year
The Commission notifies manufacturer of the provisional calculation and include data per MS on number of vehicles and their specific CO_2 emissions.
The manufacturers notify within 3 months after being notified of the provisional calculation of possible errors to the Commission
The Commission shall consider the corrections made and either confirm or amend the provisional calculations before 31 October.
Final register of CY with monitoring data. Commission Decision confirming the final targets and OEM performance.
The Commission issues of excess emission premium in case it is confirmed that an OEM exceeds its specific emissions target

4.6 Requirements and considerations for monitoring and reporting of the CO_2 emissions of HDV

For the definition of options for monitoring and reporting of CO_2 emissions of HDV, the following elements need to be considered:
- Vehicle aggregation.
- Data to be monitored, including the specification and metric of the CO_2 value(s) and possible additional technical parameters.
- Sources of monitoring information and monitoring entities. What is the source of monitoring data? Who shall be involved in the process and who has responsibilities in the monitoring process for what?

For each element above a set of options can be defined. From combinations of these options, process options can be designed: given the required data, data source and responsible entity, how could the process work?

Aggregation, segmentation
Passenger cars and vans data are currently aggregated on a calendar year basis based on the vehicle type, variant and version code combined with the type approval number. This means in practice that vehicles with the same TVV code and Type Approval number are aggregated into one data row.

Because HDVs are less homogeneous regarding construction, and variations in construction that affect the fuel consumption and CO_2 emissions than passenger cars, the option to monitor CO_2 emissions on a per vehicle basis seems logical. Monitoring on per vehicle basis requires a unique identifier, other than T-V-V, to be able to distinguish the different specific CO_2 as per difference in vehicle specifications. The VIN number is seen as the most suitable key/identifier. Such a unique identifier could ultimately be used by the manufacturer to check the monitoring database or allow combining data from different sources (i.e. Member State data with OEM data). This supports the option to certify on a per vehicle basis which is one of the options for certification in chapter 3. On the other hand the monitoring and reporting of VINs may be surrounded by certain restrictions due to the fact that these data are considered in some Member States as subject to personal data protection.

The basic working assumption is to monitor at least individual vehicles with standard bodies, but additionally completed vehicles (body builders) and trailers (trailer manufacturers) can be monitored as well. The latter two would in principle deliver more accurate CO_2 emission values but at a probably much higher effort.

Segmentation is needed because of the wide range of applications and vehicle types. Routes (trip types) vary and amongst others depend on vehicle type and usage. ACEA has defined a range of vehicle categories and has attributed mission profiles to them. To follow trends of CO_2 emissions and fuel consumption it should be considered to follow the trends of the categories and mission profiles separately.

Data parameters to be monitored
The most important are the CO_2 and fuel consumption values or set of values that need to be monitored. It has yet to be determined if this needs to be a single value, for instance an absolute CO_2 emission for the representative vehicle (with representative payload) or if it needs to be several values to monitor for instance the CO_2 emission of different types of missions (given the mission profiles and underlying mix of drive cycles) (segmentation), different levels of payload, or different metrics, for instance duty specific values like g / t.km or g / m^3.km.

As for the current methodology applied for passenger cars and vans, additional parameters, next to the specific CO_2 emission, may need to be monitored for the purpose of monitoring technical specifications of heavy-duty vehicles. Additional parameters could be specifications of the vehicle (masses, dimensions, performance), engine and specifications of the (real and or standard) bodywork.

Starting point for the definition of options, i.e. the baseline line option, would be to define a minimum set of parameters needed to follow the trends of the CO_2 emissions and the technical attributes of HDV which determine/influence the CO_2 emissions.

The data parameters:
- Vehicle identifier and legal classification (2007/46/EC).
- CO_2 emissions/fuel consumption on a per vehicle basis, as determined by VECTO (minimum requirement).
- CO_2/fuel consumption per mission profile and/or per vehicle class and/or per payload level.
- OEMs (data of the default vehicle only; minimum), second stage manufacturers (data of the completed vehicle), trailer manufacturers (data of trailers: maximum).
- Technical data, e.g. relating to the powertrain including engine, masses and dimensions, bodywork, (minimum requirements need to be defined).
- Input data for VECTO and for developing and/or reviewing default data used in the VECTO tool.

Sources of the monitoring information and monitoring entities
For HDV the monitoring data can be sourced at different moments in the process from production of a HDV to the registration of a HDV. This can be at:
- type approval
- production
- sale
- registration

Each of these options requires different stakeholders to take part in the process. The options also deliver data from different moments of the process which may require different steps to be add3d to make sure data of the whole vehicle can be retrieved. Sources can be combined, e.g. registration data can be combined with technical data from type approval or production. As such, combined monitoring processes can be designed where responsibilities are divided over stakeholders.

The different data sources:
Data sourced at the moment of type approval:
- Type approval databases, ETAES database (not clear whether these exist for all type approval authorities, the ETAES database is based on pdf documents so difficult to use)
- Responsible entity: Type Approval Authorities

Data sourced at the moment of production:
- CoC and/or type approval data relating to the base vehicle, may be both incomplete or completed or type approval documentation, or OEM specific data
- OEMs, trailer manufacturers …

Data sourced at the moment of sales:
- CoC and/or type approval data for both complete and completed vehicles
- Responsible entities: OEMs, second stage manufacturers, dealers …

Data sourced at the moment of registration of new vehicles

- o National registration documentation databases which include data from CoCs and/or type approval data; (note! – registration data do usually not include all the CoC data and may be different from one Member State to another; there is no harmonised way of data sourcing)
- o Responsible entity: National Registration Authorities

<u>The process of monitoring</u>
The process of monitoring for passenger cars and vans is based on the data collection by the national registration authorities of the EU member States of vehicles and technical data of these vehicles as newly registered in a Member State in a certain Calendar Year. The databases are annually submitted (reported) by the Member States to the Commissions delegate, the EEA who collects the databases. The final database for the given CY consists of data that have been verified or accepted by vehicle manufacturers and this data is subsequently confirmed by a Commission Decision. The EEA also annually reports cross sections of the database focusing on OEM and Member States performances in terms of CO_2 emissions.

Other processes can be distinguished where responsibilities are different than for the case of passenger cars and vans. E.g. combined monitoring can be seen as a process where a Member State delivers to the EEA limited data on the registered vehicles, for instance only a unique registration code and the manufacturer adds technical data, based on the unique code. For vans a combined process is already in place: MS collect data, manufacturers complete the dataset with certain parameters.

Relation with reporting
The options for monitoring and reporting are strongly related. The reporting requirements depend on the monitoring requirements. However, it can be decided to report more information than initially needed for monitoring. This information can then be used for the evaluation of trends of technical characteristics of the HDV fleet. For example the mass of actual bodywork or other specifications can be collected. The same can be the case for vehicle auxiliaries such hydraulic lifts, pumps, cranes, etc.. This would allow sufficient flexibility for analyses of trends of technical specifications of the vehicles. Extended reporting puts a higher demand on the entity responsible for reporting.

Multistage vehicles
Given the process of construction for a significant share of HDV in multiple stages the CO_2 value can best be attributed to the vehicle manufacturer or the base vehicle manufacturer. The CO_2 value should be for a default vehicle. The basic option for certification is thus to assume a default bodywork for all HDV with default mass and dimensions which can be entered in the VECTO tool. This keeps a level playing field for vehicle manufacturers of single stage vehicles and manufacturers of base vehicles. The downside is that the CO_2 value will be virtual and may have a weak relation with the real CO_2 value if completely different bodywork is mounted than was assumed to be the default.

There are two options defined for alternative determination of a more accurate CO_2 value for MSV i.e. an optional second stage certification, see paragraph 3.4.1.

Therefore, it may be desirable to monitor (and report) additional characteristics, of the real configuration of the complete and completed vehicle:

- Masses and dimensions of bodies (MSV) and (semi-)trailers
- For standard and for alternative bodies:
  →development in bodies can be reported and defaults can be adjusted accordingly
- Reporting based on weighted average of typical bodies
  → this can be implemented via correction factors to the database

Different ways of type approval.
Currently, in the EU different types of processes are allowed for type approval: (Whole Vehicle Type Approval (WVTA), Individual Approval (IVA), National Small Series (NSS),…). This has large consequences for the data collection process. In the case of WVTA, the base vehicle manufacturer takes care of the whole process of type approval and certification of the whole vehicle until it is complete (manufactured by the OEM) or completed (bodywork added under control, in cooperation/communication of the base vehicle manufacturer). In that case, a CoC becomes finally available that covers the whole vehicle and the certified components.

However, a lot of the HDVs are type approved on an individual basis, nationally. In that case base vehicles (incomplete vehicles) with incomplete CoCs (of the base vehicle only) are completed by second/final stage manufacturers (mostly body builders) and the completed vehicle is approved at local Technical Services. In these cases, the CoC often isn't amended with the final data of the completed vehicle as this is not part of the local national approval process. Therefore, the CoC is still not a good data carrier under all circumstances. Mandatory use of the CoC, further harmonization of the approval and certification process across MS would be needed if reliable data of MSV and IVA and NSS should become available and if reporting and monitoring should be done through the MS only.

4.7 Options for monitoring

4.7.1 Working assumptions for the definition of options for reporting and monitoring

The following working assumptions were established for the definition of the options for Monitoring and Reporting:

1. Baseline options D1 or D2 are used to determine the CO_2 emission for certification. These options for CO_2 determination are based on simulation using VECTO.
2. The heterogeneity of the HDV fleet is taken into account, especially regarding the types of vehicles, bodywork and other attributes that affect CO_2 emissions. HDV have different uses and drive cycles. HDVs comprise trucks, buses and coaches. HDVs are defined as vehicles for the transport of goods of more than 3.5 tonnes GVM or vehicles for the transport of passengers of more than 8 seats (buses and coaches). Even trucks are segmented into several categories, including long-haul, regional delivery,

urban delivery and construction. Also the EU fleet of HDV is significantly smaller than for LDV. The approach for CO_2 determination, which is based on simulation, allows the cost effective determination of the CO_2 emissions on a per vehicle basis. As such, the working assumption is that individual and whole HDV are certified, reported and monitored.

3. For HDV it is expected that, to follow and understand the trends in CO_2 emissions, the data volume would considerably increase compared to LDV, especially given the heterogeneity of the fleet of HDV and the large range of different attributes of individual HDV that affect the CO_2 emission.
4. The monitoring of HDV should be operational by Q1 of 2018 (assuming entry into force by 31.1.2017 of HDV CO_2 certification).
5. 60% of the market of HDV production is from 7 Companies, but the market is very fragmented for the rest. For HDV vehicle manufacturers range from large volume vehicle manufacturers to manufacturers of small volumes and special vehicles (vehicle OEMS, bodybuilders, bus manufacturers, SME).
6. HDV are often constructed by more than one manufacturer (in multiple stages as multi-stage vehicles, MSV)
7. HDV are type approved in different manners (WVTA, NSS, IVA, single, step-by-step)
8. Monitoring aims to monitor CO_2 emissions and fuel consumption and trends thereof of whole HDV's registered at EU territory (all Member States).

Options for monitoring and reporting envisage mainly choices to be made which:
- affect the responsibility of stakeholders for the processes or parts of the processes.
- affect mainly the administrative processes of the stakeholders for the purpose of Reporting and Monitoring and thus the costs to the stakeholders to implement and maintain the processes for Monitoring.
- affect the quality (reliability, consistency and comparability) and use of the data for the purpose of monitoring, i.e. the following of trends of the CO_2 emissions of HDV registered in the E.U.

4.7.2 Options for reporting and monitoring

Overview of options for Monitoring and Reporting:

M1: Baseline option
M2: Options related to the quantity and subject of the data
M2.1: Monitoring input data for VECTO
M2.2: Monitoring data of the completed vehicle (MSV)
M2.3: Monitoring data of trailers
M3: Options regarding the entities responsible for data collection and reporting
M3.1: Hybrid monitoring, MS + Vehicle OEM
M3.2: Hybrid monitoring, MS + TAA
M3.3: Vehicle OEM self-monitoring
M4: Options for modernization of the system
M4.1: Fully digitalized system
M4.2: Use of a (centralised) databases

M1 Baseline option

The baseline approach uses a similar process as in place for M1 and N1 passenger cars and vans with minimal adaptations needed for HDV. Member States collect the vehicle registration data (of N2, N3, M2, M3) and the technical data including the CO_2 emission, for each CY and report the data to EC/EEA. Therefore, MS bear the main responsibility for the collection of registrations and the technical data belonging to the registered vehicles. Technical data, including the CO_2 emissions, can be taken from the CoC or the TA documents.

Given individual vehicle certification as per the working assumption, and the use of one CoC per vehicle, the CoC could act as data carrier (unless the volume of data to report is too large for this kind of document). However, not all MS use CoCs to obtain the technical data. Many still use type approval documents. In any case, the CoC and/or the TA documents would need to be amended to include a section with 'environmental performances' which comprises the vehicle CO_2 emission and fuel consumption in g/km and g/t.km (and g/pass.km for buses?) per payload (three) and mission profile. Additionally, data in the 'technical data' sections (masses, dimensions, bodywork) is collected which are needed for the CO_2 metric (parameters that determine payload and passenger capacity). For this option M1 a minimum data set is defined. Further options with regard to data quantity are defined under M2.

Minimum of monitoring data needed for option M1:

- Identifier: VIN for identification
- Legislative Class: (M2, M3, N2, N3) to distinguish between LDV and HDV and sub-classes.
- HDV usage class: HDV usage class the vehicle belongs to.
- CO_2 emission and fuel consumption in g/km and l/100km per vehicle as determined by VECTO, taking into consideration possible different payload assumptions.
- Duty specific CO_2 emissions: g/t.km, g/passenger.km taking into consideration possible different payload assumptions.
- CO_2 emission and fuel consumption per mission profile taking into consideration possible different payload assumptions.
- Technical data needed to determine the duty specific metric (e.g. g/t.km) used with the CO_2 emission: determination of ton payload and passenger number require technical masses and dimensions as input.

Pros

- Allows to follow the trends of the CO_2 emissions of whole individual HDVs.
- Monitors vehicles registered in the EU.
- Comparable to the process of monitoring of passenger cars and vans.

Cons

- An increase is expected in the effort (amount of data management) for the Member States and manufacturers.
- It is mentioned by type approval experts that a large share of HDVs are approved according individual (single vehicle) approval. These vehicles are approved locally, often against national requirements and there is no harmonization of this local (type-) approval. So vehicles are registered in the EU without complete EU approval or Certification.

- There are no arrangements for handling the CO_2 emission values for local single vehicle approval or Certification.
- There is no arrangement for MSV. (Base-) vehicle manufacturers will be responsible for the certification of the base vehicle, but do not want to be responsible for the completed MSV because the CO_2 emission of this vehicle is beyond their control. The responsibility could be the same as with LD MSV. Here, a base vehicle manufacturer is responsible for the CO_2 emission of a base vehicle with assumed default bodywork.
- Multistage vehicles, monitored with default bodywork receive a fictive CO_2 emission value. Deviations between the CO_2 emissions of the real completed vehicle and a default MSVs are expected for individual MSV. Additional provisions are needed if the CO_2 emission needs to be monitored for the (real) completed vehicle. This is probably a very complex issue to solve and could require substantially increased effort and involvement for a lot of stakeholder groups (TS/TAA, Members States, Bodybuilders (SME and large) and manufacturers).
- There is still limited harmonisation across Member States for vehicle registration and still large differences in quality of data and data management.
- Time is needed for implementation, especially on the level of the MS registration authority and local Technical Service.
- There is a privacy issue of the use of VIN in some parts of the EU.
- The CoC is not always used by MS. Monitoring data (for passenger cars and vans) often origins from TA documents which are shared between the Member States and sometimes origins from the CoC. In principle the CoC is available with the vehicle and a paper version is available for use at registration. For the CoC there is not yet an arrangement where data is shared with all MS. However, a few Member States work on the development of a database where CoC data is stored and shared centrally.

Notes

- It is recommended to investigate the way type approval and certification is currently arranged for the EU fleet of HDV, hereby focussing on how the approval is arranged nationally for IVA and MSV and how in that process CO_2 data could be reliably made available for the monitoring.
- For tractors the CO_2 emission would anyway need to be calculated with a standard or norm trailer.

M2 Options related to the quantity and subject of the data

Monitoring of an extended set of technical data in addition to the minimum data set. A few types of data can be distinguished which may serve different purposes.

M2.1: Monitoring input data for VECTO.

All input data for VECTO is seen as relevant for the determination of the CO_2 emission of a HDV. The data can be used for monitoring of trends of components and for developing and/or reviewing default data as now used in VECTO tool. Some data, however, may be confidential.

Pros

- Allows to more accurately follow the trend of the CO_2 emissions and especially the development of the components that determine the CO_2 emission.

Cons

- Increase in the administrative burden for OEMs and MS due to the increase of the data.
- Possible confidentiality issues with some of the data

M2.2: Monitoring data of the completed vehicle (MSV).
Technical data and the CO_2 emission of the completed vehicle is monitored. It has yet to be established how a system could work exactly to enable this. In general this option is thought to add complexity to the system. Also it may involve final stage vehicle manufacturers (including SME) and (local, national) type approval authorities in the process. Theoretically, the CO_2 emission value can be updated after the construction of the vehicle is completed, using either of the two options for 'optional second stage certification for CO_2', using:

1) tables of CO_2 values defined by the base vehicle OEM or
2) recalculation with VECTO by the final stage vehicle OEM or at final certification/approval .

Pros

- The CO_2 emission value of a single vehicle is more accurate.
- Involving the bodybuilders opens up the possibility to drive CO_2 reducing technology that is built on trucks in the second or final stage of production which otherwise would only be covered by a default value.

Cons

- The complexity increases substantially. Bodybuilders need to work with the VECTO tool or tables of values. Bodybuilders, of which many are SME, thus also get a responsibility. New provisions need to be considered for local Technical Services who must check and certify the declared CO_2 value.
- The table values probably still have some inaccuracy because the values do not completely reflect the setup of the actual vehicle.
- More data handling and control, so the effort increases for bodybuilders and MS.
- Many bodybuilders are SME. The effort may be not proportional for SME, between SME and compared to large vehicle manufacturers.

M2.3: Monitoring data of trailers
This data can be taken from the CoC of category O vehicles, i.e. trailers. This requires all MS to register trailers and involves trailer manufacturers as each trailer would need to be certified. It would allow to follow trends with regard to technical attributes which also affect the CO_2 emission of the whole HDV.

Pros

- Allows the inclusion of trailers in the monitoring hereby more accurately following the trends of HDV CO_2 emissions and aspects of trailers that affect the CO_2 emission like mass and aerodynamic properties.

Cons

- It is difficult to collect data of trailers. Trailers are in the framework directive as 'category O vehicles' and data of the trailer must be put in the CoC. However, experts indicate that there is no consistent use of this CoC across MS and that MS register the data of trailers very differently. To solve this, it would require harmonization of the certification of trailers and harmonization of the registration.

Notes

- Trailers and tractors are no fixed combinations. Both do not necessarily match with regard to aerodynamic properties.

M3 Options regarding the entities responsible for data collection and reporting

For passenger cars and vans Member States report the registrations and technical data to the EEA/EC. However, alternatives for data collection exist where data as reported by different entities can be combined.

M3.1: Hybrid monitoring, MS + Vehicle OEM

Member States collect the registrations, i.e. the VIN numbers of HDV, based on vehicle legislative class information (HDV = N2, N3, M2 or M3) to determine the amount of registrations of HDV in a CY in a MS and report it to EEA/EC. The vehicle OEMS collect technical monitoring data of each vehicle produced and provide the VIN and report this technical data to EEA/EC. EEA/EC combines the reported data sets of MS and vehicle OEMS. This can also be done for completed vehicles and trailers. If all registered vehicles should be considered for monitoring, next to large vehicle OEMs SME would become responsible to provide data as well. The US, for instance, use small business exemptions. In this system the responsibility is distributed mainly between vehicle OEM and MS. An optional second stage certification could be introduced to leave the choice to bodybuilders if they provide data for monitoring.

Pros

- Allows to follow the trends of the CO_2 emissions of whole individual HDVs.
- Monitors vehicles registered in the EU.
- Decrease of the burden for MS given the fact that less data needs to be administered and collected.
- Distribution of responsibility (MS: collection and reporting of registrations, OEMs: collection and reporting of technical data).
- Less risk on data errors that occur at data transfer and data management (mainly at the level of the Member State Registration Authorities taking data from TA documents and CoCs) as the technical data comes directly from the OEMs.

Cons

- Bodybuilders (which include SME) would need to be involved in the reporting and CO_2 determination (only in case of second stage certification that is optional), and the CO_2 value should be certified, see also the options for MSV and the issues for individual approvals. Small volume vehicle manufacturers would also need to be involved in the reporting and CO_2 determination. SMEs (many body builders are SMEs) are not necessarily equipped for this type of monitoring.

Notes

- Exemptions for small enterprises could be considered. It is not clearly known what share of the market this comprises. It is therefore recommended to investigate this.

M3.2: Hybrid monitoring, MS + TAA

Member States collect the registrations, i.e. the VIN numbers of HDV, based on vehicle legislative class information (HDV = N2, N3, M2 or M3) to determine the amount of registrations of HDV in a CY in a MS and report it to EEA/EC. The Type Approval Authorities collect the technical data from the Type Approvals and vehicle Certification and report this data to the EEA/EC. EEA/EC combines the reported data sets of MS and the TAA.

Pros

- Allows to follow the trends of the CO_2 emissions of whole individual HDVs.
- Monitors vehicles registered in the EU.
- Decrease of the burden for MS given the fact that less data needs to be administered and collected.
- Distribution of responsibility (MS: collection and reporting of registrations, TAAs: collection and reporting of technical data).
- Less risk on data errors that occur at data transfer and data management (mainly at the level of the Member State Registration Authorities taking data from TA documents and CoCs) as the technical data comes directly from the OEMs.

Cons

- Bodybuilders (which include SME) would need to be involved in the CO_2 determination, and the CO_2 value should be certified, see also the options for MSV and the issues for individual approvals.

Notes

- Exemptions for small enterprises could be considered. It is not clearly known what share of the market this comprises. It is therefore recommended to investigate this.

M3.3: Vehicle OEM self-monitoring

Vehicle OEMS collect and report annually to the EC/EEA the required monitoring data of their completed vehicles, including sales numbers on EU territory. The responsibility for monitoring is largely with the vehicle OEM, although the process for data checking by e.g. an EC delegate like EEA, based on actual vehicle registration data is probably very important. This process therefore has some similarity with M3.1.

Pros

- Simplest process.

Cons

- A general problem is that sales numbers in the EU are not the same as registrations in the EU. Vehicles sold may be exported outside EU, not be registered in that year or even reconstructed.

- Due to the above, without additional checks probably less accurate and less reliable.

Notes
- This system demands provisions to distinguish steps in the changing fleet, e.g. designate Model Years.
- Checks against information from annual MS registrations and corrections may need to be made to the dataset, dependent on the desired accuracy of the monitoring data.
- Bodybuilders (SME) would need to be involved or be exempted.

M4 Options for modernization of the system
Today, technologies exist which enable the management of large quantities of information in an efficient, secure and consistent manner. It seems very logical not to by-pass such opportunities to reduce the burden to the stakeholders who register data and at the same time create the opportunity to allow a more thorough evaluation of trends of the vehicle fleet. The main technologies of use for Monitoring are the use of digital information and databases to collect and distribute the information. The two can obviously be seen working together very well.

M4.1: Fully digitalized system
Today TA documents and CoC are often paper documents, scanned versions of these paper documents and sometimes even the required data fields are handwritten. MS need to register vehicles based on these documents and therefore the risk of copying errors exist which is a major problem detected for the monitoring and reporting of LDV.
A digitalized system would require digital forms. Some Member States already shift to digital forms.

Pros
- The advantage would be that larger quantities of data could be retrieved from the forms with reduced effort.
- Largely reduced risk of copying errors. This could therefore lead to a more consistent and reliable dataset for monitoring.

Cons
- A mandatory shift of all Type Approval and Registration Authorities to a digitalized system means that they need to adapt their existing systems.
- Time for implementation is needed.

Notes
- Point of attention would be the protection of the digital data in the forms. Some form of data security may be needed. A harmonized data protocol needs to be used/developed.

M4.2: Use of a (centralized) databases
A (centralized) database can be used to collect the data. The idea stems from an initiative of a few members of the EREG working group who are jointly working on the development of a database that contains CoC data and registrations.
This database seems suitable for monitoring when it would be used across the EU by all MS.

Besides the option being developed now by EREG members, several other options can be envisaged as to how such a system could work. Because these options are very new, the intention is not to assess the options in-depth but it is rather the goal to poll the stakeholders whether a database system is seen as desirable or not.

Roughly the options to use database are as follows:
MS register the vehicle and the technical data as obtained from TA and CoC documents in a central or shared database. This option is currently being developed by EREG members.
MS register the vehicle in the database, vehicle OEMs update the database with the technical data from their Type Approval data of components and Certification documents of the whole vehicles.

MS register the vehicle in the database. Type Approval Authorities maintain a separate centralized secure database with the technical data of type approved components and certified vehicles and annually queries of the registration database and the technical database of the TAA are combined.

Pros

- A more transparent process of data collection and better consistency of data.
- More data can be collected with less effort.
- Additional benefits could arise from the use of a database. A database can be used to manage and contain other vehicle data than CO_2 data, like safety related vehicle information, vehicles reported as stolen and as such could serve multiple purposes which are relevant across the EU MS.

Cons

- Harmonisation and implementation across EU MS is needed with regard to the registration, type approval and certification of HDV and the use of the database.
- Use of databases comes with costs for the maintenance of the database, however, there are also cost benefits associated with a switch to databases (and digitalization) because the paper administration could be abandoned.

Notes

- Data security needs to be taken care off to prevent fraud / manipulation of data.
- The database needs to be managed. Who has what rights?
- Is there any confidential data? In principle TA and CoC data is public.

4.8 Reporting trends

Besides reporting of data by Member States to the EEA/EC as currently done for passenger cars and vans, which is in fact an important part of the monitoring option M1, there is also the reporting of the monitoring trends by the EEA in an annual report. In the EU monitoring data is reported about the specific CO_2 emission of passenger cars registered in every CY in each EU Member State. The reporting is in fact the aggregation of monitoring data to arrive at average specific CO_2 emissions. For passenger cars this is used to report and regulate the specific CO_2 emissions per manufacturer and to report the CO_2 emissions per Member State. The final "report" is the Commission Decision confirming the relevant CY data and the performance of each OEM in meeting its target (NB: the latter would not apply for HDVs as no targets are currently foreseen). This decision is published around

30 October each year and will also provide a legal basis for recovery of any excess emission premiums should an OEM exceed its target. The Commission decision is complemented by the EEA report on the monitoring exercise for the CY in question.

From eea.europa.eu: *"…The Regulation (EC) No 443/2009 requires Member States to record information for each new passenger car registered in its territory. Every year, each Member State shall submit to the Commission all the information related to their new registrations. In particular, the following details are required for each new passenger car registered: manufacturer name, type, variant, version, make and commercial name, specific emissions of CO_2, mass of the vehicle, wheel base, track width, fuel type and fuel mode. Additional information, such as type approval number, engine power and engine capacity were also submitted…*"

The EEA has collected the data from the Member States on passenger car registrations. This resulted in a provisional database and a final database for instance for 2012. For 2013 a provisional database is available. The final data for 2012 is published in Commission Decision 2013/632/EU. The evaluation of the data is summarized in the report [EEA 2013] titled CO_2 emissions performance of car manufacturers in 2012.

The Decision provides the confirmed average specific CO_2 emissions per manufacturer and the specific CO_2 emission targets per manufacturer. The average specific CO_2 emissions are corrected for phase-in, super credits, E85 reductions and eco-innovations. The specific emission targets are determined taking account of manufacturer pooling, derogation and niche derogation. Important to note is the use of a utility parameter, in the case of light duty vehicles the vehicle mass in running order. This parameter is used to define a CO_2 target per manufacturer or pool of manufacturers which depends on the average vehicle mass of the vehicles registered in a certain CY.

Mutatis mutandis, this methodology as applied for LDVs could in principle serve as base option for HDV (with clear differences e.g. the absence of targets to monitor), however taking notice of the market of HDV as well as of the typical characteristics of HDV which both are very different from LDVs.

Minimum needed for reporting are CO_2 aggregated per responsible entity (body/person), i.e. vehicle manufacturer and CO_2 aggregated per Member State. For HDV the vehicle manufacturers range from large OEMs to SME (bodybuilders). For HDV aggregation of CO_2 data per vehicle manufacturer may then also mean that SME (body manufacturers, in case of second stage certification) need to supply a CO_2 value and each of these (thousands) of SME would need to be included in the report, which seems hardly feasible. It should be considered to either exempt SME from the monitoring (like done in the US) or consider them as a single group. In that case they would still need to determine/declare a CO_2 value or the TS would need to determine a CO_2 value. But, as noted earlier, no such provisions exist in the MS.

Furthermore, data should be collected that allows monitoring of the HDV market and fleet enabling a better statistical evaluation of the fleet and trends with regard to the CO_2 emission and the attributes which affect the CO_2 emissions/fuel consumption. Therefore, it seems to make sense to also follow trends of the vehicles attributes/components that actually determine the CO_2 emission, like masses, road load, engine parameters, etc.

Further options could be reporting of data that can be used to relate CO_2 to utility (cargo mass, volume, passengers) to monitor the transport efficiency and the data needed to characterise and classify vehicles, CO_2 and fuel consumption per vehicle class and or per missions profile (*e.g.* weighing of mission profiles and cargo mass) with a view to ensuring comparability between vehicles from different OEMs.

Options for reporting could be determined as minimum to maximum amount of data to be reported.

The options for final reporting on the EU fleet should be defined taking into account the level of aggregation of data, which in turn is largely based on criteria such as comparability and coherence with other datasets, *i.e.*, LDVs.

The options mainly consider the type of CO_2 metrics, the HDV classification/aggregation and usage and the attributable entities:
- Reporting CO_2 emission in different metrics: gCO_2/km, CO_2/tonne.km, CO_2/passenger.km. Likewise for fuel consumption.
- HDV classes, mission profiles, payloads
- OEMs, trailer manufacturers, final stage manufacturers…
- Member States

As the monitoring data may provide a tool for comparing fuel efficiency between different OEMs and their vehicles, it is however expected that OEMs may wish to be actively involved in the collection and validation of the data to be reported

5 Stakeholder evaluation and cost assessment of the technical options

This section presents the findings of the stakeholder consultation exercise carried out by the ICCT on behalf of the European Commission (DG Climate Action) in the context of a service request[3] to perform a cost analysis of technical options for the certification, validation, monitoring and reporting of heavy-duty vehicle fuel consumption and CO_2 emissions. The outcome of this work will inform the development of future legislation meant to curb CO_2 emissions of heavy-duty vehicles in the European Union.

On the basis of the proposal of technical options presented to the European Commission by TNO and TÜV Nord in sections 3 and 4, a *stakeholder consultation* was carried out to gather the views of the different stakeholders regarding the technical merit, feasibility, and expected costs of the different proposals. Said consultation included a comprehensive online questionnaire (which was circulated to all stakeholders) and a series of one-on-one interviews with a subset of key stakeholders.

The feedback collected during the consultation exercise was processed and organised by stakeholder type to produce an overview of the *preferences and expectations* of the different players regarding the impending legal framework for the monitoring and reporting of CO_2 emissions from heavy-duty vehicles in the EU (covering the methods of determination of the CO_2 values, the conformity of production and the administrative schemes for monitoring and reporting the CO_2 values for each vehicle). A description of the stakeholder consultation exercise is provided in section 5.1 of this report, and its main results are presented in section 5.2.

Whenever possible, we also gathered cost estimates for the main cost items associated with the different technical options being considered. These data were coupled to commercially available European HDV market databases and various HDV industry sources to identify *cost structures* and estimate the costs that would be incurred by industrial stakeholders in the CO_2 monitoring scenarios underlying the technical options. The results of this cost analysis are presented in section 5.3 of this document.

The findings presented in this report point to widespread support of the adoption of an approach based on *component testing* and *vehicle simulation* (using the EC's VECTO software tool) for the determination of the CO_2 values from individual HDVs. For this reason, this option is taken as the baseline, and all the other options for CO_2 determination are discussed in terms of their differential aspects. As far as the technical options for checking the conformity of production and the administrative schemes for monitoring and reporting are concerned, there was a higher diversity of opinions among the stakeholders. For that reason, all of the relevant options are discussed on equal footing in the relevant subsections.

[3] Said service request was issued by the EC under Framework Service Contract CLIMA.C.2/FRA/2013/0007

The cost structures identified for the different options also seem to support the notion that the combination of vehicle simulation and component testing is the most cost-effective solution for the determination of CO_2 emission values of individual vehicles. With such an approach, the estimated costs of the determination of CO_2 per sold vehicle are kept low, and the coverage of the fleet is arguably better than what would be achieved with the options requiring the development of a “vehicle family” concept. It is also worth mentioning that large uncertainties remain about both the final implementation of the monitoring and reporting scheme and its associated costs (mostly overhead, IT and transitional costs). In any case, these are not to be overlooked, as the initial assessment suggests that they may be in the same order of magnitude as the costs associated with the determination of CO_2 emission values.

5.1 Stakeholder consultation

The primary research instruments for the quantification of costs related to the certification and reporting of HDV CO_2 emissions consisted of stated-preference methods, namely questionnaires and semi-structured interviews. An online survey was constructed in order to collect normalised data from a large number of stakeholders. Questionnaires from other consultation exercises and cost studies (*e.g.*, European Commission DG Environment, 2013) were considered in the design of the questionnaire.

The consultation process took place during the third quarter of 2014. A formal letter of invitation was emailed to a comprehensive list of stakeholders identified in cooperation with the EC. Upon acceptance of the invitation to participate in the exercise, stakeholders received a document with a detailed description of the options under consideration by the European Commission for the certification, validation, and reporting and monitoring of fuel consumption and CO_2 emissions from heavy-duty vehicles (see appendix A for a summary of the options presented to the stakeholders at the time of the stakeholder consultation, or section 3 and 4 (for a detailed description). They also received a link to an online questionnaire (see section 5.1.2). Additionally, selected stakeholders were contacted to schedule follow-up telephone interviews based on their willingness to provide additional feedback.[4] The respondents received assurance that their answers would remain strictly confidential and that the results would only be reported to the European Commission under anonymised form (*i.e.*, aggregated by stakeholder type). An additional step in the consultation process was a one-day stakeholder meeting held in Brussels on September 16, 2014, which was used to present the options for HDV CO_2 certification and monitoring/reporting and interim results of the consultation, as well as to collect further feedback prior to the drafting of the final report.

5.1.1 Identification of stakeholders

A list of critical stakeholders and key contact persons was drawn up by the ICCT in collaboration with members of the consortium and the relevant EC staff.
The relevant stakeholders included HDV manufacturers, trailer and body manufacturers, Tier 1 suppliers, type approval authorities (TAA), technical services, member state representatives and the relevant Directorate-Generals of the EC

[4] As stated in the online questionnaire itself.

(see Table 7). A total of 29 different stakeholders provided their feedback through the questionnaire (see Figure 11 for a breakdown or respondents by stakeholder type, and Figure 12 for their self-reported *expertise profile*).

Table 7: Stakeholders targeted in the consultation

Stakeholders
Individual truck manufacturers and relevant association (ACEA)
Individual trailer and body manufacturers and relevant association (CLCCR)
Individual components suppliers and relevant association (CLEPA)
European Commission Directorates-General (DG Climate Action, DG Enterprise and Industry, DG Joint Research Centre) and the European Environment Agency
Technical Services and Type Approval Authorities
LOT 3 contractors (within the consortium: TÜV Nord and TNO)
Non-EU stakeholders with relevant experience (US EPA, US HDV manufacturers)

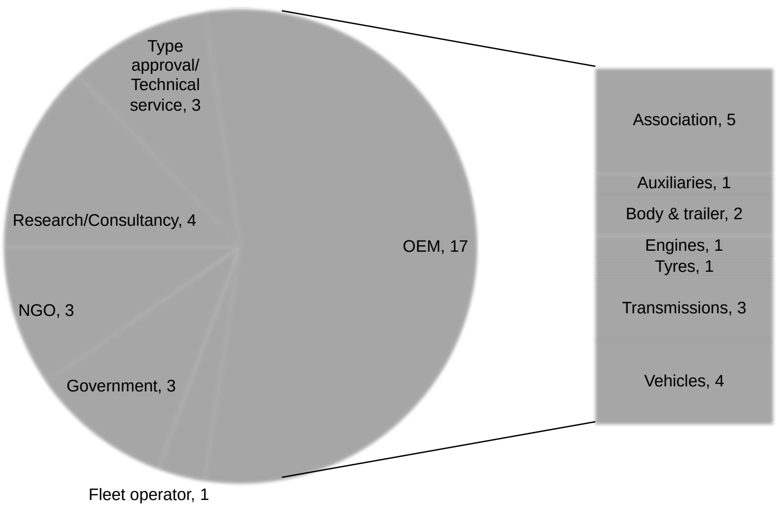

Figure 11: Questionnaire respondents, by stakeholder type

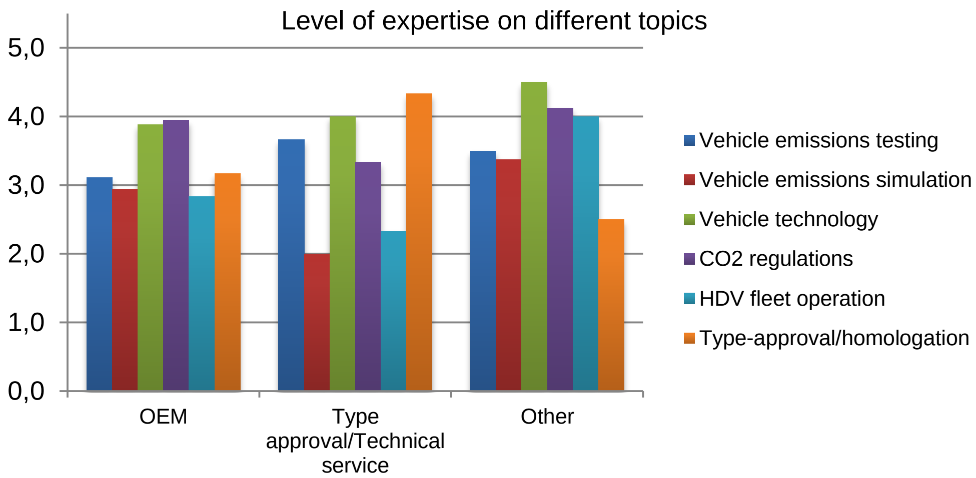

Figure 12: Self-reported expertise profile of questionnaire respondents (in a scale from 0 to 5)

5.1.2 *Stakeholder questionnaire*

Questionnaires offer a systematic, structured, and efficient manner of collecting data from a large number of respondents. Examples of questionnaires in costing analyses and consultation exercises related to environmental and transport policies are available (European Commission DG Environment, 2010; European Commission DG Environment, 2013; United States Census Bureau, 2014) and were consulted during the research design stage.

The content of the questionnaire was partially derived from previous regulatory impact analyses, cost-benefit analyses, and stakeholder consultations within and outside of the EU[5]. For example, the US Environmental Protection Agency (US EPA) quantified costs and benefits associated with GHG emissions standards and fuel efficiency standards for medium- and heavy-duty engines and vehicles (United States Environmental Protection Agency, 2011). In the accompanying regulatory impact assessment (RIA), several cost components of GHG regulations related to HDVs as well as practical ramifications of component testing procedures and vehicle simulation models were delineated; this report therefore informed the stakeholder consultation with regards to sources of costs and other barriers for industrial stakeholders. Similarly, the US EPA published a guide on producing cost estimates for feasibility studies (US EPA, 2000) that was utilised as well when designing the stakeholder questionnaire.

The aforementioned guidelines and examples were taken into consideration in order to systematically identify and categorise cost elements of certifying and reporting HDV CO_2 emissions. For questions gauging the attitudes of respondents toward CO_2 determination/monitoring/reporting options, Likert-type psychometric scales were applied to questions asking for the respondents' attitudes. The resulting output allows for quality assurance (*e.g.*, inter-item correlations as a measure of data reliability). Open format questions prompted for the quantification of cost elements and elaborations on these estimates.

Each proposed option was evaluated on the basis of three dimensions:

- *Quality*: This dimension comprises aspects such as the technical merit of each option, its prospects for further technical development, *etc*.
- *Cost:* This dimension comprises the costs borne by each stakeholder. Note that the Likert-type items can only be used for ordinal assessments (*i.e.*, stakeholder responses can be used to rank the different options in terms of cost. Quantitative cost estimates were gathered in ad-hoc text boxes in the questionnaire and also during the follow-up telephone interviews with selected stakeholders and complemented with desktop research activities during phase 2.
- *Preference:* The preference of each stakeholder regarding the relevant options will be gathered from both direct (stated preference) and indirect questions (inferred preference). To the extent possible, the preference will be separated from cost considerations.

Additionally, specific questions were included to gather information about the stakeholders, the respondents of the questionnaires and their individual attitudes (see Table 14).

[5] The questionnaire distributed to the stakeholders can be found in appendix B.

Table 8: Questionnaire overview (with number of questions and estimated time for completion)

Questionnaire section	Number of questions (repeats)
Section 1: Cover page and introductory questions	
General questions to categorise respondents and their attitudes	17
Section 2: Questions about CO_2 determination options	
General questions repeated for "D" option	23 (x5)
Specific questions for each "D" option	21
Section 3: Questions about monitoring and reporting options	
Questions repeated for "M" and "R" options	19 (x5)
Additional questions on "M" and "R" options	16
Section 4: Questions about conformity of production, "P" options	
Specific questions on "P" options	3
Section 5: Stakeholder type-specific questions	
Specific questions for vehicle OEMs, component suppliers, technical services, type approval authorities, regulatory agencies and other stakeholder types	Variable (estimated time for completion: 20 minutes)
Total sections 1 to 5 (including repeats)	270-275 (approx. 90 minutes @ 20 seconds/question)

5.1.3 Stakeholder Interviews

Since questionnaires require an a priori definition of cost elements to be studied, the questionnaire was complemented with comment sections, where respondents were free to input text. More importantly, semi-structured, follow-up interviews with key stakeholders ensured that unknown cost components could be identified and cost estimates from the questionnaire could be refined. A total of eight such interviews were conducted as part of the consultation exercise, and the feedback collected from them was incorporated into the results presented in section 5.2.

5.2 Stakeholder assessment of the technical options

This section summarises the feedback provided by the different stakeholder types for the different CO_2 certification, validation, reporting and monitoring options that were proposed.

5.2.1 Global assessment

In this section we present the global assessment of the options as inferred from the responses to the Likert-type (numerical scale) questions that were presented to all stakeholders. These allowed us to attach a normalised numerical value to each one of the options in three different dimensions: 'general preference', 'cost' and 'quality'. In each case, a high score implies that the option is favoured in that particular dimension.

Global assessment of "D" options

The global assessment of the "D" options for the determination of the CO_2 emission values from HDVs is presented in Table 15 where the numerical score (between 0 and 5) indicates the level of preference in the dimension indicated in the bottom row (either general, cost or quality) which is also represented by the cell shading (green for high preference, yellow for neutral, red for low preference[6]).

[6]Low preference: Numerical score between 1 and 2.5; Neutral: Between 2.5 and 3.5. High preference: Between 3.5 and 5.

The data are presented by stakeholder type, with an “others” column representing the average responses from NGOs, consultancies, and governments among others.

Table 9: Global assessment of the "D" options (options for CO_2 determination)[7]

	OEMs			TAA/Technical service			Others		
	General	Cost	Quality	General	Cost	Quality	General	Cost	Quality
Option D1	4.3	1.9	3.9	0.0	0.0	0.0	4.8	3.0	4.8
Option D2	2.5	2.3	2.2	0.0	0.0	0.0	2.4	3.3	2.9
Option D3	1.4	0.9	1.7	2.0	1.0	0.0	2.3	1.7	2.6
Option D4	1.5	0.7	1.3	2.0	0.0	0.0	2.7	2.0	3.0
Option D5	2.1	1.5	2.2	4.0	5.0	4.0	3.0	3.3	2.9

The assessment of the “D” options by the stakeholders reveals a strong preference toward option D1 (based on component testing and whole-vehicle simulation using the VECTO tool) in the “general preference” and “quality” dimensions. In the case of “cost”, the preference is less clear, with options D1, D2 and D5 (*i.e.*, all the options that entailed the use of vehicle efficiency simulation) scoring similarly. The results for type approval authorities/technical services are uncertain, since only one respondent filled in this section of the questionnaire (0 in this case means no answer/ I do not know).

A possible explanation for preference towards the simulation options would be that, given the amount of resources invested by the European Commission in the development of VECTO, it was widely expected by all stakeholders that the determination of the CO_2 emission values would be largely based on simulation. In this sense, option D1 may be considered as the baseline option, whereas options D2 and D5 can be seen as variations of the baseline, and options D3 and D4 as more substantial departures which appear to face some opposition from stakeholders.

Global assessment of “P” options

The global assessment of the “P” options for the determination of conformity of production is presented in

Table 10, using a simplified form in comparison to Table 9. The “P” options are only analysed from a general perspective. More specifically, the table presents results for the question: “The determination of conformity of production (CoP) should be done on the basis of option Px”. Responses ranged from “strongly disagree” to “strongly agree”. As opposed to the “D” options, it is more difficult to extract general conclusions about the preferences of stakeholders.

[7] Option D1: baseline option, combination of component testing and VECTO simulation; Option D2: simplified baseline option, simulation and reduced testing effort; Option D3: chassis dynamometer test; Option D4: fuel consumption measurement during real driving; Option D5: simulation of load profile and engine test.

Table 10: Global assessment of the "P" options (options for the determination of conformity of production [CoP])[8,9]

	OEMs	TAA/Technical service	Others
Option P1	3.4	4.0	2.2
Option P2	2.0	3.0	3.3
Option P3	1.6	3.0	4.0

According to Table 10, OEMs and TAAs/technical services show a preference for option P1 (where only the input data to the simulation are checked, option P1), whereas other stakeholder groups favoured options P2 (process-specific CoP including a complete repetition of the process, from the component testing to the simulation of the final, vehicle and application specific CO_2 value) and P3 (vehicle-specific CoP could be based on a simplified short cycle test consisting of constant speed and acceleration/deceleration events to be driven on a test track monitoring the fuel consumption, the results of which would be compared to a simulated of the same short cycle). In section 5.2.2, these results are analysed in more detail to reveal the preferences of stakeholder sub-types (*e.g.*, vehicle OEMs vs. component OEMs).

Global assessment of “M” and “R” options
A common theme in the feedback provided by stakeholders regarding the proposed CO_2 monitoring and reporting options related to the lack of clarity in the implications of the different options. A likely explanation for this is that, unlike the other options, the M+R options (as presented to the stakeholders for the consultation exercise) were not mutually exclusive and stakeholders found it hard to oversee consequences of non-existent processes. Instead, the sub-options explored different aspects of a complete monitoring and reporting scheme: scope of the data to be monitored, attribution of roles and allocation of legal responsibilities, reporting procedure (database management), *etc*. This prompted the EC to ask the consortium to further refine the options and structure them similarly to the “D” and “P” options. As a result of the restructuring of the M and R options (which happened in parallel with the stakeholder consultation exercise due to project time constraints), the options regarding CO_2 monitoring and reporting presented in section 4.7 of this document differ from the ones that were actually subject to stakeholder evaluation. Both the global and specific feedback corresponds to the “old” options, whereas the discussion (section 5.4) applies to the options in their newer formulation. The feedback on the initial options allowed to define a better baseline options which already includes some of the stakeholder preference. Table 11 summarises the correspondence between the old and the new formulation of the monitoring and reporting options.

[8] Low preference: Numerical score between 1 and 2.5; Neutral: Between 2.5 and 3.5. High preference: Between 3.5 and 5.
[9] Option P1: retesting of components; Option P2: retesting of components *and* new simulation runs; Option P3: testing of entire vehicle with real driving (track testing/PEMS)

Table 11: Correspondence between initial and the further refined technical options for CO_2 monitoring and reporting.

Refined options	**Initial formulation**
M1: Baseline option	M1.1: Monitoring of the technical characteristics as currently given in the CoC for individual HDVs
M2.1: Monitoring input data for VECTO	M2.1. Monitoring of HDV data not yet available in the CoC: CO_2 data determined with VECTO
M2.2: Monitoring data of the completed vehicle	M2.3: Monitoring of HDV data not yet available in the CoC: Other information (reformulated option includes more data)
M2.3: Monitoring data of trailers	M2.2: Monitoring of HDV data not yet available in the CoC: Trailer technical data
M3.1: Hybrid monitoring (MS + OEM)	M5.1: Combined monitoring by Member States and OEMs
M3.2: Hybrid monitoring (MS + TAA)	M3: Monitoring by member states and/or type approval authorities and reporting data to EEA
M3.3: Vehicle OEM self-monitoring	New proposal
M4.1: Fully digitalised system	New proposal
M4.2: Centralised database	New proposal

The results of the assessment of the M and R options are presented in Table 12. However, these results are to be taken with a measure of precaution for the reasons explained earlier: a perceived lack of clarity in the options likely led respondents to rank the options lower than they would normally have under the new formulation.

Table 12: Global assessment of the "M" and "R" options (old formulation, as presented to stakeholders)[10,11]

	OEM			**TA/Technical service**			**Others**		
	General	Cost	Quality	General	Cost	Quality	General	Cost	Quality
Option M1+R1	1.8	2.1	1.9	2.0	0.0	0.0	1.6	1.8	1.3
Option M2+R2	1.6	1.4	1.6	4.0	0.0	0.0	3.0	1.5	3.4
Option M3+R3	2.2	2.1	1.8	4.0	0.0	0.0	2.2	1.5	2.8
Option M4+R4	1.3	1.3	1.1	2.0	0.0	0.0	2.2	1.3	2.6
Option M5	0.9	1.1	1.1	4.0	0.0	0.0	3.4	1.5	3.2

5.2.2 *Detailed feedback by Stakeholder Type*

In this section we present the assessment of the options gathered from the specific questions found in the questionnaire, as well as the stakeholder interviews that were carried out as part of the consultation exercise. In addition, we include an analysis of publically available position papers and similar documents produced by the stakeholders.

[10] Respondents were asked to rate three statements: “I have a general preference for option Mx”; “I find that option Mx is favourable from the point of view of cost”; “I find that option Mx is favourable for the usefulness of results”.

[11] Low preference: Numerical score between 1 and 2.5; Neutral: Between 2.5 and 3.5. High preference: Between 3.5 and 5.

This feedback is presented by stakeholder type, broken down into four stakeholder types: 1) Vehicle OEMs, 2) Component OEMs, 3) Type Approval Authorities and Technical Services, and 4) All other stakeholder groups (including research firms, consultancies, NGOs, and fleets). It should be noted that the feedback described below is the opinion of the specific stakeholder (or set of stakeholders) and should not be assumed to be the opinion of the authors.

5.2.3 Vehicle OEMs

This section summarises the feedback provided by the European Automobile Manufacturers' Association (ACEA), and by individual vehicle manufacturers (which remain unnamed, as specified in the terms of reference of the stakeholder consultation exercise)[12].

"D" options

In the view of ACEA, options D1 and D2 are the ones that should be further explored and enhanced to maintain the existing legal principles of the type approval framework Directive 2007/46/EC. Vehicle manufacturers propose a "certification of the CO_2 declaration process", whereby it could be verified whether the vehicle manufacturer has the proper processes in place to ensure that the correct input data are used for the simulation of a specific vehicle configuration. Special emphasis would be placed on ensuring that all input data are measured according to the provisions, and properly stored and maintained. In this sense, ACEA underlined the importance of proper quality management systems, secure handling of certified data and the role of technical services as witnesses of the component tests.

Option D1 is the option preferred by the manufacturers' association. However, some elements from option D2 could be retained and included in option D1, such as the inclusion of CFD simulations for the determination of the air drag coefficient, and the use of default parameter values (*e.g.*, for transmission and axle efficiencies) in the simulation runs in some cases.

The possibility of using default values or a simplified CFD simulation for an optional, second stage certification of multistage vehicles (relevant to options D1 and D2) was in principle supported by ACEA. In order to provide values representative of the real-world performance of the vehicle, it is important to be able to show the impact of the completed vehicle including the bodywork, trailer, etc. Tools such as *simplified CFD simulations* are needed to support the manufacturer of the bodywork, trailers etc. CFD simulations show significant promise in terms of improved accuracy, lower cost and increased flexibility with regard to planning and execution (since the simulations could be performed even before the actual vehicle configuration physically exists). However, reliable, comparable and cost-effective CFD simulations also require a *common method* (agreed by OEMs) for the geometry preparation (from CAD model to computational mesh), which is lacking in the current state of development of the VECTO methodology.

On the other hand, options D3 (chassis dynamometer testing) and D4 (fuel consumption measurement during real driving) do not have the support of ACEA because they are viewed as unsuitable to support the market forces that would

[12] The same convention applies to other stakeholder types in the relevant sections: individual stakeholders are left unnamed, but associations with public relevance are not.

drive fuel efficiency. The shortcomings cited for these options for the determination of CO_2 emission values relate to the lack of reliability/ability to represent real-world performance and increased costs with respect to the baseline option (D1; see Table 13).

Table 13: Shortcomings of options D3, D4 as identified by ACEA during the consultation

Issue	**Comment from ACEA**
Testing costs	Chassis dynamometer/on-road testing is less cost-efficient than whole-vehicle simulation (assuming equal coverage of the HDV fleet)
Accuracy/quality of results	Chassis dynamometer testing (option D3) is considered repeatable when using the same laboratory. Reproducibility issues could be handled by a calibration procedure. The accuracy of on-road testing with PEMS or a FC meter (option D4) is expected to be poor, due to the difficulties to control ambient conditions, driver performance, *etc.*
Definition of vehicle families	This is required for options D3 and D4. Leads to less accurate/realistic CO_2 values

Lastly, option D5 (simulation and engine testing) is deemed an unrealistic alternative. The comments on this option from both ACEA and the individual manufacturers surveyed point out to the large number of possible combinations for transmissions, axles, air drag coefficients, auxiliaries and tyres, which would require many engine tests, thus increasing the costs of this options.

"P" options
Vehicle manufacturers favour the determination of conformity of production (CoP) being done on the basis of individual component testing alone (where only the input data to the simulation are checked, option P1). ACEA notes that such an option should include provisions to ensure that appropriate data management systems are in place. A CoP scheme on the basis of individual component testing *and* a new simulation run (whereby the inputs to the simulation *and* the simulation itself are checked, option P2) received partial support from vehicle OEMS. In their view, such an approach could be accepted as long as it is not intended as a complete replication of the declaration process, focusing instead on the parameters relevant to ensure that he production conforms to data from the certified process.

On the other hand, a CoP scheme on the basis of comparing the results of a simplified track test—or, alternatively, a PEMS test—to a simplified simulation run (option P3, "process-oriented" CoP) did not garner the support of vehicle OEMS, as this approach was dismissed for not being "accurate enough to serve any useful purpose for CoP". Vehicle OEMS did point out that some process-oriented aspects could be included in the initial assessment of the input data and the CO_2 calculation process. In particular, whole-vehicle testing could play a role in the further development of the VECTO methodology (*e.g.*, to improve default parameter values, as an "ex-post" exercise). However, the manufacturer' association view this type of tests as a separate activity, outside of the certification procedure.

"M+R" options
Due to the issue noted, the specific feedback on the "M+R" options does not allow the authors to establish which of the options presented in section 4.7 is preferred by manufacturers. Still, it was clear that European manufacturers advocate a

monitoring system at the vehicle level (as opposed to monitoring at the vehicle type or “family” level); that the monitoring and reporting scheme should cover more information than is currently reported in the CoC pursuant to Directive 2007/46/EC; and that it should be harmonised across EU member states to ensure overhead costs are kept low.

Vehicle manufacturers view the applicant (*i.e.*, the vehicle manufacturer itself) as responsible for the input data for the simulations, including the Conformity of Production of the data. At the same time, they propose that all input data and other relevant parameters be included in one single document used for information purposes. ACEA stressed that the monitoring and reporting scheme should be implemented in such a way that not only monitoring and reporting to authorities is covered, but also declaration of fuel efficiency/CO_2 to the customers in order to reap the expected benefits. The increase of the administrative burden is a concern, as are the costs associated with the secure handling of all the data produced under the new regulation.

ACEA expect that the monitoring and reporting will bring about significant costs for vehicle manufacturers. One major cost is the investment and the management of new internal system for databases and data management. The introduction of a new reporting system, separate from the CoC system, could include some additional costs but these are not expected to be significant compared to the other costs for databases and data management. In this sense, the benefits of being able to provide additional information to customers outweigh the added costs.

As far as the *parameters that should be monitored*, ACEA proposed (assuming VECTO is used for simulations) to monitor the CO_2 emission values determined for individual vehicles (covering different mission profiles), vehicle combinations (EMS), fuels (with the inclusion of alternative fuels) and payloads. In ACEA’s view (which was largely shared by the vehicle manufacturers interviewed), the input data to the simulations should not be monitored, as these are thought to be confidential in nature. Instead, the monitoring scheme should focus on the simulated CO_2 values.

A further issue in need of careful examination is the *allocation of legal responsibilities*. In the view of ACEA, the certification of input data would not affect the manufacturer’s responsibility for the declared CO_2 values: the component supplier would be accountable to the Type Approval Authority for its component, needing to prove that the component fulfils the regulation at the time of type approval, and that the processes to ensure produced products still comply with the approved type (CoP). The vehicle manufacturer is accountable for the correct installation of the component according to the regulation, and has the same obligations towards the Type Approval Authority.

5.2.4 Component OEMS

This section summarises the feedback provided by individual vehicle component OEMs (mostly transmission, engine, tyre and body and trailer manufacturers) and by the relevant associations such as the European Association of Automotive Suppliers (*Comité de Liaison de la Construction d'Equipements et de Pièces d'Automobiles*, CLEPA), the Liaison Committee of the Body and Trailer Building Industry (*Comité de Liaison de la Construction de Carrosseries et de Remorques*, CLCCR), and the European Tyre and Rubber Manufacturers’ Association (ETRMA).

"D" options
The vast majority of component OEMS expect the European Commission to quantify CO_2 of HDVs through detailed ("high fidelity") vehicle simulations to be performed for individual vehicle configurations, and covering one or more relevant mission profiles. The computer simulation approach is widely perceived as the most realistic methodology in view of the large number of combinations and the capabilities of modern computational tools. The possibility to use default values is lauded as a valuable alternative to reduce testing efforts, especially for less frequent (niche) applications. The possibility to use measurements on certified test benches is important to prove improvements in efficiency (D3, D4 options play a role after all). The possibility to apply *families on a component level* combined with well-balanced control mechanisms helps to reduce effort to a reasonable degree.

The main concerns expressed by component OEMs relate to the level of detail with which components should be modelled, and to the ability of VECTO to capture the influence of some fuel-saving technologies. Some stakeholders noted that current technological developments focus on improved control systems (e.g., as applied to auxiliaries) and deeper component integration (*e.g.*, between engines and transmissions), which may not be reflected in simulation modelling. The outstanding issues with the CO_2 determination options based on vehicle simulation (D1 and D2) most frequently cited by component OEMs are summarised in Table 14.

Table 14: Feedback on open issues regarding the simulation of CO_2 emissions from HDVs

Issue	**Comment from component OEMs**
Simulation of advanced control strategies	A backward-looking model like VECTO requires that all input signals of all subsystems be known at the beginning of each simulation time step (*e.g.*, efficiency maps dependent on input torque cannot be used). 'Black box' systems cannot be integrated.
Simulation of component integration	Joint management of engine torque demand and the shifting strategy can achieve substantial CO_2 savings during normal driving, especially by reducing transient operation (*e.g.*, through power shifting or electrically-assisted shifting). These may not be fully modelled in VECTO, are not captured by steady-state engine testing.
Transmission testing	As the efficiency of power transmission moves close to 98-99%, the accuracy of transmission tests may become problematic.
Simulation of hybrid powertrains	Hybrid powertrains can achieve substantial CO_2 savings through load levelling and should be covered by the simulations. A possible alternative would be to make use of option D5 for hybrid powertrain simulations.

Due to their unique position in the HDV market, the views of (non vertically integrated) engine manufacturers differ notably from those of other stakeholders. Some stakeholders involved in the production of integrated engines and transmissions specifically mentioned the possibility of a standard combining engine testing using a transient cycle such as WHTC, and simulation modelling in VECTO using a common, generic fuelling map (mimicking US EPA's Phase 1 approach with their simulation tool GEM) as an alternative CO_2 determination method. Some stakeholders also noted that a regulation focusing on improvements at the vehicle levels could put independent component manufacturers in the position of having to deal with multiple, differing efficiency targets from all the vehicle OEMS they serve, thus leading to an diversification of products that would put these OEMs at a disadvantage.

"P" options
Component OEMs showed a general preference for the P1 option (conformity of production checks done on the basis of individual component testing alone, where only the input data to the simulation are checked). However, the transmission manufacturers surveyed were more in favour of option P3 (vehicle-specific CoP based on a simplified, short cycle test or on an on-road measurement during real driving). This is arguably in connection with the issues with transmission testing listed in Table 14, as well as with the relatively high costs associated with transmission testing (see section 5.3 for a more detailed discussion of the cost structures associated with the different technical options being proposed).

Some stakeholders voiced specific concerns about the allocation of responsibilities for component data reporting. In particular, representatives of the European tyre industry (ETRMA) pointed out that the tyre industry operates on the basis of contractual agreements with vehicle OEMs whereby they must supply tyres meeting certain technical parameters (one of them being rolling resistance, measured according to ISO 28580 standard, as specified in the tyre type approval directive EC 458/2011). Therefore, in the view of the tyre manufacturers, the CoP tolerances for tyre rolling resistance could be dealt with between the vehicle manufacturer and its tyre supplier within the existing contractual agreements.

"M+R" options
A common theme in the feedback provided by component OEMs is the concern about data confidentiality, which becomes especially relevant if option D1 is finally implemented for the determination of CO_2 emission values. In that case, the VECTO tool could require input data which is mentioned to be sensitive data by vehicle OEMs (engine maps, transmission efficiencies, air drag coefficients) to be stored outside of the manufacturer's control. If that is the case, industrial stakeholders have overwhelmingly called for robust provisions to ensure that these data are kept confidential.

In connection with these issues, some component manufacturers made the point that the costs of producing, supplying and storing the data required by the simulations will likely be passed along the value chain and ultimately be borne by the customer. Therefore, it is important to strike a reasonable balance between costs and reliable, transparent data generation.

5.2.5 Type approval authorities and technical services

As is the case with other European regulations affecting vehicle emissions, it is expected that type approval authorities and technical services will play an essential role once the scheme for monitoring CO_2 emissions from HDVs is in place. Still, some uncertainty remains about the *allocation of responsibilities*. In the probable context of a determination of CO_2 emission values from a combination of *component simulation and vehicle simulation* (options D1 and D2), this group of stakeholders would be in charge of the following tasks: 1) to verify that the vehicle or component OEM producing input data has a quality management/data management scheme in place, 2) to verify that the tests are performed in accordance to the methodology included in the regulation (eventually witnessing those tests as required), 3) to ensure that the data are declared to the type approval authority, 4) to manage the extension of type approvals upon changes or additions, 5) to carry out the CoP control plan (the tests/checks to be carried out should be agreed with the corresponding type approval authority).

In general terms, the views of technical services and type approval authorities tend to align with those of OEMs as far as purely technical matters are concerned (especially relating to the “D” options). Some respondents within this stakeholder group noted that a great deal of technical work would need to be performed in collaboration with industry for the implementation of the monitoring scheme. Enough lead time will have to be given in order for the registration authorities in the Member states to design the procedures and handle all the new data that these will produce. The appropriate amount of lead time is connected with the level of complexity of the technical options ultimately implemented (especially the M+R options, which determine the amount of data (e.g. for MSV) that is produced along the certification process).

It should also be noted that technical services and type approval authorities would have an additional role to play if the verification of CO_2 values is performed as a separate activity outside of the certification procedure. In such a scenario, additional tests (presumably whole-vehicle tests) would have to be performed to improve the whole methodology (*e.g.*, to update default values). The design and performance of such tests would have to be carefully executed by a third party, to ensure that they represent real-world driving conditions and that the vehicles tested are not different from OEM offerings.

5.2.6 All other stakeholders (research organisations, consultancies and environmental NGOs and fleet operators)

This section summarises the feedback provided by research organisations, consultancies, environmental NGOs and fleet operators (including the International Road Transport Unit, IRU). These stakeholders show the highest degree of support for the implementation of a monitoring scheme (as well as for eventual mandatory standards).

In general terms, these stakeholders welcome the implementation of a regulation for the monitoring of CO_2 emissions from HDVs, and their feedback regarding the method for the determination of CO_2 emission levels is broadly in line with those of industrial stakeholders (expectations for a simulation-based approach, general preference for option D1). A few of the consultancies and research organisations surveyed, stressed the importance of vehicle light-weighting, improved aerodynamics and lowered rolling resistance as key areas of potential technological improvement. In this sense, option D1 is preferable to option D2 to capture the improvement in these areas, in spite of the additional complexity.

This group of stakeholders tended to put the focus of the monitoring scheme in the real-world representativeness of the CO_2 and fuel consumption figures that are ultimately reported, in the possibility of verification of such figures by a third party (*e.g.*, a Member State), and in a comprehensive, transparent monitoring by the competent authorities. Words like transparency, robustness, traceability, and reproducibility are frequently cited in the feedback provided by this group of stakeholders, which tends to favour detailed simulation solutions at the vehicle level, as well as monitoring and reporting options based on the complete vehicle (including improvements done on body and trailer).

Some stakeholders in this group pointed out that the determination of the CO_2 emissions should be reported using metrics that include the level of utility or service. This could be accomplished by expressing the emissions as g CO_2/ton*km or g CO_2/passenger*km, and by reporting average (simulated) speeds along with the CO_2 results and for different payload levels and also for different missions. For vehicles that can be equipped with more than one trailer, it should be possible to simulate the results for all of them, as well as for different payload levels.

A recurring observation from this stakeholder group is related to the link between the regulation of conventional pollutants (Euro VI) and the new CO_2 monitoring regulation. In particular, it was pointed out that safeguards would be required to ensure that the certified CO_2 emission values are achieved without detriment to low emissions of regulated pollutants. These stakeholders also called for provisions to ensure that third parties (*e.g.*, EU member states) shall be able to perform verifications of the CO_2 emissions values that are reported (in a similar fashion as PEMS are used to check in-service conformity with Euro VI standards as per Regulation 58/2011 (EC 2011). These could be implemented in connection with a durability requirement for the declared CO_2 emission values.

5.3 Cost study

This section presents the results of a cost study of the technical options for the monitoring of CO_2 emissions from HDVs presented to stakeholders. The cost study identifies the main cost elements identified with the implementation of a monitoring scheme for CO_2 from HDVs from the determination of the emission values to the reporting and monitoring, for all the relevant technical options described in this document. The study was performed on the basis of quantitative cost information provided by the relevant stakeholders during the consultation exercise (see section 5.1), on expert judgment from members of the research consortium, and on additional data sources listed in section 5.3.2.

5.3.1 Introduction

The costs and burdens to major stakeholders associated with a new regulatory action must be well understood prior to its implementation. Some vehicle regulations (*e.g.*, the Euro regulations of conventional pollutants) require the introduction of new technologies to meet certain emission limits. However, the regulation under analysis here would be limited to mandatory certification (measurement), validation, reporting and monitoring of CO_2 emissions from HDVs without a specific target. The costs directly attributable to compliance with such a programme will be lower than the costs associated with a limit-setting rule requiring substantial investments in research and development and changes in the hardware of the vehicles.

Mandatory measurement and reporting of CO_2 emissions is not a new concept. Besides the CO_2 standard in place for passenger cars and vans, in 2012 the European Commission adopted a regulation for monitoring and reporting of greenhouse gas emissions and on verification and accreditation of verifiers under the EU Emissions Trading System (EC, 2012). The associated impact assessment discusses the cost analysis associated with the rule without carrying out a full-fledged quantitative assessment of costs of the different policy options. However, cost effectiveness was taken into consideration when deciding between various policy options. In order to determine cost effectiveness, there were consultations with external experts (consultants) as well as stakeholder engagement (technical working group, workshops and online surveys). These steps were necessary to find the right balance between accuracy of monitoring and reporting and cost efficiency.

As a second example, in 2009 the US issued a final rule on the Mandatory Reporting of Greenhouse Gases from all sectors of the economy.[13] The rule does not require control of greenhouse gases, rather it requires only that sources above certain threshold levels monitor and report emissions. Complete detail of the economic impacts of the final rule can be found in the text of the Regulatory Impact Analysis (RIA) for the final rule (US EPA, 2009). The US EPA estimated costs of complying with the rule by using available industry and US EPA data to estimate the cost of incremental monitoring, recordkeeping, and reporting activities for both public and private stakeholders. Major costs included labour costs (monitoring and reporting for the private sector and assuring and releasing data cost to the public sector) and equipment costs (including the initial purchase of equipment as well as any facility modifications or upgrades).

For mandatory certification, validation, reporting and monitoring of HDV CO_2 emissions, a similar strategy can be carried out to those mentioned above. The strategy that is proposed here is discussed in more detail in the methodological description of the cost study (section 5.3.2). This section investigates the costs associated with the different options for measuring, monitoring, and reporting carbon dioxide emissions from new registrations of heavy-duty vehicles in the EU.

5.3.2 *Methodology*

In order to ensure accurate and representative results, a number of sources on cost-benefit analyses (CBA), regulatory impact analyses (RIA), and costing studies in environmental policy making were consulted. These sources include guidance documents, documents related to environmental regulations in the transportation sector, case studies, journal papers, and public responses to previous regulations. Best practices were distilled from these sources and applied to the process of quantifying the costs associated with certification, validation, and monitoring and reporting of HDV fuel consumption and CO_2 emissions. The cost/benefit framework outlined by Renda et al. (2013; see section 5.3.2) particularly provided a structure for identifying, delineating, and attributing costs in the context of a number of diverse stakeholder groups.

Goal and scope

The cost analysis aimed to identify and quantify the costs resulting from measuring CO_2 emissions from HDVs. The focus of the cost study was to provide a reliable estimate of the costs borne by the different *industrial stakeholders* (*i.e.*, vehicle and component OEMS, as well as technical services). Due to the complexity of the European HDV market and to some remaining uncertainties about the final implementation of the regulatory scheme, a number of *simplifying assumptions* were made (see Table 15).

[13] http://www.epa.gov/ghgreporting/documents/pdf/2009/GHG-MRR-FinalRule.pdf

Table 15: Simplifying assumptions adopted for the performance of the cost study

Assumption	**Rationale**
The estimated costs are referred to *vehicle* OEMs	Vehicle OEMs have a key position in the value chain. Most OEMs in the European HDV market are vertically integrated. This assumption enables the allocation of estimated cost to vehicle sales by means of commercial HDV databases (see Table 16)
Segmentation of vehicle OEMs	Two different tiers of vehicle OEMs were defined to investigate the changes in the impact of the regulation with the size of OEMs.
Time horizon	The commercial lifetime of a vehicle variant was required for the calculation of annual costs of determination options. Based on IHS1, the lifetime was determined to be approximately five years. Similarly, while the precise definition of vehicle families has yet to be determined, the commercial lifetime of vehicle families was determined to be ten years.
The costs of testing tyres and auxiliaries are not included	Tyre manufacturers already determine the rolling resistance coefficient of tyres according to EC 458/2011, and thus the CO_2 should not impose additional testing burdens. Auxiliaries were excluded due to the uncertainty about nature of tests and lack of cost data.
Marginal cost of simulations	The cost of simulation covers all the relevant runs necessary for the given vehicle. Simple modifications of the simulation file and subsequent re-runs (*e.g.*, simulation for different trailers, leaving all other simulation parameters unchanged) do not bring about additional costs.
Fixed costs differ between manufacturer tiers	Estimates of fixed costs were derived from questionnaire data. It was assumed that medium and large manufacturers would incur different levels of fixed costs. The fixed costs were thus scaled according to manufacturer size.
Annual and transitional fixed costs are equal	Fixed costs were assumed to be recurring on an annual basis. Fixed costs would be incurred during the transitional year and each year thereafter.
Fixed costs occur throughout the supply chain	Fixed costs estimates were collected from multiple stakeholders at different positions in the value chain. Fixed cost estimates were thus multiplied by the number of members in the supply chain, which in the model consists of vehicle, transmission, and axle manufacturers.
Training and staff costs	Training costs were estimated to amount to EUR 600 per person-day while salaries were assumed to be near EUR 60,000 per full-time equivalent.

The costs were divided into direct (mostly related to physical testing required for compliance, especially relevant for the “D” options) and indirect costs (administrative and other types of overhead costs. As for the *time horizon* of measuring costs, both the transition costs and annual costs were estimated: the *transition costs* here refer to expenses associated with the certification of CO_2 emissions for all vehicle variants currently being marketed (*i.e.*, it is assumed that, once the regulation is in place, a substantial, one-off economic effort will be made to ensure that the current product portfolio is in compliance)[14]. *Annual costs* refer to recurrent costs associated with certifying new vehicles and vehicle components as they enter the market, assuming that the rest of the product portfolio is already certified (in other words, these are the “business as usual” costs to be expected once the regulatory scheme is fully phased in).

In addition to the time dimension, the costs were also estimated for two representative categories of vehicle OEMs. To that avail, the European market for HDVs was divided into two tiers, namely three brands with more than 30,000 newly registered vehicles each in 2012 (“large manufacturers”), and four vehicle brands with 10,000 to 30,000 registered vehicles in 2012 (“medium manufacturers”). These two tiers cover around 95 percent of all registrations in 2012. While results are presented for large and medium vehicle manufacturers, costs throughout the entire industrial value chain were considered.[15]

Data sources
In addition to the questionnaire data (see section 5.1.2), semi-structured interviews were conducted with a subset of stakeholders. While interviews provide less structured data, an advantage of (semi-) structured interviews is the opportunity to collect qualitative data and gather tacit knowledge. For this investigation, these benefits are particularly relevant for unforeseen cost elements and elaboration on quantitative cost estimates. Guidance documents and examples from the healthcare industry (Mogyorosy & Smith, 2005) and transport sector (Grosvenor, 2000; AEA Technology, 2011) were consulted in preparation for the stakeholder interviews. Data pertaining to the structure of the EU’s heavy-duty vehicle market were also collected from a variety of sources. Registration numbers for 2012 and production forecasts for vehicle chassis and engines were extracted from commercially available data sources compiled by IHS (IHS 2012a, 2012b, 2013). In addition, manufacturers’ annual reports, vehicle configurator websites (Daimler 2013, other) and trade magazines were employed to estimate quantitative characteristics of the European HDV market. A summary of the data sources and their role in the configuration of the cost structures is provided in Table 16.

[14] Note that these transition costs may be spread over several years depending on the regulatory provisions for the phase-in of monitoring scheme.
[15] The value chain for heavy-duty vehicles is defined here as vehicle manufacturers and component manufacturers, including axle, transmission, and engine manufacturers. Marginal costs for tyre and auxiliary manufacturers were deemed negligible.

Table 16: Data sources used in the definition of the cost structures

Data source	Primary use
Stakeholder questionnaire	Identification of cost components associated to certification. Estimation of capital investments required for each "D" option, as well as the individual costs of the relevant physicals tests and simulations.
Structured interviews	Further refinement of the cost components and estimates gathered from the stakeholder questionnaire. Estimation of capital investments and running costs required for each "M" and "R" option.
Database IHS1 (IHS 2013)	IHS1 includes European HDV registration data for 2012. Segmentation of European HDV market in "large" and "medium" manufacturers (for a total coverage of 95%) for the allocation of costs to vehicles sold. Estimation of the average variant-to-manufacturer ratios. Estimation of average commercial lifetime. Estimation of cost allocation ratios (Q coefficients in section 5.3.4): average model family-to-variant and transmission-to-variant ratios.
Database IHS2 (IHS 2012a)	Database on European HDV engine production, including forecasts up until 2018. Yields engine-to-variant, transmission-to-variant and other relevant ratios for the allocation of costs to vehicle variants).
Database IHS3 (IHS 2012b)	Database on European HDV chassis production, including forecasts up until 2018. Yields estimates for unique tractor bodies and commercial lifetime and lifetime sales of models.
Trade journals and on-line vehicle configurators (LastAuto Omnibus, 2014)	Estimation of cost allocation ratios (Q coefficients in section 5.3.4): average transmission-to-variant, axle-to-family, tyre type-to-family and other relevant ratios for the allocation of costs to vehicle variants.
Expert judgement within the consortium	Further refinement of all cost components and estimates.

Cost estimation methodology

The framework for identifying costs and benefits associated with policy initiatives proposed by Renda et al. (2013) was adapted to identify costs from monitoring CO_2 emissions of European HDVs. The costing study thus includes *direct* variable and fixed costs as well as *indirect* fixed costs resulting from measuring CO_2 emissions from HDVs. *Direct costs* refers to cost components that are attributable to the cost object (*i.e.*, component testing and modelling), whereas *indirect costs* refer to cost components that can be attributed to other activities or projects not directly related to the cost object (*e.g.*, staff or data management costs). Indirect costs are generally more difficult to precisely attribute to specific regulations (since they may be used for other purposes beyond strict compliance with the regulations; *e.g.*, for research and development).

The different generic cost components of implementing a new regulation outlined by Renda et al. (2013) were adapted to our case of study. Each cost item is assigned to one or more stakeholder types (see Table 17) to provide an *overview* of the type of costs that will conceivably be borne by each type of stakeholder.

Table 17: Attribution of generic cost components of implementing the HDV CO_2 monitoring regulation (adapted from Renda *et al.*, 2013)

			Stakeholder type				
			OEM, vehicle	OEM, components	Technical services	Regulators	Fleet operators
Costs	Direct costs	Administrative burdens	X	X	X		
		Substantive compliance costs	X	X			
		Capital expenditure	X	X			
		Operating and maintenance costs	X	X		X	
		Hassle costs	X	X			
	Indirect	Compliance costs	X	X			
		Enforcement costs				X	

Our cost study focuses on the estimation of the costs borne by *industrial stakeholders, i.e.*, vehicle and vehicle component OEMs (shaded cells in Table 17). As explained in 5.3.2, we adopt the point of view of an integrated vehicle manufacturer as a key simplifying assumption. With this assumption (and the others listed in Table 16), we drew up the *generic cost structure* applicable to the “D” options (Table 18).

Table 18: Generic cost components of a “D” option for industrial stakeholders (from the point of view of an integrated vehicle manufacturer)

	Variable costs	**Fixed costs**
Direct costs	**Air drag**: cost of performing an air drag test. This may be a physical air drag test (constant speed test, options D3, D4) or a CFD simulation (relevant to option D2) [EUR/test or simulation]	**Staff training**: costs incurred [additional annual person-hours multiplied by an estimate of hourly training costs]
	Transmission: cost of performing a transmission test to determine the power transmission efficiency for all gears [EUR/test]	
	Axle: cost of performing an axle test to determine the power transmission efficiency [EUR/test]	**Additional staff**: costs incurred [additional number of staff required multiplied by an estimate of annual staff costs][16]
	Engine: cost of performing a modal engine test to determine a steady-state fuelling rate map (options D1, D2) or a transient test (D5)	
	VECTO: cost of entering the relevant data to the simulation tool and running the simulation according to the requirements of the regulation (using the tool’s “declaration mode”; this is a desktop activity) [EUR/vehicle simulated; marginal cost of simulation runs is negligible]	
Indirect costs	No indirect variable costs were identified within the scope of the analysis.	**Other:** Lump estimate of indirect fixed costs [EUR p.a.]

[16] Since the stakeholder responses did not yield sufficient estimates of additional staff required for each determination option, an average number of staff, amounting to three FTEs for large vehicle OEMs and one FTE for medium OEMs, was applied to all options.

The procedure for estimation of variable costs for industrial stakeholders associated with the different "D" options consisted of the following steps:
- Determining which cost components are relevant to the option
- Evaluating the cost associated with each component (as a synthesis of several different sources)
- Aggregating and allocating the costs for each option (based on the number of times that each cost component is required for each vehicle certified or sold as estimated from the data sources, depending on the basis for the allocation of costs)

Most cost items correspond to processes required to determine CO_2 emissions ("D" options). Estimates of direct and indirect costs of measuring CO_2 emissions were largely based on central estimates derived from questionnaire responses. The aggregation of costs was a more involved process, due to the heterogeneity of some cost objects across different options. For example, under options D3 and D4, costs are attributable to vehicle families whereas, options D1, D2, and D5 attribute costs to single certified vehicles. Moreover, a comparison of costs between vehicles and vehicle families requires assumptions about the size of families. This type of discrepancy makes like-to-like comparisons difficult. Consequently, a number of assumptions about the interrelations of tested components, certified vehicles, and vehicle families, as well as the lifetime of vehicles, were required for the cost estimates of the D options. These assumptions (which are based on a variety of sources) are explained in section 5.3.2.

For transition costs associated with component testing and component simulation under options D1 and D2, the average number of components in the current product portfolio (per manufacturer tier) was estimated on the basis of commercially available datasets and trade journals. Annual variable costs were then calculated as the number of unique components per manufacturer, divided by the estimated product lifetime of vehicles (which was also estimated on the basis of commercially available datasets).

For the cost of VECTO simulations, further information about the HDV market composition was required. Since the simulations would likely be run for each individual vehicle variant introduced to the market, it was necessary to estimate the number of unique vehicle variants in the vehicle OEMs portfolio (per manufacturer tier), as well as the rate of introduction of new vehicle variants to the market. For this purpose, the number of vehicle variants registered during 2012 (where a vehicle variant is defined as a *unique combination* of engine, transmission, axles, and chassis) constitutes the proxy for the current number of vehicle variants in the European HDV market. This estimate was utilised as a proxy for the number of transient engine tests required under options D5, which are assumed to be required for each vehicle variant. On the other hand, for options D3 and D4, vehicle variants were grouped by vehicle OEM and model groups included in database IHS1. Based on this grouping, vehicles were assigned to vehicle families. As the precise definition of families under options D3 and D4 is unknown, this method was deemed to provide a suitable classification. Other variable costs (*e.g.*, manufacturers' data management activities) and fixed costs (*e.g.*, staff training, hiring additional staff) were estimated for each manufacturer class based on questionnaire data.

Estimates for fixed costs associated with measuring CO_2 emissions using the measurement techniques proposed in the "D" options were collected in the stakeholder questionnaire (see section 5.1.2). The respondents consistently identified staff training and additional staff hires as substantive cost items. Responses regarding the required number of training days and additional full-time equivalent staff members were multiplied with estimated training costs and salaries[17] to arrive at aggregate cost estimates. The response rates for questionnaire items concerning other fixed costs were deemed insufficient to draw meaningful and statistically significant conclusions about absolute or relative differences between the different determination options. A constant cost element, termed "*other fixed costs"*, was therefore added to all "D" options. This component is intended to cover cost items such as emission test benches, software, and other test equipment. It was assumed that all members of the value chain would incur costs for additional staff, staff training, and other fixed costs.[18]

Aggregate cost estimates are, whenever possible, presented as costs *per sold vehicle*. This metric uses the costs per manufacturer and year associated with testing (and simulating) new components or vehicles and divides by the number of annual vehicle sales by a manufacturer in each tier.[19] While this metric mixes cost objects (*i.e.*, the costs of testing new components is not necessarily attributed to the sales of said component), the metric is easily comparable and illustrative of the additional costs resulting from measuring CO_2 emissions. For transition costs, the "*costs per sold vehicle"* metric is also presented in order to enable comparisons between transition and business-as-usual costs. No claim to the distribution of costs throughout the value chain (for example, whether vehicle prices would increase) is made.

5.3.3 *Cost estimates*

In the next sections, the costs estimations derived in accordance with the methodology described in section 5.3.2 are presented for each one of the technical options under discussion.

5.3.3.1 *Determination of CO_2 emissions ("D" options)*

The following subsections present estimates of *annual costs* faced by vehicle OEMs for the five proposed CO_2 determination options. The cost components of each option are presented for "large" and "medium" heavy-duty vehicle manufacturers. Estimates are normalised by dividing costs of determining CO_2 emissions from new variants by the number of vehicles sold per year, as estimated from a commercial database on the European HDV market (IHS 2012; see Table 16).

The cost structures are presented for each of the options in tabular form hereafter in the sections about D1 to D5. In these tables, the cost components previously listed in Table 18 are assigned an estimated cost, and these are allocated to the estimated number of vehicles sold for the two tiers of vehicle OEMs. The allocation is performed via "Q" coefficients, which are in turn estimated from the data sources

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[17] Assumptions for the calculation of fixed costs: annual salary of one full-time equivalent position = EUR 60000 p.a.; training costs: EUR 600 per person-day of training.

[18] A central estimate for the different fixed cost items was determined and multiplied by the number of members of the value chain.

[19] The calculation uses an "average manufacturer" per tier, meaning that average Q and Q' coefficients are determined for the tier and subsequently multiplied by cost estimates and divided by the average sales in the tier.

listed in Table 16.The interpretation of these Q coefficients is as follows:

a Q coefficient indicates how many unique components were marketed during 2012 per manufacturer. Q' coefficients represent the new vehicle variants and components entering the vehicle OEM's portfolio annually, gathered from the current composition of the European HDV market. Q coefficients are thus used to estimate the *transition costs* described in 5.3.2 while Q' coefficients apply to the *annual costs* once the CO_2 monitoring is in place. In relation to fixed costs, N coefficients represent the number of member of the supply chain. Lastly, VS refers to vehicles sold; this metric allows for comparisons of different determination options.

Option D1

Option D1 requires the most extensive effort in terms of component testing (see Table 19 and Table 20). This is reflected in a relatively high share of direct variable costs. Air drag testing accounts for the largest variable cost due to the large variety of chassis configurations (Q' factor of roughly 11 for large manufacturers and 5 for medium manufacturers) and to the high unit costs of determining the aerodynamic resistance and transmission efficiency through physical tests. According to stakeholder questionnaire responses, training and staff requirements are average for this option in comparison to other options.

Table 19: Transition cost estimates for option D1 (component testing + simulation)

Cost type	Item costs				Transition costs					
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q	Q * C	Q * C / VS	Q	Q * C	Q * C / VS
Direct variable costs	air drag	test	€ 10 000	component	132.0	1 320 000	€ 34.46	53.3	532 500	€ 29.63
	transmission	test	€ 20 000	component	39.0	780 000	€ 20.36	31.3	625 000	€ 34.77
	axle	test	€ 6 250	component	3.5	21 875	€ 0.57	3.5	21 875	€ 1.22
	engine	test	€ 5 325	component	39.0	207 675	€ 5.42	31.3	166 406	€ 9.26
	VECTO	simulation	€ 100	certified vehicle	1 609.7	160 967	€ 4.20	1 066.0	106 600	€ 5.93
	RRC	default	€ -	component	-	-	€ -	-	-	€ -
	auxiliaries	default	€ -	component	-	-	€ -	-	-	€ -
	Total direct variable costs			manufacturer	-	2 490 517	€ 65.02	-	1 452 381	€ 80.81
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q	Q * C * N	Q * C * N / VS	Q	Q * C * N	Q * C * N / VS
Fixed costs	Training	estimate	€ 600	manufacturer	16.3	29 250	€ 0.76	5.7	10 293	€ 0.57
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 079 250	€ 28.17	-	379 796	€ 21.13
Grand total					-	3 569 767	€ 93.19	-	1 832 178	€ 101.94

Table 20: Annual cost estimates for option D1 (component testing + simulation)

Cost type	Item costs				Annual costs					
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C	Q' * C / VS	Q'	Q' * C	Q' * C / VS
Direct variable costs	air drag	test	€ 10 000	component	10.6	105 783	€ 2.76	4.9	48 835	€ 2.72
	transmission	test	€ 20 000	component	2.5	50 874	€ 1.33	2.2	43 519	€ 2.42
	axle	test	€ 6 250	component	1.2	7 292	€ 0.19	0.9	5 469	€ 0.30
	engine	test	€ 5 325	component	2.5	13 545	€ 0.35	2.2	11 587	€ 0.64
	VECTO	simulation	€ 100	certified vehicle	321.9	32 193	€ 0.84	213.2	21 320	€ 1.19
	RRC	default	€ -	component	-	-	€ -	-	-	€ -
	auxiliaries	default	€ -	component	-	-	€ -	-	-	€ -
	Total direct variable costs			manufacturer	-	209 688	€ 5.47	-	130 729	€ 7.27
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C * N	Q' * C * N / VS	Q'	Q' * C * N	Q' * C * N / VS
Fixed costs	Training	estimate	€ 600	manufacturer	16.3	29 250	€ 0.76	5.7	10 293	€ 0.57
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 079 250	€ 28.17	-	379 796	€ 21.13
Grand total					-	1 288 938	€ 33.65	-	510 525	€ 28.40

Option D2

As a simplified version of D1, option D2 significantly reduces variable costs associated with determining CO_2 emissions from HDVs (see Table 21 for transition costs, and Table 22 for annual costs). Replacing air drag testing with air drag simulation proves particularly effective at reducing determination costs (with a central cost estimate of EUR 4,667 for individual CFD simulations[20]).

Table 21: Transition cost estimates for option D2 (simplified component testing + simulation)

Cost type	Item costs				Transition costs					
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q	Q * C	Q * C / VS	Q	Q * C	Q * C / VS
Direct variable costs	engine	test	€ 5 325	component	39.0	207 675	€ 5.42	31.3	166 406	€ 9.26
	air drag	simulation	€ 4 667	component	132.0	616 000	€ 16.08	53.3	248 500	€ 13.83
	transmission	default	€ -	component	39.0	-	€ -	31.3	-	€ -
	axle	default	€ -	component	3.5	-	€ -	3.5	-	€ -
	auxiliaries	default	€ -	component	-	-	€ -	-	-	€ -
	RRC	default	€ -	component	-	-	€ -	-	-	€ -
	VECTO	simulation	€ 100	certified vehicle	1 609.7	160 967	€ 4.20	1 066.0	106 600	€ 5.93
	Total direct variable costs			manufacturer	-	984 642	€ 25.71	-	521 506	€ 29.02
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q	Q * C * N	Q * C * N / VS	Q	Q * C * N	Q * C * N / VS
Fixed costs	Training	estimate	€ 600	manufacturer	20.0	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	2 070 642	€ 54.06	-	903 678	€ 50.28

[20] The cost estimate for CFD simulations was based on three questionnaire responses, ranging from EUR 3,000 to EUR 5,000.

Table 22: Annual cost estimates for option D2 (simplified component testing + simulation)

Cost type	Item costs				Annual costs					
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C	Q' * C / VS	Q'	Q' * C	Q' * C / VS
Direct variable costs	engine	test	€ 5 325	component	2.5	13 545	€ 0.35	2.2	11 587	€ 0.64
	air drag	simulation	€ 4 667	component	10.6	49 366	€ 1.29	4.9	22 790	€ 1.27
	transmission	default	€ -	component	2.5	-	€ -	2.2	-	€ -
	axle	default	€ -	component	1.2	-	€ -	0.9	-	€ -
	auxiliaries	default	€ -	component	-	-	€ -	-	-	€ -
	RRC	default	€ -	component	-	-	€ -	-	-	€ -
	VECTO	simulation	€ 100	certified vehicle	321.9	32 193	€ 0.84	213.2	21 320	€ 1.19
	Total direct variable costs			manufacturer	-	95 104	€ 2.48	-	55 696	€ 3.10
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C * N	Q' * C * N / VS	Q'	Q' * C * N	Q' * C * N / VS
Fixed costs	Training	estimate	€ 600	manufacturer	20.0	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	1 181 104	€ 30.83	-	437 868	€ 24.36

Option D3

In contrast to options D1 and D2, option D3 employs a “vehicle family” concept to group vehicles. This is required due to the considerable cost and effort associated with individual air drag and chassis dynamometer tests, which cannot be realistically applied to all new vehicle variants. In the absence of a precise definition of how the vehicle families would be constructed for the determination of CO_2 values, vehicles were grouped according to two family concepts in order to investigate the influence of the vehicle family definition upon costs. The options requiring a family concept (D3, and also option D4) were thus split in two (D3a, D3b and D4a, D4b):

- Family concept "a" is built by querying the HDV databases for unique combinations of the following fields: [manufacturer], [engine cylinders], [engine capacity], [fuel type], [turbo], [model group], and [body type]. This resulted in an average of 128 families per large manufacturer and 107 per medium manufacturer.
- Family concept "b" (smaller family concept for improved coverage) is built by querying the databases for unique combinations of the aforementioned fields, plus [axle configuration] and [driven wheels]. This increases the number of vehicle families to 384 for large manufacturers and 334 for medium manufacturers (roughly a threefold improvement in fleet coverage).

The estimated *annual* and *transition costs* for option D3a can be found in Table 23 and Table 24, and the estimated *annual* and *transition costs* for option D3b can be found in Table 27 and 28.

As stakeholder questionnaire responses indicate that on-road tests are less labour-intensive than chassis dynamometer and air drag tests, the variable costs under D4 sub-options were lowered. As with option D3, the estimated costs of CO_2 determination for medium manufacturers are higher than those of large manufacturers. The estimated *annual* and *transition costs* for option D4a can be found in Table 27 and Table 28, and the estimated *annual* and *transition costs* for option D4b can be found in Table 29 and Table 30.

Even after the introduction of vehicle families (which results in a worse coverage of the HDV market in comparison to options D1 or D2 for both family concepts), variable costs of D3 remain comparably high. Moreover, due to the large number of vehicle variants marketed by medium manufacturers, the predicted determination costs per sold vehicle are considerably higher for this tier.

Table 23: Transition cost estimates for option D3 (full-vehicle chassis dynamometer testing, large family)

Cost type	Item costs				Transition costs					
					Large manufacturers			Medium manufacturers		
Direct variable costs	Cost component	Cost type	Estimated Cost	Base	Q	Q * C	Q * C / VS	Q	Q * C	Q * C / VS
	on-road	test	€ 10 417	family	128.0	1 333 333	€ 34.81	107.0	1 114 583	€ 62.01
	Total direct variable costs			manufacturer	-	1 333 333	€ 34.81	-	1 114 583	€ 62.01
					Large manufacturers			Medium manufacturers		
Fixed costs	Cost component	Cost type	Estimated Cost	Base	Q	Q * C * N	Q * C * N / VS	Q	Q * C * N	Q * C * N / VS
	Training	estimate	€ 600	manufacturer	20	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	3	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	2 419 333	€ 63.16	-	1 496 755	€ 83.28

Table 24: Annual cost estimates for option D3 (full-vehicle chassis dynamometer testing, large family)

Cost type	Item costs				Annual costs					
					Large manufacturers			Medium manufacturers		
Direct variable costs	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C	Q' * C / VS	Q'	Q' * C	Q' * C / VS
	on-road	test	€ 10 417	family	12.8	133 333	€ 3.48	10.7	111 458	€ 6.20
	Total direct variable costs			manufacturer	-	133 333	€ 3.48	-	111 458	€ 6.20
					Large manufacturers			Medium manufacturers		
Fixed costs	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C * N	Q' * C * N / VS	Q'	Q' * C * N	Q' * C * N / VS
	Training	estimate	€ 600	manufacturer	20.0	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	1 219 333	€ 31.83	-	493 630	€ 27.46

Table 25: Transition cost estimates for option D3b (full-vehicle chassis dynamometer testing, small family)

Cost type	Item costs				Transition costs					
					Large manufacturers			Medium manufacturers		
Direct variable costs	Cost component	Cost type	Estimated Cost	Base	Q	Q * C	Q * C / VS	Q	Q * C	Q * C / VS
	air drag	test	€ 10 000	family	383.7	3 836 667	€ 100.16	334.0	3 340 000	€ 185.83
	chassis dyno	test	€ 14 333	family	383.7	5 499 222	€ 143.56	334.0	4 787 333	€ 266.36
	Total direct variable costs			manufacturer	-	9 335 889	€ 243.72	-	8 127 333	€ 452.19
					Large manufacturers			Medium manufacturers		
Fixed costs	Cost component	Cost type	Estimated Cost	Base	Q	Q * C * N	Q * C * N / VS	Q	Q * C * N	Q * C * N / VS
	Training	estimate	€ 600	manufacturer	20.0	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	10 421 889	€ 272.07	-	8 509 505	€ 473.45

Table 26: cost estimates for option D3b (full-vehicle chassis dynamometer testing, small family)

Cost type	Item costs				Annual costs					
					Large manufacturers			Medium manufacturers		
Direct variable costs	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C	Q' * C / VS	Q'	Q' * C	Q' * C / VS
	air drag	test	€ 10 000	family	38.4	383 667	€ 10.02	33.4	334 000	€ 18.58
	chassis dyno	test	€ 14 333	family	38.4	549 922	€ 14.36	33.4	478 733	€ 26.64
	Total direct variable costs			manufacturer	-	933 589	€ 24.37	-	812 733	€ 45.22
					Large manufacturers			Medium manufacturers		
Fixed costs	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C * N	Q' * C * N / VS	Q'	Q' * C * N	Q' * C * N / VS
	Training	estimate	€ 600	manufacturer	20.0	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	2 019 589	€ 52.72	-	1 194 905	€ 66.48

Option D4

Similar to option D3, the fourth determination option needs to be built upon a vehicle family concept. For the purposes of the cost estimations, we carried over the same family definitions used for option D3, thus making the sub-option pairs D3a, D4a and D3b, D4b equal in terms of coverage of the HDV market).

As stakeholder questionnaire responses indicate that on-road tests are less labour-intensive than chassis dynamometer and air drag tests, the variable costs under D4 sub-options were lowered. As with option D3, the estimated costs of CO_2 determination for medium manufacturers are higher than those of large manufacturers. The estimated *annual* and *transition costs* for option D4a can be found in Table 27 and Table 28, and the estimated *annual* and *transition costs* for option D4b can be found in Table 29 and Table 30.

Table 27: Transition cost estimates for option D4 (on-road testing)

Cost type	Item costs				Transition costs					
					Large manufacturers			Medium manufacturers		
Direct variable costs	Cost component	Cost type	Estimated Cost	Base	Q	Q * C	Q * C / VS	Q	Q * C	Q * C / VS
	on-road	test	€ 10 417	family	128.0	1 333 333	€ 34.81	107.0	1 114 583	€ 62.01
	Total direct variable costs			manufacturer	-	1 333 333	€ 34.81	-	1 114 583	€ 62.01
					Large manufacturers			Medium manufacturers		
Fixed costs	Cost component	Cost type	Estimated Cost	Base	Q	Q * C * N	Q * C * N / VS	Q	Q * C * N	Q * C * N / VS
	Training	estimate	€ 600	manufacturer	20	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	3	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	2 419 333	€ 63.16	-	1 496 755	€ 83.28

Table 28: Annual cost estimates for option D4 (on-road testing)

Cost type	Item costs				Annual costs					
					Large manufacturers			Medium manufacturers		
Direct variable costs	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C	Q' * C / VS	Q'	Q' * C	Q' * C / VS
	on-road	test	€ 10 417	family	12.8	133 333	€ 3.48	10.7	111 458	€ 6.20
	Total direct variable costs			manufacturer	-	133 333	€ 3.48	-	111 458	€ 6.20
					Large manufacturers			Medium manufacturers		
Fixed costs	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C * N	Q' * C * N / VS	Q'	Q' * C * N	Q' * C * N / VS
	Training	estimate	€ 600	manufacturer	20.0	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	1 219 333	€ 31.83	-	493 630	€ 27.46

Table 29: Transition cost estimates for option D4b (on-road testing, small family)

Cost type	Item costs				Transition costs					
					Large manufacturers			Medium manufacturers		
Direct variable costs	**Cost component**	**Cost type**	**Estimated Cost**	**Base**	**Q**	**Q * C**	**Q * C / VS**	**Q**	**Q * C**	**Q * C / VS**
	on-road	test	€ 10 417	family	383.7	3 996 528	€ 104.33	334.0	3 479 167	€ 193.57
	Total direct variable costs			manufacturer	-	3 996 528	€ 104.33	-	3 479 167	€ 193.57
					Large manufacturers			Medium manufacturers		
Fixed costs	**Cost component**	**Cost type**	**Estimated Cost**	**Base**	**Q**	**Q * C * N**	**Q * C * N / VS**	**Q**	**Q * C * N**	**Q * C * N / VS**
	Training	estimate	€ 600	manufacturer	20	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	3	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	5 082 528	€ 132.68	-	3 861 338	€ 214.84

Table 30: Annual cost estimates for option D4b (on-road testing, small family)

Cost type	Item costs				Annual costs					
					Large manufacturers			Medium manufacturers		
Direct variable costs	**Cost component**	**Cost type**	**Estimated Cost**	**Base**	**Q'**	**Q' * C**	**Q' * C / VS**	**Q'**	**Q' * C**	**Q' * C / VS**
	on-road	test	€ 10 417	family	38.4	399 653	€ 10.43	33.4	347 917	€ 19.36
	Total direct variable costs			manufacturer	-	399 653	€ 10.43	-	347 917	€ 19.36
					Large manufacturers			Medium manufacturers		
Fixed costs	**Cost component**	**Cost type**	**Estimated Cost**	**Base**	**Q'**	**Q' * C * N**	**Q' * C * N / VS**	**Q'**	**Q' * C * N**	**Q' * C * N / VS**
	Training	estimate	€ 600	manufacturer	20.0	36 000	€ 0.94	7.0	12 669	€ 0.70
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 086 000	€ 28.35	-	382 172	€ 21.26
Grand total					-	1 485 653	€ 38.78	-	730 088	€ 40.62

Option D5

From a technical point of view, Option D5 can be viewed as a reversal of sorts of the baseline option (D1). From the cost perspective, it has a distinct cost structure: according to the description of the technical option, the input data for the simulation could be based on component testing, simulation (for air drag values), or default data. As the different methods for deriving the input data for the simulations come at vastly different costs, the process selection greatly influences the costs associated with option D5. For the calculation of variable costs in Table 31 and Table 32, *simulation* and *default values* were selected as data sources in order to arrive at a comparable cost; it should however be noted that this may reduce the granularity and representativeness of the resulting CO_2 values in comparison to the baseline option (D1).

Despite the use of inexpensive data sources (default values for components, CFD simulation for air drag determination), and of the lower unit cost of transient engine tests with respect to modal engine tests for mapping, option D5 remains one of the more costly pathways considered in the study. This is due to the high number of required transient engine tests (which would have to be performed for each certified vehicle).

Table 31: Transition cost estimates for option D5 (simulation and transient engine testing)

Cost type	Item costs				Transition costs					
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q	Q * C	Q * C / VS	Q	Q * C	Q * C / VS
Direct variable costs	engine transient	test	€ 2 233	certified vehicle	1 609.7	3 594 922	€ 93.85	1 066.0	2 380 733	€ 132.46
	air drag	simulation	€ 4 667	component	132.0	616 000	€ 16.08	53.3	248 500	€ 13.83
	transmission	default	€ -	component	39.0	-	€ -	31.3	-	€ -
	axle	default	€ -	component	3.5	-	€ -	3.5	-	€ -
	auxiliaries	default	€ -	component	-	-	€ -	-	-	€ -
	RRC	default	€ -	component	-	-	€ -	-	-	€ -
	Total direct variable costs			manufacturer	-	4 210 922	€ 109.93	-	2 629 233	€ 146.29
					Large manufacturers			Medium manufacturers		
Fixed costs	Cost component	Cost type	Estimated Cost	Base	Q	Q * C * N	Q * C * N / VS	Q	Q * C * N	Q * C * N / VS
	Training	estimate	€ 600	manufacturer	10.0	18 000	€ 0.47	3.5	6 334	€ 0.35
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 068 000	€ 27.88	-	375 837	€ 20.91
Grand total					-	5 278 922	€ 137.81	-	3 005 071	€ 167.20

Table 32: Annual cost estimates for option D5 (simulation and transient engine testing)

Cost type	Item costs				Annual costs					
					Large manufacturers			Medium manufacturers		
	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C	Q' * C / VS	Q'	Q' * C	Q' * C / VS
Direct variable costs	engine transient	test	€ 2 233	certified vehicle	321.9	718 984	€ 18.77	213.2	476 147	€ 26.49
	air drag	simulation	€ 4 667	component	10.6	49 366	€ 1.29	4.9	22 790	€ 1.27
	transmission	default	€ -	component	1.0	-	€ -	1.0	-	€ -
	axle	default	€ -	component	1.0	-	€ -	1.0	-	€ -
	auxiliaries	default	€ -	component	-	-	€ -	-	-	€ -
	RRC	default	€ -	component	-	-	€ -	-	-	€ -
	Total direct variable costs			manufacturer	-	768 350	€ 20.06	-	498 936	€ 27.76
					Large manufacturers			Medium manufacturers		
Fixed costs	Cost component	Cost type	Estimated Cost	Base	Q'	Q' * C * N	Q' * C * N / VS	Q'	Q' * C * N	Q' * C * N / VS
	Training	estimate	€ 600	manufacturer	10.0	18 000	€ 0.47	3.5	6 334	€ 0.35
	Additional staff	estimate	€ 60 000	manufacturer	2.5	450 000	€ 11.75	0.9	158 358	€ 8.81
	Other	estimate	€ 200 000	manufacturer	1.0	600 000	€ 15.66	0.4	211 145	€ 11.75
	Total direct/indirect fixed costs			manufacturer	-	1 068 000	€ 27.88	-	375 837	€ 20.91
Grand total					-	1 836 350	€ 47.94	-	874 774	€ 48.67

5.3.3.2 *Cost comparison of "D" options*

Figure 13 and Figure 14 provide an overview of the *transition* and *annual costs* associated with the different options for the determination of CO_2 emissions from HDVs ("D" options). According to these estimates, option D2 would impose the lowest compliance costs to the manufacturing value chain. Looking at transition and annual costs, option D1 provides one of least costly pathways for determining CO_2 emissions from European HDVs, only surpassed by options D2 and D4a. However, considering the data quality benefits of option D1 with respect to option D2, and to the fleet coverage benefits in comparison to option D4a, D1 is considered a highly cost-effective option (see discussion in section 5.4.2). Also, due to the variety of vehicle variants in the HDV market, options D3, D4, and D5 could prove more costly to manufacturers, particularly for "medium" tier manufacturers.

The figures also show that the costs (both annual and transition costs) of options D3 and D4 are quite sensitive to the definition of the family; options D3, D4 are only comparable in cost with D1 if a broad family definition (concept "a") is adopted, and that they quickly become more expensive than the baseline as the family concept becomes smaller (concept "b"). It is also worth noting that family concept "b" provides a substantially lower fleet coverage than the baseline option D1 (for which only air drag tests apply a family concept, whereas the rest of the components are covered by individual physical tests).

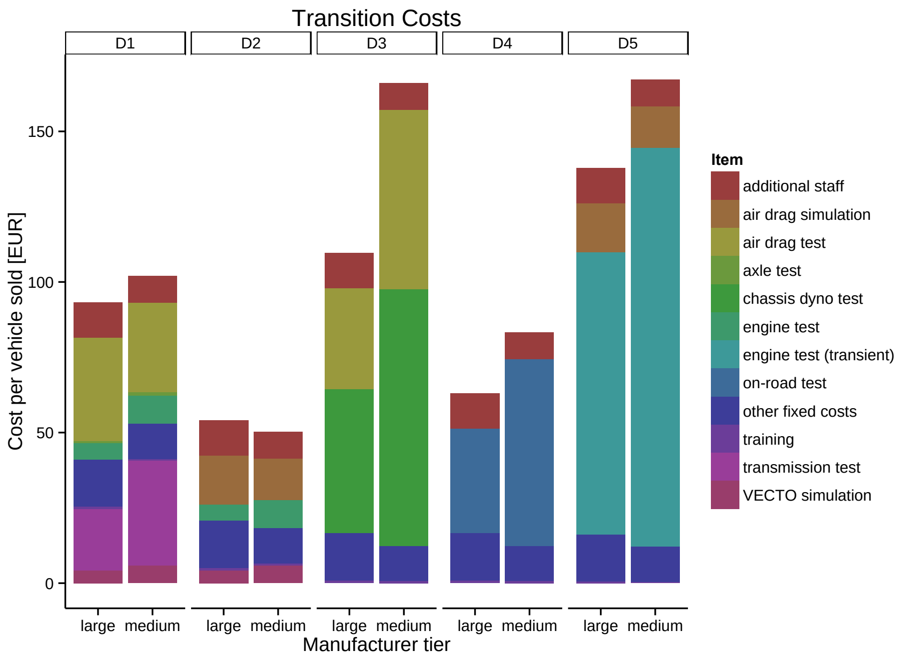

Figure 13: Overview of *transition cost* estimates for “D” options (in EUR, allocated to individual vehicles sold, by manufacturer tier [L=large; M=medium])

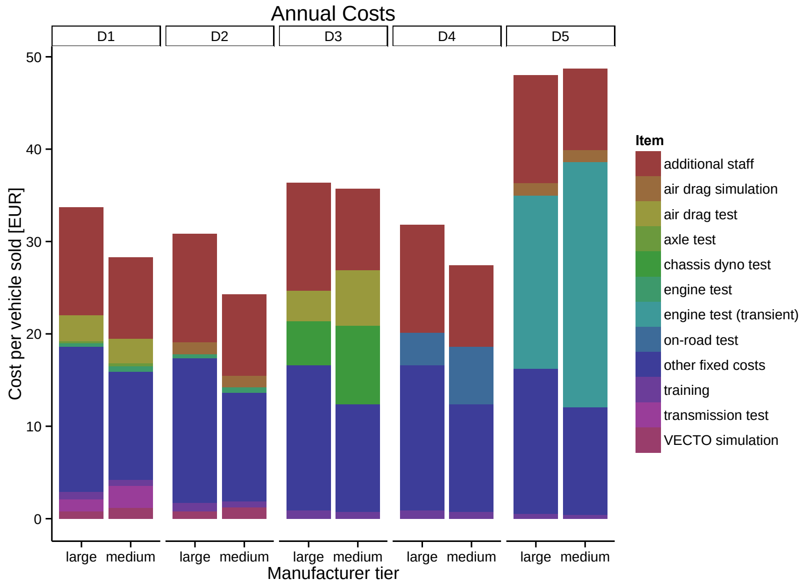

Figure 14: Overview of *annual cost* estimates for “D” options (in EUR, allocated to individual vehicles sold, by manufacturer tier [L=large; M=medium]).

5.3.3.3 Conformity of production (“P” options)

This section estimates costs of checking the conformity of production (CoP) according to the different “P” options. The costs of CoP arise from a replication of component testing (option P1, “component-specific”), of the whole CO_2 determination process (option P2, “process-specific”), or from additional vehicle testing (option P3, “vehicle-specific”). This replication is performed on a subset of the certified vehicles to achieve a reasonable coverage. For the purposes of this study, we have referred our estimations to a 1% of the certified vehicles.[21] Other assumptions on the implementation of the "P" options made during the estimation of the costs are listed in Table 33.

Table 33: Assumptions on the implementation of the "P" options

P option	Implementation assumptions
Option P1: Component-specific CoP	Option P1 relies on ensuring that the input data for the simulation of CO_2 emissions is valid (it therefore applies to options D1, D2 and D5). This option is based on the assumption that, if the specifications of the different components conform to the data delivered for the certification of the vehicle, then the certified vehicle is in conformity. This option represents the lowest level of additional effort. Such an approach could be implemented in the form of quality audits to the data management and quality systems set up by OEMs, complemented with selective component re-tests and excluding re-runs of the vehicle simulations. It was assumed that one percent of components would be retested. In the case of determination option D5, it was assumed that one percent of certified vehicles would be retested.
Option P2: Process-specific CoP	Option P2 consists of replicating the CO_2 determination process, including retesting components and rerunning the simulation for a portion of certified vehicles. It was assumed that one percent of component tests and simulations would be repeated. The process-specific CoP was determined to be unsuitable for options D3 and D4, as these options do not rely on simulations.
Option P3: Vehicle-specific CoP	Option P3 relies on confirming a vehicle's CO_2 emission value based on PEMS on-road measurements or measurements on a test track. Under determination options D1, D2, and D5, one percent of the certified vehicles would be tested. Under options D3 and D4, one percent of vehicle families would be retested.

A specific challenge of the estimation of these costs is the achievement of equal levels of coverage across the different "P" options to enable direct comparisons among them. For option P3, it is straightforward to establish the level of coverage achieved during CoP because a 1% coverage of the total number of certified vehicles is achieved by re-testing a 1% of the vehicles. However, for options P1 and P2, re-testing a 1% of the components would lead to a coverage level that may be either below or above 1% of the certified vehicles, and which is in principle unknown. However, a targeted (not random) selection of the components to be re-tested could optimise the market coverage (by sales), and in this sense *options P1 and P2 can potentially provide a better coverage than option P3 for a comparable testing effort*.

5.3.3.4 Cost comparison of "P" options

Estimates for the additional costs per sold vehicle arising from the different CoP options are presented in Figure 15 (for medium manufacturers) and Figure 16 (for large manufacturers). These figures present the costs associated with the different "P" options[22] relative to the different CO_2 determination ("D") options, based on the

[21] Note that a targeted selection of the variants to be subject to CoP can lead to a market coverage (by sales) substantially above 1%.
[22] The estimated cost of option P3 is calculated for on-road testing with PEMS.

assumption that a 1% of components are re-tested (option P1), a 1% of components are re-tested and a 1% of the vehicle simulations are re-run (option P2, relevant to options D1, D2 and D5 only) and a 1% of whole-vehicle tests are conducted. Note that for a similar (potentially better) level of coverage, *i.e.*, with approximately ten percent components being retested, options P1 and P2 are far less expensive than option P3. For both options P1 and P2, large manufacturers are expected to incur lower costs of CoP, as the cost is spread across a larger number of vehicles sold. For the combination of options D1 and P2, the estimated additional costs per sold vehicle are EUR 0.05 and 0.07 for large and medium manufacturers, respectively.

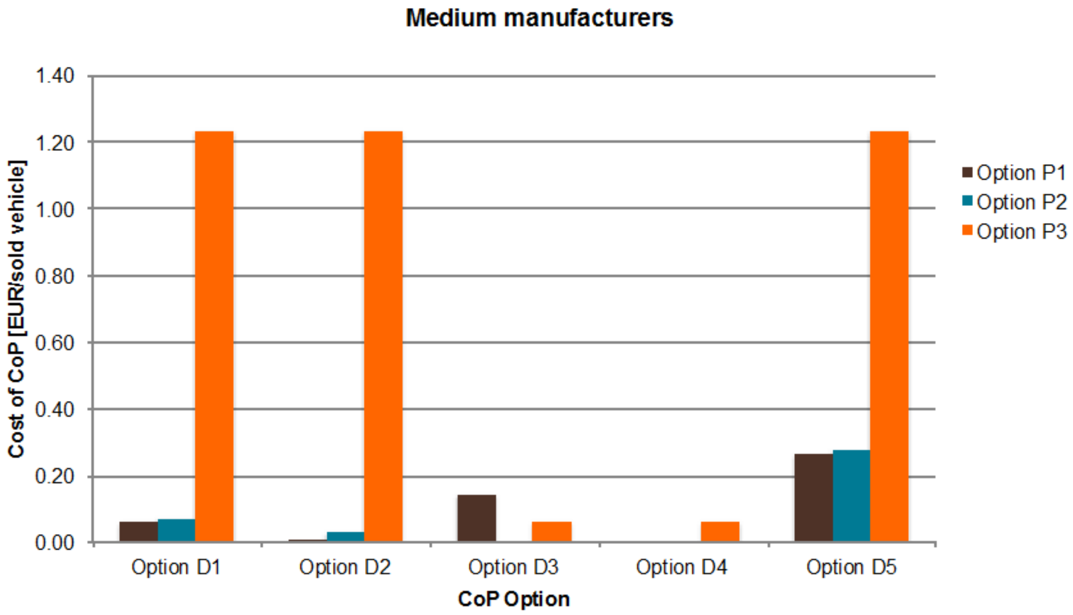

Figure 15: Estimated costs of *medium manufacturer* tier for the different conformity of production options relative to all CO_2 determination options ("D" options)[23]

[23] Option P2 was determined to be unsuitable for CO_2 determination options D3 and D4 as these options do not rely on simulation. Option P1 was deemed unsuitable for option D4 as the entire vehicle, not singular components, are tested under D4.

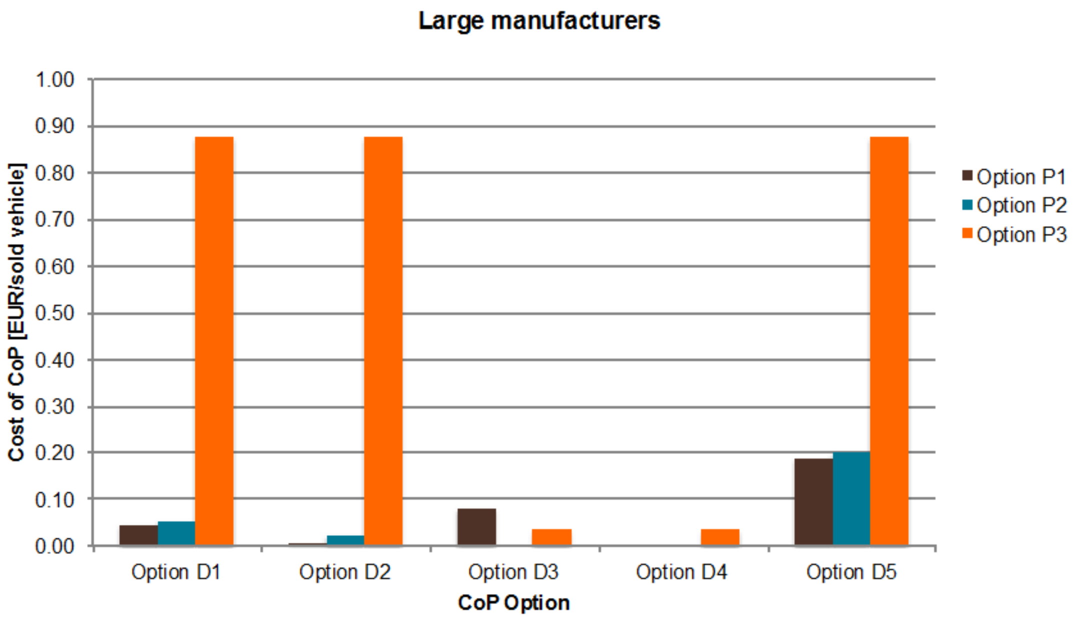

Figure 16: Estimated costs of *large manufacturer* tier for the different conformity of production options relative to all CO_2 determination options ("D" options)[24]

5.3.3.5 *Monitoring and reporting ("M" options)*

This section estimates costs of CO_2 emissions data monitoring and reporting according to the different "M" options. The methodology for the estimation of these costs differs substantially from the one followed for the "D" and the "P" options. This is due to three main reasons: first, no quantitative cost estimates could be collected from stakeholders in the questionnaire or in the interviews. Second, the formulation of the options was changed between the time that they were initially presented to stakeholders and the time that this report was drafted. Third, an objective appraisal of the costs of the monitoring options is particularly challenging in absence of a precise attribution of responsibilities (and the corresponding allocation of costs to stakeholder types). Therefore, the evaluation of the costs of monitoring and reporting is performed in a semi-quantitative way. The starting point of the construction of the cost estimates was a limited, ad hoc consultation with selected stakeholders (the United States EPA and the European Environment Agency[25]).

The US EPA maintains several HDV databases of vehicle and engine emissions certification data, emissions averaging, banking and trading (ABT) and production reporting. US EPA has developed Microsoft Excel-based templates to facilitate the submission and processing of Compliance Reports (US EPA, 2014). Under the US EPA compliance programmes, manufacturers are required to submit a number of reports. The US EPA provides the required electronic file templates for certifying some heavy-duty engines and vehicles to US EPA standards, and for submitting reports required under various compliance programmes. Even though the scope of

[24] Option P2 was determined to be unsuitable for determination options D3 and D4 as these options do not rely on simulation. Option P1 was deemed unsuitable for option D4 as the entire vehicle, not singular components, are tested under D4.

[25] These two organisations were deemed appropriate due to their experience with CO_2 monitoring from LDVs (EEA) and HDVs (US EPA). The feedback provided by Cinzia Pastorello (EEA) and Stephen Healy and his team (US EPA) is gratefully acknowledged.

US EPA's programmes differ from the technical options proposed in this document, they are deemed to be a suitable reference point for our cost estimates. According to US EPA sources (personal communication, December 2014), the development cost for one of these databases (for either heavy-duty engines or heavy-duty vehicles) is around USD 500,000 (EUR 420,000), and the annual maintenance cost of these databases amounts to approximately 10% of the initial development cost (*i.e.*, USD 50,000, or EUR 42,000). This second estimate for database maintenance costs is in line with that obtained in consultation with EEA (personal communication, December 2014). Additional estimates required for the construction of the cost structures (*e.g.*, about the cost of additional staff and person-hours) were carried over from the cost estimates of the "D" options from section 5.3.3.1 for the sake of consistency.

A number of methodological assumptions regarding the expected cost implications of the different M options were made. These are explained in
Table 34, where the "M" options are also briefly explained. Taking the available cost estimates and the assumptions of
Table 34 as a starting point, we constructed the cost estimates for the "M" options, which we describe in section 5.3.3.6. It must be noted that, in contrast to the "D" options, the "M" options are not always formulated in this document as different, mutually exclusive alternatives. Instead, they all build upon option M1 (the baseline), upon which additional layers of complexity are built. These relate to three different dimensions: 1) the data to be monitored (M2 sub-options), 2) the attribution of responsibilities (M3 sub-options) and 3) the modernisation of the system from an information technology point of view (M4 sub-options; see Table 34).

Table 34: Summary of M options and sub-options, and their associated cost assumptions

Option	Notes
M1	*Baseline option*. This is an adaptation of the scheme already in place for M1 and N1 vehicles with some special requirements for use with HDV. This option assumes monitoring individual vehicles and that the volume of data to be monitored and reported will be increased with respect to the LDV programme already in place in Europe. The CoC is the main data carrier and MS bear the main responsibility for the collection of vehicle registration data and technical data corresponding to the registered vehicles. Most of the costs associated to the baseline are incurred regardless of the combination with any of the M2, M3 or M4 sub-options.
M2	These sub-options relate to the *quantity and subject of the data* to be monitored. These sub-options are *not* mutually exclusive. Each one of them implies an increased volume of data to be handled has an impact upon the cost of database development, and it also increases transaction and reporting costs. Some sub-options have further cost implications due to data confidentiality issues, or to the involvement of additional stakeholders. • M2.1: All the input data from VECTO are monitored. These data are widely considered as sensitive by OEMs and deserve special confidentiality considerations. This has an impact upon the architecture of the databases, and thus their development and maintenance costs. • M2.2: Monitoring data of the completed vehicle (MSV): This sub-option requires the involvement of final stage manufacturers, and implies additional data infrastructure and delivery costs for them. • M2.3: Monitoring data of trailers: Trailer data are in principle included in the CoC but, in practice, member states register trailer data differently. To make this sub-option applicable, a harmonisation of registration procedures would be required.
M3	These sub-options relate to the *responsibilities for data collection and reporting*. These sub-options are mutually exclusive. For the sake of simplicity, these options are assumed to have the effect of shifting transaction costs among stakeholders, *without substantially affecting the costs themselves*. • M3.1: Hybrid monitoring (MS + Vehicle OEM): The vehicle OEMs collect technical monitoring data of each vehicle produced and report these, along with the VIN, to the EEA/EC. This implies a shift of transaction costs from Member States to type vehicle OEMs. • M3.2: Hybrid monitoring (MS + TAA): Member States collect the registrations and the type approval authorities report type approval data to EEA/EC. This implies a shift of transaction costs from Member States to type approval authorities. • M3.3: Vehicle OEM self-monitoring: Vehicle OEMs collect and report annually to the EEA/EC the required data to be monitored for their completed vehicles, including sales numbers in EU territory. Some transaction costs associated to intermediate data handling steps are eliminated.
M4	These sub-options relate to the modernisation of the system. These sub-options explore information technology upgrades and changes in the architecture of the database system. These sub-options are *not* mutually exclusive. The expected effect of these sub-options is to lower the *transaction costs* associated to data handling, as well as the improvement of the data quality and accuracy of monitored data (see section 4.7). • M4.1: Fully digitalised system. The whole system would be moved to digital forms (paperless). This sub-option would require appropriate lead time and a substantial adaptation effort from Member States and type approval authorities, but the transition to a fully digitalised system is seen as practically inevitable in the long run considering current trends in document management. A harmonised approach could lower these transition costs (*e.g.*, if the EC produced a complete technical specification for the database. • M4.2: Use of a centralised database. A central database would be used to collect the data. This could build on the initiative by the EREG working group in charge of the development of a database that contains CoC and vehicle registrations data. The centralised approach would also require a substantial investment, but it would likely improve data consistency and the transparency of data collection, and would lower *transaction costs* by removing intermediate data exchange operations. It is assumed that the application of sub-option M4.2 requires a fully digitalised system (sub-option M4.1).

5.3.3.6 *Cost comparison of “M” options*

A fair amount of uncertainty remains about the implementation of the monitoring and reporting scheme, among other reasons due to the interdependencies with the technical options for the determination of CO_2 emissions. For the purposes of the cost estimates in this section, and for the sake of simplicity, it is assumed that *either options D1 or D2 will be used to determine the CO_2 emission through simulation using the VECTO tool*. Under this assumption, the data of *individual, whole HDVs are certified, reported and monitored*.

In contrast to the methodology followed for the estimation of the “D” and “P” options, it was necessary to include stakeholder groups other than OEMs to assess the cost of the “M” options. *The costs associated with the “M” options were therefore estimated for OEMs, member states and EEA/EC*. Whenever relevant, the two-tier approach for OEMs was carried over from the cost estimates for the “D” options (see section 5.3.3.2). A similar approach was also adopted for member states/HDV markets: we estimated the costs for both a hypothetical “large member state” with registrations of 50,000 vehicles per year and a “small member state” with 5,000 annual vehicle registrations[26].

In addition to the different stakeholder point of view, it was also necessary to propose a different cost structure to tie the costs to the amount of data being handled. The main cost components identified relate to *data infrastructure and investment costs* (which are one-time costs, analogous to the transition costs estimated for the “D” options) and *data management and delivery costs* (which are annual costs derived from managing databases and transferring data between stakeholders). The cost sub-components for these two large costs blocks associated to the “M” options are described in Table 35. Based on the cost structure outlined in Table 35, and also on the assumptions listed in Table 34, we proceeded to build the qualitative matrix of cost influences (Table 36) and the cost structure configuration by stakeholder type (Table 37).

[26] For comparison purposes, Germany had approximately 76,000 registrations of HDVs in the year 2013, whereas France had 47,000, Belgium had 8,000 and Portugal had roughly 3,000 (LastAuto Omnibus 2014).

Table 35: Generic cost structure of the "M" options

<table>
<tr><th>Cost component</th><th>Sub-component description</th></tr>
<tr><td rowspan="2">Data infrastructure investment costs [Transition costs, in EUR]</td><td>Database development costs. The central cost estimate is EUR 420,000 for a large, comprehensive database to cover all the vehicles registered in the European HDV market in one year[27].
• These are one-time costs, incurred in the first year that the database is developed.
• The cost of developing smaller databases is scaled according to the number of vehicle data records managed by the stakeholder (e.g., by the number of vehicle sales for OEMs or by the number of vehicle registration for Member States).
• A 15% increase in development costs is assumed for sub-option M2.1 due to the increased technical complexity.</td></tr>
<tr><td>Digitalisation costs. These are transition costs required to move from paper records to a fully digital system.
• A 100% increase in development costs from the baseline is assumed for both sub-options M4.1 and M4.2 due to digitalisation and database harmonisation efforts.
• It is assumed that sub-option M4.2 (centralised database) requires a fully digitalised system (sub-option M4.1).
• For sub-option M4.2, there are no database setup costs for MS, but there are some costs derived from harmonisation. These costs are estimated to be equivalent to database setup (i.e., EUR 420,000, scaled to market size).</td></tr>
<tr><td rowspan="3">Data management and delivery costs [Annual costs, in EUR/year]</td><td>Data management costs. The central cost estimate is EUR 42,000 for a large, comprehensive database to cover all the vehicles registered in the European HDV market in one year.
• The cost of managing smaller databases is scaled according to the number of vehicle data records managed by the stakeholder (e.g., by the number of vehicle sales for OEMs or by the number of vehicle registration for Member States).
• A 50% increase in data management costs is assumed for sub-option M2.1 due to the increased technical complexity imposed by data confidentiality issues.</td></tr>
<tr><td>Data delivery costs. These are transaction costs derived from transferring data between stakeholders. The costs are assumed to accrue to the provider of the data, not the recipient. They are estimated on the basis of the staff time required to process the data records.
• The time required to process an individual vehicle record using a semi-manual is estimated as 1/3 of an hour. Hourly staff rates are estimated at 30 EUR/hour.
• The time required to process an individual vehicle record using an automated system (fully digitalised forms, harmonised databases) is negligible (data delivery costs are zero).
• Data delivery costs do not scale with data complexity (they are not affected by the application of the M2 sub-options).</td></tr>
<tr><td>Reporting costs. These are costs incurred by EEA/EC for reporting to the public. These are assumed to be equivalent to 1 full-time equivalent additional staff (or EUR 60,000 per year), as estimated from the requirements of the European LDV monitoring scheme.</td></tr>
</table>

[27] This amounts to 308,000 vehicles for the year 2012 (IHS, 2013).

Table 36: Influence of M options upon the cost structures of stakeholder types (qualitative impact of change from baseline)

	Data infrastructure investment costs					**Data management and delivery costs**				
	EEA/ EC	*MS*	*OEM (vehicle)*	*OEM (component)*	*OEM (trailer & body)*	*EEA/ EC*	*MS*	*OEM (vehicle)*	*OEM (component)*	*OEM (trailer & body)*
M1 (baseline)	-	-	-	-	-	-	-	-	-	-
M2.1 (all input data from VECTO)	↑	↑	↑	↑	-	↑	↑	↑	↑	-
M2.2 (data of completed vehicles)	-	-	-	-	↑	-	-	-	-	↑
M2.3 (data of trailers)	↑	↑	-	-	↑	↓	↓	-	-	↑
M3.1 (responsibilities: MS + OEM)	-	-	-	-	-	-	↓	↑	-	-
M3.2 (responsibilities: MS + TAA)	-	-	-	-	-	-	↑	↓↓	-	-
M3.3 (responsibilities: OEM)	-	↓	↑	↑	-	-	↓	↑	-	-
M4.1 (fully digitalised system)	↑	↑	↑	↑	↑	↓	↓	↓↓	↓	↓
M4.2 (centralised database)	↑↑	↓	↑	↑	↑	↓	↓↓	↓↓	↓	↓

↑ Moderate increase; ↑↑ Substantial increase; - No significant change from baseline; ↓ Moderate decrease; ↓↓ Substantial decrease

Table 37: Cost structures for the "M" options, by stakeholder type. Cost elements in grey are assessed in a qualitative manner only

Option	OEM (vehicle)	OEM (other)	Member States	EEA/EC
M1	*Database development* and *data management* costs (database costs scaled to number of sales) *Data delivery* costs of communicating technical data to vehicle registration authorities.	[Component manufacturers]: *Database development* and *data management* costs.	*Database development* and *data management* costs (database costs scaled to number of registrations) *Data delivery* costs of reporting to EEA.	*Database development* and *data management* costs (large database). *Reporting costs* from reporting data to stakeholders. Development and validation costs for VECTO.
M2.1	*Data delivery* costs as M1 (transaction costs do not scale with extended technical data). Additional costs for data management (50% increase over baseline). Additional costs for data security (15% premium on *database development*).	[Component manufacturers]: Increased *database development* and *data maintenance* costs.	*Data delivery* costs as M1 (transaction costs do not scale with extended technical data). Additional costs for data management (50% increase over baseline). Additional costs for data security (15% premium on *database development*).	Additional costs for data management (50% increase over baseline). Additional costs for data security (15% premium on *database development*). Additional *reporting costs* from reporting data to stakeholders (50% increase over baseline).
M2.2	Same as M1, with additional *data delivery* costs from CO_2 emissions from completed vehicle. Additional *data management* costs of adjustment of CO_2 values for completed vehicle.	[Body builders]: Additional costs arising from having to run simulations with VECTO tool or tables of values.	Same as M1, with additional *data management* and *data delivery* costs for collecting and reporting data on completed vehicle.	Same as M1, with additional *data management* costs for completed vehicles.
M2.3	Same as M1.	[Trailer manufacturers]: Additional costs arising from product certification.	Same as M1, with additional *data delivery* and *database management* costs for registering trailers.	Same as M1, with additional *database management* costs for trailer data. Additional costs to harmonise certification of category O vehicles.
M3.1	*Data delivery* costs from communicating technical data to EEA.	Same as M1.	*Data delivery* costs from communicating registration data to EEA. *Data management* costs from handling registration data.	*Database management* costs from maintaining technical and registration data. Administrative costs from increased data handling (combining datasets).
M3.2	Savings in *data management costs* (50% reduction from baseline). Reduced *data delivery* costs (-100% from baseline).	Same as M1.	*Data management* costs of handling technical data (increase by 50% from baseline). *Data delivery* costs of communicating technical data to EEA.	Same as M3.1.
M3.3	Increased *database development* costs (50% over baseline). High *data management* costs from handling technical and sales data (100% increase over baseline).	Same as M1.	*Database development* costs are reduced by 50% from baseline.	Same as M1.

Option	OEM (vehicle)	OEM (other)	Member States	EEA/EC
M4.1	*Digitalisation costs* (additional costs of 100% of the baseline *database development* costs). Cost savings in the long run: *data management* costs are lowered by 50% and *data delivery* costs are lowered by 100% from baseline.	[Component manufacturers]: *Digitalisation costs* (high)	*Digitalisation costs* (high). Cost savings in the long run: *data management* costs are lowered by 50% and *data delivery* costs are lowered by 100% from baseline.	Higher upfront transaction and administration costs for digital infrastructure and security. Cost savings in the long run due to lowered *data management* costs (-50% from baseline).
M4.2	*Digitalisation costs* (additional costs of 100% of the baseline *database development* costs). Cost savings in the long run: *data management* costs are lowered by 50% and *data delivery* costs are lowered by 100% from baseline.	[Component manufacturers]: *Digitalisation costs* (high)	Reduction in *database development costs* (-50% from baseline). Reduction in *data management costs* (-75% from baseline, databases of Member States become much smaller after centralisation).	*Digitalisation costs* (additional costs of 100% of the baseline *database development* costs). *Database development* and *data management* costs are increase by 50% compared to the baseline. Additional costs for database harmonisation.

The estimated transition and annual costs for vehicle OEMs (both in EUR and in EUR per vehicle sold; see Table 38 and Table 39), Member States (both in EUR and in EUR per vehicle monitored; see Table 40 and Table 41) and the EC/EEA (see Table 42) were estimated for selected monitoring options using the cost structures from Table 37. It should be noted that most monitoring options are not mutually exclusive, which means that different monitoring options can be combined (leading to a number of possible monitoring schemes higher than the number of sub-option presented). For example, it appears possible to increase the data requirements for monitoring, as is the case for option M2.1, while also implementing a fully digitalised system, as is the case for option M4.1. These interactions effects are not considered in the cost estimates as a comprehensive evaluation of all possible combinations transcends the scope of the study. Instead, we evaluate the costs of the baseline option (M1), and the costs of adopting sub-options M2.1, M3.1, M3.2, M3.3, M4.1 and M4.2 in a one-at-a-time fashion.[28]

The costs of the sub-options include the baseline costs. Sub-options M2.2 and M2.3 are not assessed due to the lack of quantitative cost estimates for the relevant cost components (see Table 37).

Table 38: Costs incurred by vehicle OEMs for different monitoring options

	Transition costs		Annual costs	
	Large OEM	**Medium OEM**	**Large OEM**	**Medium OEM**
M1	€ 52 162	€ 24 475	€ 443 053	€ 207 885
M2.1	€ 59 986	€ 28 146	€ 473 053	€ 221 961
M3.1	€ 52 162	€ 24 475	€ 473 053	€ 221 961
M3.2	€ 52 162	€ 24 475	€ 30 000	€ 14 076
M3.3	€ 78 243	€ 36 712	€ 503 053	€ 236 038
M4.1	€ 104 323	€ 48 950	€ 30 000	€ 14 076
M4.1+4.2	€ 104 323	€ 48 950	€ 30 000	€ 14 076

[28] Options M4.1 and M4.2 are presented in combination because it is assumed that the adoption of option M4.1 is a prerequisite of option M4.2. No further interactions among the sub-options are modelled.

Table 39: Costs incurred by vehicle OEMs for different monitoring options (normalised to costs per sold vehicle)

	Transition costs		Annual costs	
	Large OEM	**Medium OEM**	**Large OEM**	**Medium OEM**
M1	€ 1.36	€ 1.36	€ 11.57	€ 11.57
M2.1	€ 1.57	€ 1.57	€ 12.35	€ 12.35
M3.1	€ 1.36	€ 1.36	€ 12.35	€ 12.35
M3.2	€ 1.36	€ 1.36	€ 0.78	€ 0.78
M3.3	€ 2.04	€ 2.04	€ 13.13	€ 13.13
M4.1	€ 2.72	€ 2.72	€ 0.78	€ 0.78
M4.1+4.2	€ 2.72	€ 2.72	€ 0.78	€ 0.78

Table 40: Costs incurred by Member States for different monitoring options

	Transition costs		Annual costs	
	Large MS	**Small MS**	**Large MS**	**Small MS**
M1	€ 68 087	€ 6 809	€ 560 000	€ 110 000
M2.1	€ 78 300	€ 7 830	€ 590 000	€ 140 000
M3.1	€ 68 087	€ 6 809	€ 530 000	€ 80 000
M3.2	€ 68 087	€ 6 809	€ 590 000	€ 140 000
M3.3	€ 34 043	€ 3 404	€ 30 000	€ 30 000
M4.1	€ 136 174	€ 13 617	€ 30 000	€ 30 000
M4.1+4.2	€ 34 043	€ 3 404	€ 15 000	€ 15 000

Table 41: Costs incurred by Member States for different monitoring options (normalised to costs per monitored vehicle)

	Transition costs		Annual costs	
	Large MS	**Small MS**	**Large MS**	**Small MS**
M1	€ 1.36	€ 1.36	€ 11.20	€ 22.00
M2.1	€ 1.57	€ 1.57	€ 11.80	€ 28.00
M3.1	€ 1.36	€ 1.36	€ 10.60	€ 16.00
M3.2	€ 1.36	€ 1.36	€ 11.80	€ 28.00
M3.3	€ 0.68	€ 0.68	€ 0.60	€ 6.00
M4.1	€ 2.72	€ 2.72	€ 0.60	€ 6.00
M4.1+4.2	€ 0.68	€ 0.68	€ 0.30	€ 3.00

Table 42: Transition and annual costs incurred by the EC/EEA for different monitoring options

	Transition costs	Annual costs
M1	€ 420 000	€ 120 000
M2.1	€ 483 000	€ 180 000
M3.1	€ 420 000	€ 120 000
M3.2	€ 420 000	€ 120 000
M3.3	€ 420 000	€ 120 000
M4.1	€ 840 000	€ 90 000
M4.1+4.2	€ 1 050 000	€ 150 000

Finally, in Figure 17 and Figure 18, we graphically represent the *comprehensive costs* (both transition costs and annual costs) of selected “M” options. For the estimation of these comprehensive costs, we assumed a market composed of 3 large OEMs and 4 medium vehicle OEMs, and of 3.5 large member states and 24.5 small member states.[29]

[29] This is a coarse approximation of the actual European HDV market composition, but it is useful to visualise the estimated distribution of costs among stakeholder types, and the influence of the different “M” options upon this distribution.

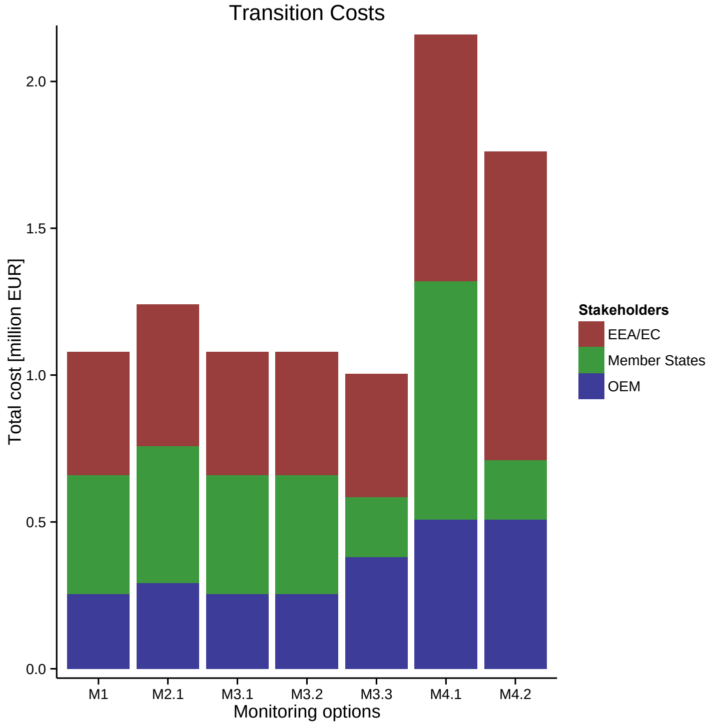

Figure 17: Comprehensive *transition costs* of monitoring and reporting for selected “M” options (in EUR)

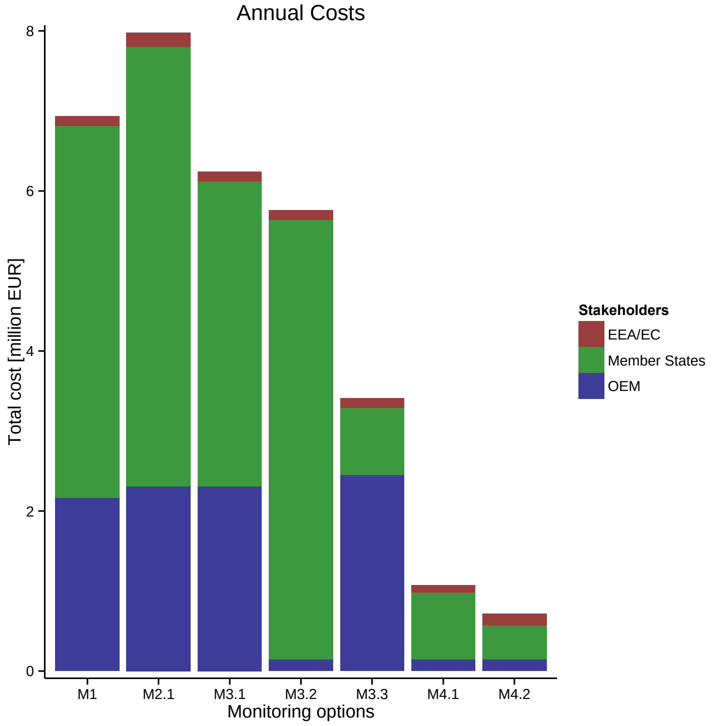

Figure 18: Comprehensive *annual costs* of monitoring and reporting for selected “M” options (in EUR/year)

5.4 Discussion of the stakeholder consultation and costs study

The objectives of our project were to identify, define and analyse options for certification, validation, and reporting and monitoring of fuel consumption and CO_2 emissions from heavy-duty vehicles and to determine the costs of these options to the relevant stakeholders. This section discusses the technical options proposed in sections 3, 3.5 and 4, in relation to the findings of the stakeholder consultation (section 5.2), as well as the results of the cost study (section 5.3).

5.4.1 Stakeholder consultation

The European Commission will ultimately use the output of this work to support future legislation. Stakeholder engagement was therefore critical for the success of this project to make sure that 1) no important options are missed, 2) the processes behind the options are understood and can be developed, 3) industrial stakeholders and third parties provide input to the costs calculations, and 4) stakeholders generally accept the results of the study.

The feedback collected during the consultation exercised was processed and organised by stakeholder type to produce an overview of the *preferences and expectations* of the different players regarding the impending legal framework for the monitoring and reporting of CO_2 emissions from heavy-duty vehicles in the EU (covering the methods of determination of the CO_2 values, the conformity of production and the administrative schemes for monitoring and reporting the CO_2 values for each vehicle).

A number of interesting patterns arose from this activity. Regarding the *technical options for the determination of* CO_2, a large majority of stakeholders manifested a clear preference for those based on *component testing and vehicle simulation* with an ad hoc tool (options D1 and D2). The baseline option (D1, requiring more detailed component testing than option D2) was widely identified across the different stakeholder groups as the better option both in terms of *expected quality of the results* and *general preference*. On the other hand, option D2 (simplified simulation using default values for some components) was also ranked high in these aspects, and *stakeholder groups consistently identified it as the most convenient option from a cost perspective*. These results have a double interpretation: on the one hand, the stakeholders recognise the technical benefits that vehicle efficiency simulation can bring to the European HDV market (e.g., the ability to cost-effectively produce several results for each vehicle variant using different mission profiles, the reproducibility and repeatability of results, the real-world accuracy of simulated emissions through the use of realistic simulated cycles). On the other hand, stakeholder responses also send the message that the best option in absolute terms is not necessarily the cheapest, and they widely acknowledge that the quality of simulated results depends largely on the quality of the input data.

It could be argued that the lop-sidedness of the results is conditioned by prior actions from the European Commission signalling that vehicle simulation and component testing was their preferred method for the determination of CO_2 emissions (*e.g.*, the investment in the development of VECTO. These actions would bias the results of the stakeholder consultation and, in an extreme case, make it a moot exercise. While it is true that D1 was presented as the “front runner” option, it is also clear that it would be overly simplistic to propose a single technical option to address the challenge of monitoring the CO_2 emissions from the complex European HDV market. In this sense, the responses of stakeholders have been particularly useful to identify the cases in which it may be useful to retain “alternative” determination methods (*e.g.*, option D2 for some niche applications, option D5 for hybrid vehicles). A further benefit of the consultation was to be able to gather the views of industrial stakeholders with special needs due to their unique positions in the value chain—as is the case of tyre manufacturers or non-integrated component OEMs— and to receive input from research organisations and NGOs.

The results of the stakeholder consultation regarding the options for the *validation of the measured CO_2 values* (conformity of production, CoP) show a difference in views between industrial stakeholders (who favour a component-specific approach to CoP) and all of the rest (who support both the process-specific and the vehicle-specific approach). As is the case with the options for the determination of the CO_2 values, the final implementation could make use of different technical options to validate the measured values. A possible way forward would be to rely on (component-specific) plausibility checks applied to all of the input data for the simulations, and complement these with punctual process-specific checks (*e.g.*, a repetition of component testing and simulation for the complete vehicle performed or witnessed by a technical service). Whole-vehicle tests (*e.g.,* at the chassis dynamometer, to improve the reproducibility of results), while considered by some stakeholders as being outside of the scope of the validation of the measured CO_2 values, will nonetheless be required for the validation of VECTO as it is further developed once the regulation is in place.

The results of the stakeholder consultation regarding the *data monitoring and reporting* are somewhat limited in their usefulness due to changes in the formulation and the further refinement needed of the “M” options since the time they were presented to the stakeholders. One of the reasons for this reformulation was precisely the feedback received from stakeholders requesting more clarity in key issues such as the attribution of responsibilities and roles, the configuration of the administrative arrangements and the confidentiality of data input to the simulations. During the project it was discussed that options attributing clear roles for different stakeholders in the process needed to be defined more clearly and precisely.

While some uncertainty remains about all of these issues (which will have to be addressed not just from a technical perspective, but also taking into account the constraints imposed by existing administrative setups), it is also clear that the general sentiment of stakeholders towards monitoring and reporting the CO_2 emissions from HDVs is positive: both industrial and non-industrial stakeholders support the “extended” monitoring and reporting scheme (more parameters than currently covered in the CoC) as a means to improve transparency, and they call for a harmonised approach to data handling in order to reduce the additional administrative burden. The monitoring of individual vehicles is also generally seen as useful. A few type approval authorities and the EEA favour the M4 sub-options (digitalization and centralised database) because they think it could have clear benefits for the data handling as is also suggested above.

5.4.2 *Cost study*

The cost study presented in section 5.3 relied on cost data collected during the stakeholder consultation exercise, which were complemented with additional data sources and expert judgment from the consortium members. A key aspect of the cost study was the estimation of the *costs borne by industrial stakeholders*. The European HDV market is too complex to be captured within the reduced scope of this study. For this reason a number of simplifying assumptions had to be made regarding the configuration of the value chain. We found that estimating the additional costs from the point of view of an *integrated vehicle OEM* provided the most useful results because it allowed us to allocate the average additional costs to individual vehicles sold. The tiered approach that classified manufacturers as “large” or “medium” provided some additional granularity to the results and showed that the relative size of the manufacturer has an appreciable influence in the ultimate impact from the regulation.

In the stakeholder consultation exercise, it was observed that the general preferences of industrial stakeholders were, to a degree, decoupled from cost considerations. Still, it could be argued that the cost study would be a sort of circular reasoning or “self-fulfilling prophecy”, whereby the outcome of the study would simply mirror the expectations of stakeholders (collected via the questionnaire) without bringing additional information to the table. There are two reasons to disprove these concerns: first, the input from stakeholders was pre-processed to check its plausibility, and expert judgement was applied to ensure that the presence of outliers did not bias the estimates. Second, the allocation of the costs to sales was performed according to a market analysis following documented criteria and supported by some of the best available data sources about the present configuration of the European HDV market. This market analysis (used, for example, to estimate the average number vehicle families or variants per manufacturer and tier, or the number of new engines and transmissions introduced to the market) was performed independently from any of the stakeholders surveyed, and it had a distinct impact upon the cost estimates for each one of the “D” options.

The annual cost estimates for the “D” options (see Figure 14) are, in general terms, aligned with the expectations expressed by the stakeholders during the consultation exercise. The options using vehicle simulation concepts bring about the lowest additional costs per sold vehicle. Option D2 (simplified simulation) is the cheapest, followed by option D1 (baseline). The technical options that rely on whole-vehicle testing (D3, D4) and transient engine tests (D5) are more expensive in terms of additional cost per sold vehicle. However, one should be cautious when directly comparing the options: for the purpose of the study, it was assumed that all the options provide the same level of utility, but in a practical application there would be qualitative differences in the performance of the options. An obvious difference between the simulation options (D1, D2 and D5) and the whole-vehicle testing options (D3, D4) relates to the degree of coverage of the HDV fleet that these options provide (at the individual vehicle level for the former, at the family level for the latter). Even within the simulation options there are clear differences (option D1 has a cost premium over option D2, but it should provide better results in terms of accuracy; option D5 may appear as a competitive alternative to option D1, but the cost estimate is sensitive to the accuracy of the cost estimate for the transient engine tests, and also to the number of vehicle variants certified per year).

Ultimately, the small differences in the results mean that technical feasibility and quality can prevail over cost considerations.

As far as the options for checking the conformity of production are concerned, our analysis suggests that, for similar levels of coverage, options P1 (component-specific) and P2 (process-specific) are vastly more cost-efficient than option P3 (vehicle-specific conformity of production). This advantage can be amplified if a targeted selection of components to be re-tested is done to maximise the market coverage of the CoP programme. For the proposed estimated level of coverage (1% of components being re-tested), the cost of CoP for the combination of options D1 and P2 (which is slightly more expensive than P1), the estimated additional costs per sold vehicle are EUR 0.05 and 0.07 for large and medium manufacturers, respectively. These costs are fairly low in comparison with the estimates of the CO_2 determination costs per additional sold vehicle (EUR 28.4 and 33.6 for large and medium manufacturers, respectively), which suggests that the coverage could be improved beyond 1% while keeping the costs within reasonable limits.

Finally, the cost estimates for the technical options for monitoring and reporting were derived from a very limited ad-hoc consultation with US EPA and EEA, complemented with a semi-quantitative analysis. The baseline estimates can be considered quite robust, but the final costs will largely depend on the final implementation, and there remains some uncertainty about this point. The semi-quantitative analysis strongly suggests that harmonisation efforts and infrastructure investments to improve data exchange operations have a large effect upon the annual costs of monitoring and reporting, and that they benefit all stakeholder types in the long run.

6 Conclusions and recommendations

CO_2 Determination
For the CO_2 determination methodology 5 options have been identified and assessed. The baseline option D1 is a combination of component testing and simulation of a vehicle and application specific CO_2 value / fuel consumption. Option D1 is an accurate approach allowing a detailed analysis of the different fuel consumption influencing components and eliminating undesirable effects like driver influence or ambient conditions. The high effort for the component testing faces the fact that a vehicle family approach can be avoided to the greatest possible extend.

Option D2 is a simplification of the baseline approach D1 and foresees a reduction of testing effort by replacing component testing by technology specific table values / functions. This will inevitably lead to a reduction of the overall accuracy of the methodology and therewith to a more inaccurate result in terms of CO_2 value. The influence of the simplification on the final result should be investigated further.

Referring to the CO_2 determination methodology for passenger cars, a chassis dyno approach was assessed as third option (D3). Issues related to this approach are beside the availability of test benches, the high effort due to the high number of variants within the HDV sector, which finally will make a vehicle family approach necessary. Furthermore, the influence of the driver on the final result is not negligible.

The measurement of fuel consumption / CO_2 emission during real driving under defined conditions (D4) leads to realistic values at the first glance, but due to the influence of the driver, the ambient conditions and the route characteristics the repeatability and reproducibility of results are not good. Similar to the chassis dyno option a vehicle family approach is necessary to handle the huge variety of HDVs.

The simulation of load profiles based on measured input data and determination of fuel consumption / CO_2 emissions on a transient engine test bench (D5) is an approach with high accuracy, including effects of the dynamic behaviour of the engine. Compared to the baseline option D1 the accuracy can be even higher (under the same conditions for component testing) but the effort regarding the testing of the engine is a multiple higher which does not justify the small improvement of accuracy.

Concluding, option D1 seems to be the most promising approach from a technical point of view in terms of accuracy, repeatability, reproducibility and comparability. Furthermore, this option allows to determine CO_2 emissions of single vehicles for different mission profiles and payloads at a relatively low effort. Possibilities for the optimization of the methodology in terms of the determination of actual component data instead of default data have to be further explored and assessed.
The determination of the air drag by CFD simulations, which could address inaccuracies and uncertainties of the currently discussed approach (constant speed test) needs to be further investigated. This should focus on the alignment of CFD simulation software results and the corresponding boundary conditions to build a basis for reproducible and accurate air drag test results. Also more data is needed for other vehicle categories.

Finally, it is worth mentioning that there can be differences between results from testing and simulation and the real world CO_2 of the whole vehicle.

Conformity of Production
The conformity of production is a corner stone within the type approval process and shall ensure constant quality of the product. The 2007/46/EC allows some freedom in defining CoP procedures. A CoP test does not need to be a repetition of the type approval test. Therewith, different options are possible as CoP test.

A CoP on component level (P1) checks the conformity of component data, assuming that similar input data to the simulation tool will result in a similar CO_2 value. Besides the repetition of the complete test, as done for the certification, a simplified test would be thinkable at least for efficiency maps for transmission and axle as well as the fuel map of the engine. Possibilities for a simplification have to be analysed and assessed further. Failures in data handling or use of the simulation tool within the certification run cannot be identified by this option.

Option P2 foresees a repetition of the complete certification process and therewith a direct comparison of the final CO_2 value and identification of failures during the certification run is possible. Simplifications for testing are not possible within this approach. A control of component input quality is not possible if only the final CO_2 value is assessed.

Option P3 focuses on a complete vehicle test and is therewith not directly linked to the certification approach in terms of a repetition of the component test. Conclusions on the quality of the single components are therewith not directly possible. It has to be further discussed if such a simplified approach shall serve as CoP or as a possible ex-post validation. A process has to be developed, describing the different layers of the CoP for the case the measured results are not conform to the certified (control value) one. Comparing the two described sub options (SiCo and real driving), the SiCo test has clear advantages in terms of repeatability, reproducibility and effort.

Ex-post validation
The ex-post validation shall be an additional measure to show that the specification of the final vehicle in terms of fuel consumption / CO_2 emission is in line with the simulated values. On vehicle level the two approaches SiCo and testing under real driving conditions are in principle thinkable. As already discussed in terms of CoP, the SiCo test has clear advantages in terms of repeatability, reproducibility and effort. Considering the SiCo test as CoP, an ex-post validation becomes unnecessary.

Monitoring and reporting
Monitoring options where elaborated in close cooperation with the EC. It proved to require some additional time to define these options, because the process of monitoring, although it is already an integrated process for passenger cars and vans, for HDV has some complexity which needed to be investigated first before a list of options could be established. The complexity is mainly caused by the fact that HDV are constructed and certified quite differently than it is done for passenger cars and vans. We noted the different ways used for type approval and construction of HDV in multiple stages and for the monitoring of HDV, besides for the basic option,

the roles and possible responsibilities were not clear. For the latter reason, a few new options have been introduced halfway the project in which responsibilities have been more clearly specified. These options have not been fully assessed with the stakeholders and therefore it is recommended to do this at a later stage in close cooperation with the stakeholders.

It was also recognized that HDV require a somewhat different approach compared to passenger cars and vans for monitoring. The main difference with passenger cars and vans is the heterogeneity of the fleet of HDV with regard to utility and the vehicles themselves and all the attributes that affect the CO_2 emissions.
This difference would mean for HDV that to follow and understand the trends of the CO_2 emissions of HDV, individual vehicles should be monitored and that probably more technical data of the vehicles would need to be monitored as well. This was generally recognized and is supported by most stakeholders.

The following options were elaborated:
M1 is the baseline option. Regarding responsibilities and involved entities it works the same as for passenger cars and vans. Type approval data and CoC data is collected by registration authorities of the Member States. When a vehicle is registered in a MS the vehicle will be reported together with all others registered in a given calendar year to the EC/EEA. The EEA collects all reports from the MS and checks and calculates aggregated CO_2 emissions (for MS and for vehicle manufacturers). Important new working assumption for this option, as opposed to the existing monitoring of passenger cars and vans, is that CO_2 emissions are to be monitored of single whole HDVs. This baseline option was generally supported by the stakeholders. It must be noted that alternatives to M1, options with different responsibilities (M3) where not yet assessed.

Options under M2 entail mainly additions to the monitoring with different types of data. As a general merit this data allows to more accurately follow and understand the trends of CO_2 emissions of whole HDVs.

Option M2.1 requires VECTO input to be monitored, because each VECTO input contributes to the CO_2 emission of the vehicle and therefore this would allow to also monitor the trends of the components. This option is generally not favoured by vehicle OEMS as they consider a part of the data confidential.

M2.2 is the inclusion of actual technical data and the CO_2 emission of completed vehicles (MSV) instead of data of default (base) vehicles. This option requires a substantial adaptation of processes and probably a substantial increase in the effort for technical services and bodybuilders (final stage manufacturers) due to the fact that additional procedures are needed to ensure that the CO_2 data of the completed vehicle is determined and certified. The complexity is also due to the fact that different ways of approval are used. Due to timing issues of implementation and harmonization which is needed at the level of the Members States and bodybuilders, this option could probably only be introduced at a later stage. It is recommended to further explore this issue with a special focus on possibilities to determine and certify CO_2 emissions of MSV and at single vehicle approvals done at local technical services.

M2.3 entails the monitoring of data of trailers (category O in the framework directive). This would require a harmonization of the registration of the trailers or trailer manufacturers to be involved to report trailer data (from the CoC for instance). Given the lack of harmonization between Members States registrations which was voiced, this option can probably only be introduced at a later stage
For the M3 options mainly the responsibilities and data reporting change compare to the baseline (M1).

M3.1 is the option where the registration authorities of MS only collect and report the unique identifiers, e.g. VIN numbers, of vehicles registered in a CY to the EC/EEA. Vehicle manufacturers separately report the technical data to the EC/EEA and based on the unique identifier the reported datasets can be merged. This option reduces the effort for the Member States (to collect and report technical data) and distributes the responsibilities for the reporting of data over the MS and the vehicle OEMs. For this option, however, final stage manufactures, including SME, would also need to be involved to report data. This would come with the same issues as with MSV and single vehicle approvals.

M3.2 is a variant to M3.1 where the type approval authorities report the technical data instead of the vehicle manufacturers. M3.3 is a completely different approach compared to the baseline and M3.1 and 3.3 because for this option the vehicle OEM collects and reports the technical data and the CO_2 emission data, which would need to be done based on sales figures.

M4 is about options for modernization of the data handling which could make the process more robust and transparent.
M4.1 is the mandatory digitalization of the data administration (TA documents, CoC)
M4.2 considers the use of a (centralized) database to collect all vehicle technical data, for instance from type approvals and CoCs. Such a database is already being developed in cooperation between type approval authorities of a few Member States. Because of the merits of digitalization and the use of databases these options should be further worked out and discussed with stakeholders.

For monitoring, the baseline option with a somewhat extended dataset is generally supported. It is recognized by the stakeholders that more data would be needed to follow the trends of HDV. Mentioned are data of different mission profiles, payload levels, addition of an alternative CO_2 metric and technical data that determines the utility of a vehicle. This M1option still comes with the same responsibilities as for the monitoring of passenger cars and vans. The general favour of stakeholders may partly come from the fact that most stakeholders are best known with this already existing approach and the consequences of alternatives, where responsibilities could shift, can't yet be overseen. For instance, M3.2 is an interesting option where the responsibility would shift and would be distributed between the MS and the vehicle OEM. The M3 options still need to be further discussed with stakeholders.
For the M2 options (VECTO data, MSV and trailers), none seems to be feasible on a short term which also accounts for the M4 options (modernization). The latter will in the end probably require hardly extra effort or costs if any, as it could help to automate the monitoring process and make it more transparent and robust. An additional important note made by vehicle OEMs is that the CO_2 and fuel consumption data should also become available for the customer. If still has to be discussed how this is envisaged.

Stakeholder consultation
The stakeholder consultation revealed the preference of a large majority of stakeholders for CO_2 determination options based on *component testing and vehicle simulation* with an ad hoc tool (options D1 and D2). The baseline option (D1, requiring more detailed component testing than option D2) was widely identified across the different stakeholder groups as the better option both in terms of *expected quality of the results* and *general preference*. This supports the notion that D1 has enough stakeholder support to become the preferential option once the CO_2 monitoring scheme is in place. However, the responses of stakeholders also suggest that the retention of alternative technical options (*e.g.*, option D2 for some niche applications, option D5 for hybrid vehicles) may be necessary to ensure a comprehensive coverage of the fleet.

The results of the stakeholder consultation regarding the options for the *validation of the measured CO_2 values* (conformity of production, CoP) showed a difference in views between industrial stakeholders (who favour a component-specific approach to CoP) and all of the rest (who support both the process-specific and the vehicle-specific approach). In spite of the limitations of the stakeholder consultation exercise, its results demonstrate that there is a generally positive sentiment of stakeholders towards monitoring and reporting the CO_2 emissions from HDVs: both industrial and non-industrial stakeholders support the “extended” monitoring and reporting scheme (more parameters than currently covered in the CoC) as a means to improve transparency, and they call for a harmonised approach to data handling in order to reduce the additional administrative burden.

Cost study
The cost study focused on the estimation of the *costs borne by industrial stakeholders*. The scope of the study was rather limited, and so a number of simplifying assumptions regarding the configuration of the value chain and the composition of the European HDV market had to be made. These assumptions allowed the estimation of costs from the point of view of an *integrated vehicle OEM* and the allocation to individual vehicles sold, which provided a good basis for general comparisons of the technical options.

The annual cost estimates for the different “D” options were aligned with the expectations expressed by the stakeholders during the consultation exercise but, at the same time, the estimates were relatively close to each other. As expected, the options using vehicle simulation concepts bring about the lowest additional costs per sold vehicle. Option D2 was found to be the cheapest, followed by option D1 (baseline) and option D3. However, the utility provided by the different options is not directly comparable: the options that rely on vehicle simulation (D1, D2 and D5) are able to provide a superior fleet coverage than those that use whole-vehicle testing and therefore require the definition of a vehicle family concept (options D3, D4). Also, not every simulation option provides the same level of accuracy or data quality. All in all, and in spite of its cost premium over D2, option D1 seems to provide the best balance between cost and fleet coverage, accuracy of results and data quality.

The results of the cost study suggest that, for similar levels of coverage and assuming that a vehicle simulation option is adopted for the determination of CO_2, options P1 (component-specific) and P2 (process-specific) are vastly more cost-efficient than option P3 (vehicle-specific conformity of production). This advantage can be amplified if a targeted selection of components to be re-tested is done to maximise the market coverage of the eventual CoP programme. However, whole-vehicle tests (*e.g.,* at the chassis dynamometer, to improve the reproducibility of results, or with PEMS, for better real-world representativeness), while considered by some stakeholders as being outside of the scope of CoP, will nonetheless be required for the validation of VECTO as it is further developed once the regulation is in place.

Finally, the costs of monitoring and reporting were elaborated on the basis of a very limited set of point estimates, but these came from reliable sources and can be considered quite robust. While significant, these estimated costs are relatively less important than the estimated costs for the “D” and the “P” options, and unlike these, they are mostly one-time costs. Our analysis also suggests that the adoption of solutions that are both more comprehensive in terms of the number of parameters to be monitored and the sophistication of the system (full digitalisation, use of a centralised database) would be the most cost-effective considering the improvements in data quality, transparency and consistency that they could bring.

7 References

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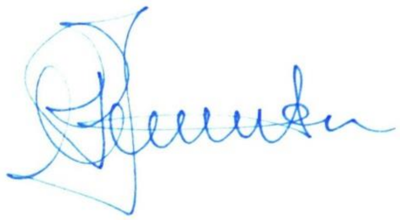
8 Signature

Delft, 24 February 2015

Project leader	Author
Ruud Verbeek	Robin Vermeulen

A Summary of the proposed technical options (supporting document for the online stakeholder survey)

Option D1: Combination of component testing and simulation/VECTO
Option D1 employs the VECTO vehicle simulation tool to determine the vehicle's performance. Input parameters for air drag, transmission/axle, and engine are determined by component testing, while a default constant power demand is added to the engine load to account for auxiliaries. The rolling resistance coefficient (RRC) is available from tyre manufacturers. In the case of multi-stage vehicles, a non-mandatory second-stage certification could be performed on the basis of tabulated values (e.g. additional CO_2 as a function of vehicle weight and C_d) or simplified CFD simulations. This sub-option would apply to option D2 as well.

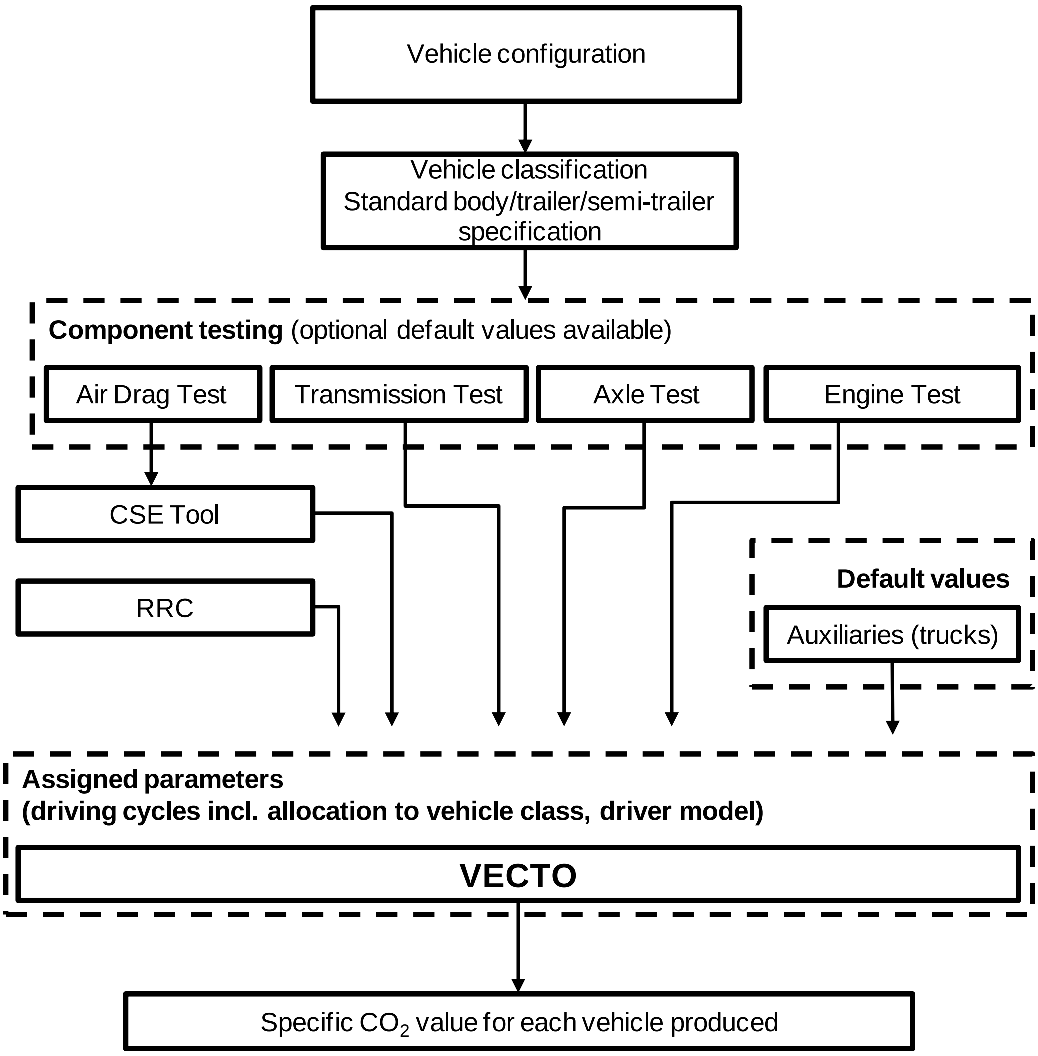


Figure 19: Overview of Option D1

Option D2: Simulation and reduced testing effort
Compared with option D1, option D2 limits testing to the engine; default values are employed for transmission, axle, and auxiliaries. Air drag is estimated by means of a CFD simulation.

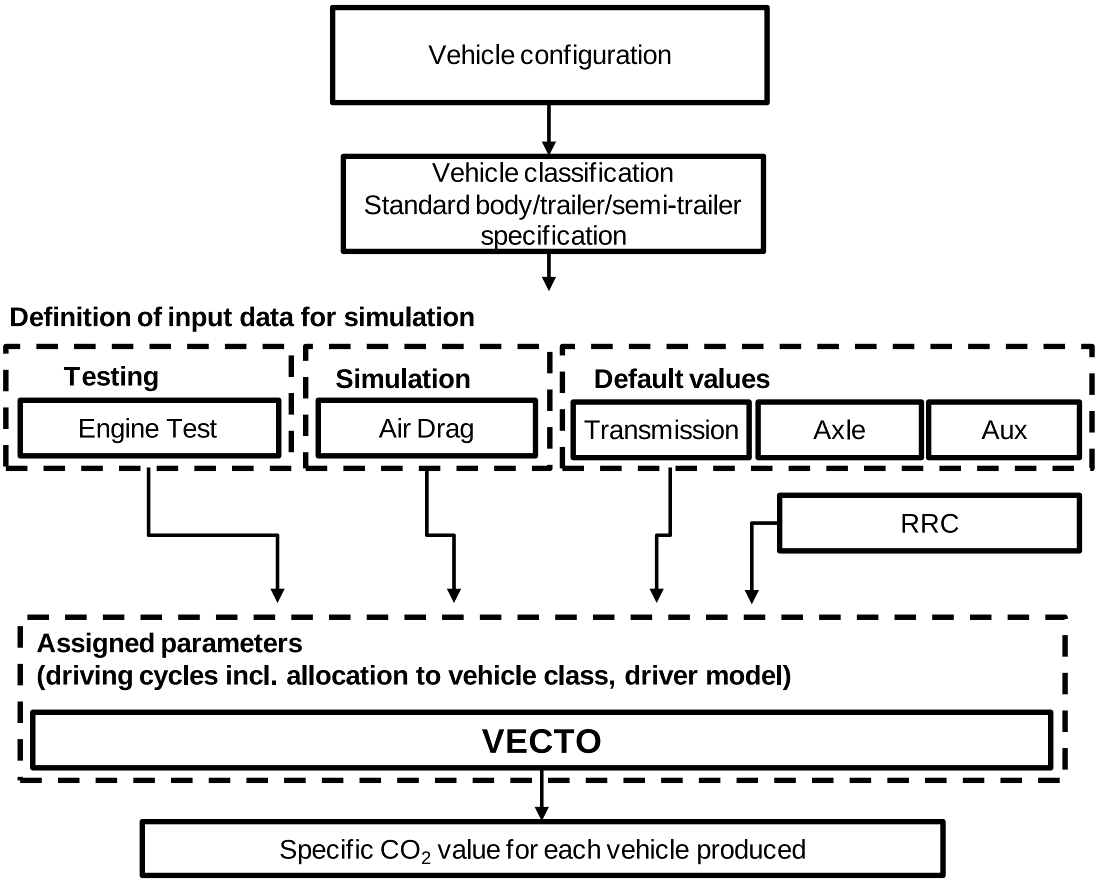


Figure 20: Overview of Option D2

Option D3: Chassis dynamometer testing
Option D3 relies on chassis dynamometer testing; however, due to the myriad of vehicle configurations, this type of testing is infeasible for all vehicle variants. Consequently, one option to reduce the testing efforts is to assign CO_2 values to vehicle families. These values would be determined by testing of air drag and RRC and chassis testing of the remaining powertrain components. Technology-specific bonifications could then be used to account for variances among vehicle designs.

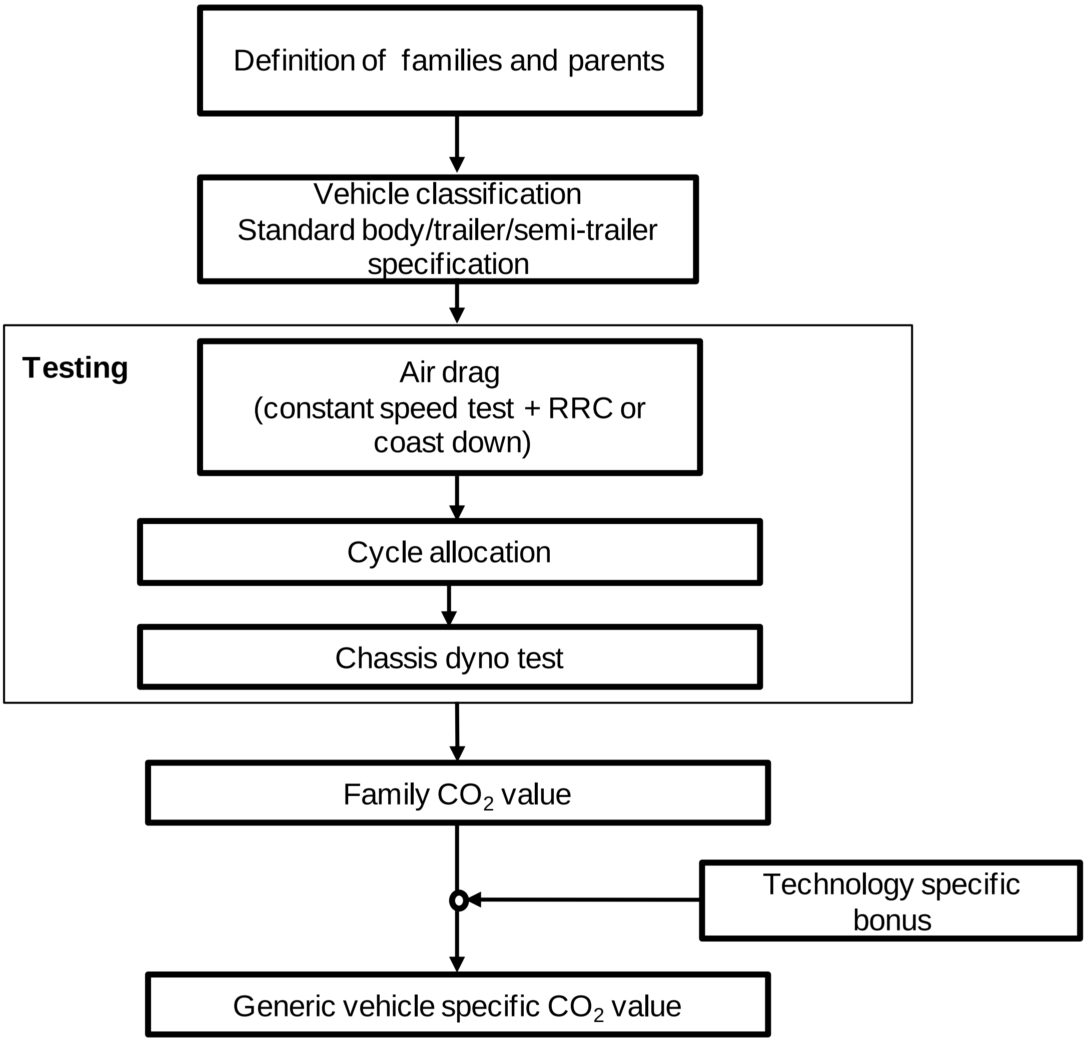


Figure 21: Overview of Option D3

Option D4: Fuel consumption measurement during real driving
Option D4 relies on direct measurement of CO_2 emission or fuel consumption under real driving conditions. Similar to option D3, vehicle families and technology-specific boni could reduce testing efforts while taking into consideration specific vehicle designs.

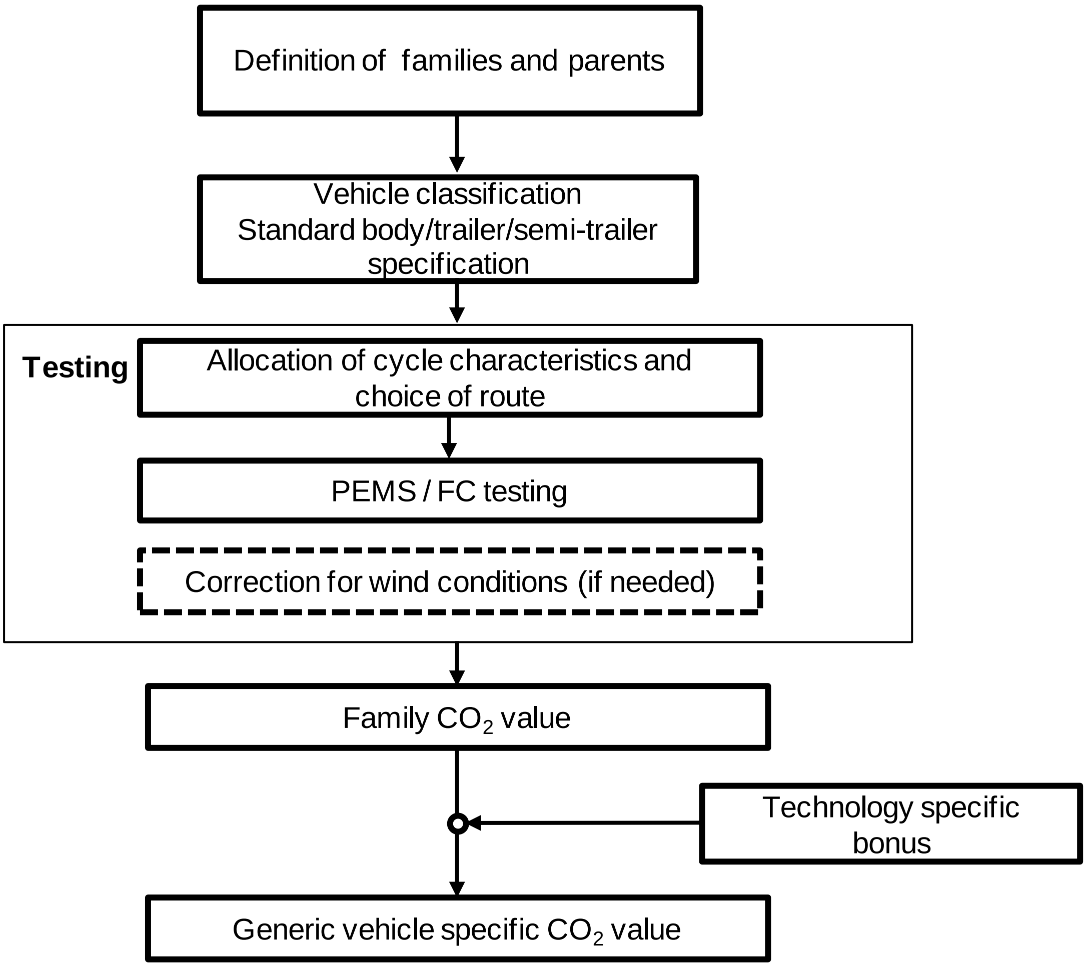


Figure 22: Overview of Option D4

Option D5: Simulation and engine test

Option D5 uses tested, simulated, or default data for air drag, rolling resistance, transmission, axle, and auxiliaries in order to generate a vehicle-specific engine load profile. Based on this load profile, engine tests are performed to determine fuel consumption and/or CO_2 emissions.

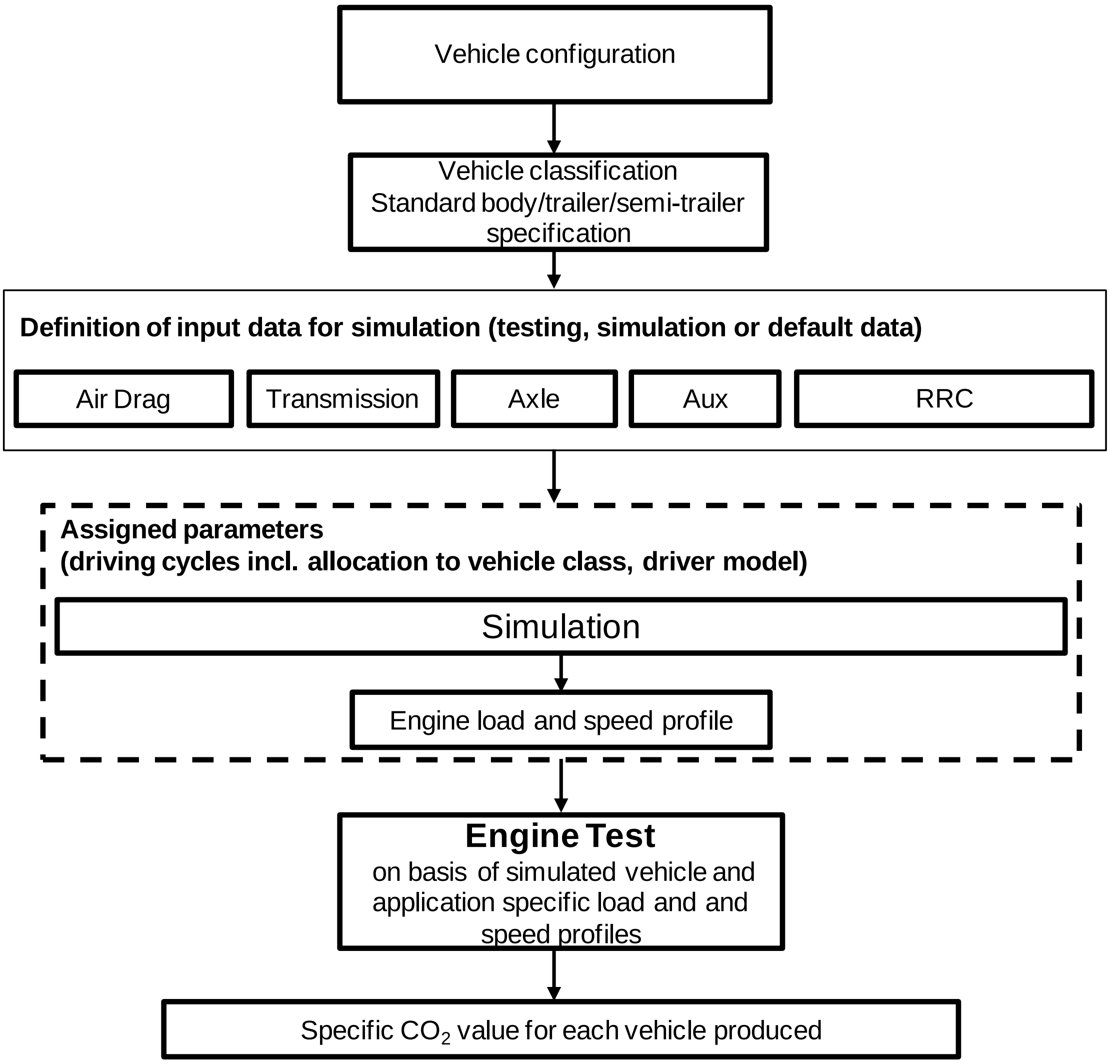


Figure 23: Overview of Option D5

For testing the Conformity of Production[30] of the HDVs, the following options are laid out:

Option P1: Component-specific CoP
This option is related to an approach based on a combination of component testing and simulation for the determination of CO_2 values (options D1 or D5). The input data to the simulation would be in the focus of a CoP. This option is based on the assumption, that if the different components and therewith the input data to the simulation are conform to the data delivered for the certification of the vehicle/CO_2 value, the certified product (vehicle) is still conform.

Option P2: Process-specific CoP
The process-specific CoP includes a complete repetition of the process, from the component testing to the simulation of the final, vehicle and application specific CO_2 value. This allows the certified and retested/simulated CO_2 values to be directly compared.

Option P3: Vehicle-specific CoP
The vehicle-specific CoP could be based on a Simplified Short Cycle Test (consisting of constant speed and acceleration/deceleration events to be driven on a test track monitoring the fuel consumption, the results of which would be compared to a simulated of the same short cycle) or, alternatively, a direct on-rad measurement of CO_2 or fuel consumption during real driving on a similar basis as defined for the In-Service Conformity measurements according to 582/2011/EC.

[30] Note: A random verification of the VECTO calculated fuel consumption and CO_2 emission versus real on-road measured fuel consumption and CO_2 emissions is considered necessary as additional measure. The simulated CO_2 value for a certain vehicle can be checked by applying real-world testing to vehicles equipped with fuel flow measurement devices. In this sense, option P3 can be considered as ex-post validation of the certified CO_2 value.

M+R options: Monitoring and reporting
The goal of the monitoring and reporting is to gain more information to enable a better statistical evaluation of the fleet and trends with regard to the CO_2 emission and the attributes that affect the CO_2 emission.

The technical options for monitoring and for reporting are described in this section. For both monitoring and reporting, a baseline option is defined on the basis of the existing scheme for LDVs, using current or similar procedures, data sources and responsible entities. A difference from the existing scheme for LDVs is that HDVs are monitored on an individual basis for all options.

Further options are defined as changes to the data, data source, procedure or responsible entities.

Indicative datasets to be monitored - options

M1 Monitoring of HDV technical data from the current CoC (Certificate of Conformity; see Annex IX of 2007/46/EC)

M1.1 Monitoring of the technical characteristics as currently given in the CoC for individual HDV. The CoC for N3 vehicles now contains about 90 entries: from these entries a number of essential parameters (that have an influence on CO_2 emission) is taken. The basic working assumption for monitoring of individual HDV requires the monitoring of a unique vehicle identifier, i.e. the VIN. The CO_2 emission is not monitored as this is not a data field in the CoC.

M1.2 As option 1.1, but with calculation of the vehicle CO_2 emissions from the available vehicle technical data and generic data for air drag and transmission. This also requires the CO_2 emission (WHTC) from the information generated for the purpose of EC Type Approval (Annex I of 2007/46/EC)

M2 Monitoring of HDV data not yet available in the CoC. This will require amendments to the Type Approval Framework Directive 2007/46/EC).

M2.1 CO_2 data determined with VECTO. E.g. CO_2 emissions per vehicle segmentation, mission profile as defined for VECTO.

M2.2 Trailer technical data (CoC data, O category vehicles)

M2.3 Other information. Essential characteristics that determine the level of CO_2 emissions of a HDV that was used as input to VECTO or data that determines the utility of a HDV. For instance: technical masses, payload, air drag, information about bodywork, drag reducing components, information about the tyres, engine, auxiliaries.

Procedure, data sources and entities responsible - options

M3 Monitoring by Member States National registration authorities and/or type approval authorities and reporting data to the EEA (current system for LDVs). Data on new registrations of vehicles (as currently done for LDVs) is obtained by the Member States and supplied to the EEA. Current LDV data is based mainly on

CoCs and to a lesser extent data sourced from type approval data bases. Member States National registration authorities and/or type approval authorities are involved in the monitoring.

M4 Monitoring by OEMs and reporting to the EEA. The OEM collect sales data and technical HDV data. Annual EU sales data is used together with HDV technical data from the CoC or type approval, both supplied by the OEM to EEA. The is a sole responsibility for the monitoring for the OEM .

M5 Combined monitoring

M5.1 Combined monitoring by Member States and OEMs, i.e. similar to the new system that will apply for N1 vehicles from 2015, i.e. a limited dataset is reported by Member States (i.e. principally VINs for newly registered vehicles and mass of the completed vehicle) complemented by OEM data including VINs + HDV technical data. There is a combined responsibility for the monitoring, i.e. the OEM and Member States.

M5.2 Combined monitoring using the CoC databases and VIN reported by MS for new registered vehicles. The EEA could retrieve the required data directly from the CoC databases). i.e. a network of CoC databases (as discussed in the Ereg/Taam/Eucaris project) or use of Type Approval Databases. There is a combined responsibility for the monitoring, i.e. the Member States and the EEA.

Reporting options

Reporting data – options

R1 Reporting data according the current system for LDVs, but applied to HDVs. The CO_2 emission is reported with standard (semi-)trailer and/or standard body aggregated per vehicle category and per responsible entity (body/person), i.e. manufacturer. CO_2 aggregated per Member State.

R2 Reporting more data. Similar as for option R1 but extended with more data to be reported.
R2.1 Reporting of segregated data, e.g. CO_2 emissions per vehicle segmentation, mission profile as defined for VECTO.

R2.2 Reporting of numbers and specifications of semi-trailers and trailers.

R2.3 Number and specifications of real bodywork are separately reported and presented additional to the technical data and results based on standard bodies. Reporting of number and specifications of bodies of completed vehicles for rigid trucks

R2.4 Reporting of essential characteristics that determine the level of CO_2 emissions of a HDV that was used as input to VECTO or data that determines the utility of a HDV. For instance: technical masses, payload, air drag, information about bodywork, drag-reducing components, information about the tyres, engine, auxiliaries.

Reporting procedure – options

R3 A process similar to that for LDVs, i.e. the publication of provisional data by EEA, verification by OEMs of the provisional data and reporting back to EEA/COM, and the final confirmation of the data either by formal decision or as a report.

R4 A more "light weight process" than R3. Setting up a database by EEA/COM and publication of an annual report by the Commission/EEA.

B Questionnaire distributed to stakeholders

Stakeholder Consultation
Cost-Benefit Analysis of Options for the Certification and Reporting of Heavy-Duty Vehicle Fuel Consumption and CO_2 Emissions
Introduction
Welcome to the Stakeholder Consultation questionnaire for the cost-benefit analysis of options for certification, validation, monitoring and reporting of heavy-duty vehicle fuel consumption and CO_2 emissions.

The time required to complete the survey is approximately one hour. Additionally, selected stakeholders will be contacted to schedule follow-up telephone interviews. Your answers will remain **strictly confidential**, and the results will only be reported to the European Commission under anonymised form (by stakeholder type).

Most questions will be formulated as positive statements. For these questions–marked as **[agree]**–you are asked to specify your level of agreement according to the following scale:

0 = I don't know / no answer
1 = I strongly disagree
2 = I disagree
3 = I neither agree nor disagree
4 = I agree
5 = I strongly agree

A few questions (marked with **[Y/N]**) are simple, yes/no questions. Others require open-ended (numeric or written) input from you (marked **[open])**.

Introductory questions
Background information
a1. First name [open]:
a2. Last name [open]:
a3. Job position [open]:
a4. Organization [open]:
a5. e-mail [open]:

a6. Please indicate the number of employees in your organization (full-time equivalent employees) [open]:

a7. Please indicate the annual revenue of your organization (in EUR, *optional*) [open]:

General questions
Please evaluate the following statements.

b1. I am an expert in vehicle emissions testing [agree]:
b2. I am an expert in vehicle emissions simulation [agree]:
b3. I am an expert in vehicle technology [agree]:
b4. I am an expert in CO_2 regulations [agree]:

b5. I am an expert in HDV fleet operations [agree]:
b6. I am an expert in vehicle type approval/homologation [agree]:
b7. I think monitoring HDV CO_2 emissions is beneficial for the European HDV industry [agree]:
b8. I think monitoring HDV CO_2 emissions is beneficial for the environment [agree]:
b9. I think monitoring HDV CO_2 emissions is beneficial for type approval authorities and technical services [agree]:
b10. I think monitoring HDV CO_2 emissions is beneficial for operators of HDV fleets [agree]:

Questions about CO_2 determination options

Global evaluation of the CO_2 determination options

Please take a minute to read the description of the technical options for the **determination of CO_2 emissions from HDVs** before answering the following questions.

Please evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree).

c1. I have a general preference for option D1 [agree]:
c2. I have a general preference for option D2 [agree]:
c3. I have a general preference for option D3 [agree]:
c4. I have a general preference for option D4 [agree]:
c5. I have a general preference for option D5 [agree]:

c6. I find that option D1 is favourable from the point of view of *cost* [agree]:
c7. I find that option D2 is favourable from the point of view of *cost* [agree]:
c8. I find that option D3 is favourable from the point of view of *cost* [agree]:
c9. I find that option D4 is favourable from the point of view of *cost* [agree]:
c10. I find that option D5 is favourable from the point of view of *cost* [agree]:

c11. I find that option D1 is favourable for *the quality of results* [agree]:
c12. I find that option D2 is favourable for *the quality of results* [agree]:
c13. I find that option D3 is favourable for *the quality of results* [agree]:
c14. I find that option D4 is favourable for *the quality of results* [agree]:
c15. I find that option D5 is favourable for *the quality of results* [agree]:

Option D1: Combination of component testing and simulation/VECTO
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option D1…
d1. …will produce reliable results [agree]:
d2. …will produce transparent results [agree]:
d3. …will produce repeatable results [agree]:
d4. …will produce results that are representative of real-world conditions [agree]:
d5. …will improve stakeholder trust in the reported results [agree]:

Option D1 …
d6. …is a technically sound option [agree]:
d7. …is future-proof [agree]:
d8. …will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
d9. …will foster innovation in HDV efficiency at the *engine* level [agree]:
d10. …will foster innovation in HDV efficiency at the *vehicle* level [agree]:
d11. …is likely to be adopted in other regions of the world [agree]:

Option D1 …
d12. …will be easy to implement in the EU legislation [agree]:
d13. …will increase the administrative burden for my organization [agree]:

Option D1 …
d14. …is a costly option for my organization [agree]:
d15. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (e.g. test equipment, software, new laboratory) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
d16. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
d17. …will require hiring additional staff [Y/N]:
if relevant, indicate estimated additional number of staff in my organization (1 is equivalent to one full-time staff member) [open]:
d18. …will bring new customers to my organization [agree]:
d19. …will increase the revenue in my organization [agree]:
d20. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
d21. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:

d22. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:
d23. …will lower the entry barriers for new competitors to my organization [agree]:

Option D2: Simulation and reduced testing effort
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option D2…
e1. …will produce reliable results [agree]:
e2. …will produce transparent results [agree]:

e3. …will produce repeatable results [agree]:
e4. …will produce results that are representative of real-world conditions [agree]:
e5. …will improve stakeholder trust in the reported results [agree]:

Option D2 …
e6. …is a technically sound option [agree]:
e7. …is future-proof [agree]:
e8. …will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
e9. …will foster innovation in HDV efficiency at the *engine* level [agree]:
e10. …will foster innovation in HDV efficiency at the *vehicle* level [agree]:
e11. …is likely to be adopted in other regions of the world [agree]:

Option D2 …
e12. …will be easy to implement in the EU legislation [agree]:
e13. …will increase the administrative burden for my organization [agree]:

Option D2 …
e14. …is a costly option for my organization [agree]:
e15. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (e.g. test equipment, software, new laboratory) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
e16. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
e17. …will require hiring additional staff [Y/N]:
if relevant, indicate estimated additional number of staff in my organization (1 is equivalent to one full-time staff member) [open]:
e18. …will bring new customers to my organization [agree]:
e19. …will increase the revenue in my organization [agree]:
e20. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
e21. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:

e22. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:
e23. …will lower the entry barriers for new competitors to my organization [agree]:

Option D3: Chassis dynamometer testing
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option D3…
f1.…will produce reliable results [agree]:
f2.…will produce transparent results [agree]:
f3.…will produce repeatable results [agree]:
f4.…will produce results that are representative of real-world conditions [agree]:
f5.…will improve stakeholder trust in the reported results [agree]:

Option D3 …
f6.…is a technically sound option [agree]:
f7.…is future-proof [agree]:
f8.…will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
f9.…will foster innovation in HDV efficiency at the *engine* level [agree]:
f10. …will foster innovation in HDV efficiency at the *vehicle* level [agree]:
f11. …is likely to be adopted in other regions of the world [agree]:

Option D3 …
f12. …will be easy to implement in the EU legislation [agree]:
f13. …will increase the administrative burden for my organization [agree]:

Option D3 …
f14. …is a costly option for my organization [agree]:
f15. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (e.g. test equipment, software, new laboratory) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
f16. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
f17. …will require hiring additional staff [Y/N]:
if relevant, indicate estimated additional number of staff in my organization (1 is equivalent to one full-time staff member) [open]:
f18. …will bring new customers to my organization [agree]:
f19. …will increase the revenue in my organization [agree]:
f20. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
f21. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:

f22. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:
f23. …will lower the entry barriers for new competitors to my organization [agree]:

Option D4: Fuel consumption measurement during real driving
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or

by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option D4…
g1. …will produce reliable results [agree]:
g2. …will produce transparent results [agree]:
g3. …will produce repeatable results [agree]:
g4. …will produce results that are representative of real-world conditions [agree]:
g5. …will improve stakeholder trust in the reported results [agree]:

Option D4…
g6. …is a technically sound option [agree]:
g7. …is future-proof [agree]:
g8. …will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
g9. …will foster innovation in HDV efficiency at the *engine* level [agree]:
g10. …will foster innovation in HDV efficiency at the *vehicle* level [agree]:
g11. …is likely to be adopted in other regions of the world [agree]:

Option D4…
g12. …will be easy to implement in the EU legislation [agree]:
g13. …will increase the administrative burden for my organization [agree]:

Option D4…
g14. …is a costly option for my organization [agree]:
g15. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (e.g. test equipment, software, new laboratory) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
g16. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
g17. …will require hiring additional staff [Y/N]:
if relevant, indicate estimated additional number of staff in my organization (1 is equivalent to one full-time staff member) [open]:
g18. …will bring new customers to my organization [agree]:
g19. …will increase the revenue in my organization [agree]:
g20. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
g21. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:

g22. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:
g23. …will lower the entry barriers for new competitors to my organization [agree]:

Option D5: Simulation and engine testing

Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option D5…
h1. …will produce reliable results [agree]:
h2. …will produce transparent results [agree]:
h3. …will produce repeatable results [agree]:
h4. …will produce results that are representative of real-world conditions [agree]:
h5. …will improve stakeholder trust in the reported results [agree]:

Option D5…
h6. …is a technically sound option [agree]:
h7. …is future-proof [agree]:
h8. …will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
h9. …will foster innovation in HDV efficiency at the *engine* level [agree]:
h10. …will foster innovation in HDV efficiency at the *vehicle* level [agree]:
h11. …is likely to be adopted in other regions of the world [agree]:

Option D5…
h12. …will be easy to implement in the EU legislation [agree]:
h13. …will increase the administrative burden for my organization [agree]:

Option D5…
h14. …is a costly option for my organization [agree]:
h15. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (e.g. test equipment, software, new laboratory) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
h16. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
h17. …will require hiring additional staff [Y/N]
if relevant, indicate estimated additional number of staff in my organization (1 is equivalent to one full-time staff member) [open]:
h18. …will bring new customers to my organization [agree]:
h19. …will increase the revenue in my organization [agree]:
h20. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
h21. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:

h22. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]:
if relevant, indicate the nature of these costs [open]:

if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:
h23. …will lower the entry barriers for new competitors to my organization [agree]:
Specific questions about option D1
Please answer the following questions specifically related to **option D1**.

sp.D1.1. Please estimate the cost (in EUR) for the *air drag test* (constant speed test evaluation) for a single heavy-duty vehicle (relevant to option D1) [open]:
sp.D1.2a. Please estimate the cost (in EUR) for the *transmission test* (determination of efficiency of the drivetrain) for a single heavy-duty vehicle (relevant to option D1) [open]:
sp.D1.2b. Please estimate the cost (in EUR) for the *axle test* (determination of efficiency of the drivetrain) for a single heavy-duty vehicle (relevant to option D1) [open]:
sp.D1.3. Please estimate the cost (in EUR) for the *engine test* (determination of fuelling map) for a single heavy-duty vehicle (relevant to option D1) [open]:
sp.D1.4. I support the possibility of using default values for the air drag coefficient, transmission/axle efficiency and engine maps (relevant to option D1) [agree]:
sp.D1.5. I support the possibility of using default values or a simplified CFD simulation for an optional, second stage certification of multistage vehicles (relevant to options D1 **and** D2) [agree]:
Specific questions about option D2
Please answer the following questions specifically related to **option D2**.

sp.D2.1. Please estimate the cost (in EUR) for the *on-road fuel consumption test* (PEMS of FC measurement) for a single heavy-duty vehicle (relevant to option D4) [open]:
sp.D2.2. Option D2 would significantly reduce the testing effort in comparison to option D1 [agree]:
sp.D2.3. Option D2 would imply a significant loss of accuracy in comparison to option D1 [agree]:
sp.D2.4. Computational fluid dynamics (CFD) simulations (relevant to option D2) are a viable alternative to air drag tests [agree]:
sp.D2.5. Please estimate the cost (in EUR) for the *CFD* simulation to determine the drag coefficient for a single heavy-duty vehicle [open]:
Specific questions about option D3
Please answer the following questions specifically related to **option D3**.

sp.D3.1. Please estimate the cost (in EUR) for the *full-vehicle chassis dynamometer* testing for a single heavy-duty vehicle (relevant to option D3) [open]:
sp.D3.2. Option D3 would significantly reduce the testing effort in comparison to option D1 [agree]:
sp.D3.3. The building of the type approval vehicle families based on a worst-case approach is uncomplicated (relevant to option D3) [agree]:
Specific questions about option D4
Please answer the following questions specifically related to **option D4**.

sp.D4.1. Please estimate the cost (in EUR) for the *on-road fuel consumption test* (PEMS of FC measurement) for a single heavy-duty vehicle (relevant to option D4) [open]:

sp.D4.2. Option D4 would significantly reduce the testing effort in comparison to option D1 [agree]:
sp.D4.3. The definition of boundary conditions for the on-road fuel consumption test is straightforward (relevant to option D4) [agree]:
sp.D4.4. Correction factors for wind and other environmental conditions should be developed as a fundamental element of option D4 [agree]:
Specific questions about option D5
Please answer the following questions specifically related to **option D5**.

sp.D5.1. Please estimate the cost (in EUR) for the *engine test* (transient test) for a single heavy-duty vehicle (relevant to option D5) [open]:
sp.D5.2. Option D5 would significantly reduce the testing effort in comparison to option D1 (engine mapping not required, but an engine dynamometer test is run at the end of the process) [agree]:
sp.D5.3. Option D5 would significantly reduce the testing cost in comparison to option D1 (transient engine testing *vs.* steady state engine mapping) [agree]:

Questions about monitoring and reporting options

Global evaluation of the monitoring options
Please take a minute to evaluate the options for monitoring and reporting the CO_2 emissions from HDVs.

Please evaluate the following statements:

i1. I have a general preference for option M1 [agree]:
i2. I have a general preference for option M2 [agree]:
i3. I have a general preference for option M3 [agree]:
i4. I have a general preference for option M4 [agree]:
i5. I have a general preference for option M4 [agree]:

i6. I find that option M1 is favourable from the point of view of *cost* [agree]:
i7. I find that option M2 is favourable from the point of view of *cost* [agree]:
i8. I find that option M3 is favourable from the point of view of *cost* [agree]:
i9. I find that option M4 is favourable from the point of view of *cost* [agree]:
i10. I find that option M4 is favourable from the point of view of *cost* [agree]:

i11. I find that option M1 is favourable for the *usefulness of results* [agree]:
i12. I find that option M2 is favourable for the *usefulness of results* [agree]:
i13. I find that option M3 is favourable for the *usefulness of results* [agree]:
i14. I find that option M4 is favourable for the *usefulness of results* [agree]:
i15. I find that option M4 is favourable for the *usefulness of results* [agree]:

Option M1
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option M1…
j1.…will produce reliable results [agree]:
j2.…will produce transparent results [agree]:
j3.…will improve stakeholder trust in the reported results [agree]:
j4.…will improve the availability and quality of public data on CO_2 emissions from HDVs [agree]:

Option M1…
j5.…is a technically sound option [agree]:
j6.…is future-proof [agree]:
j7.…will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
j8.…will foster innovation in HDV efficiency at the *engine* level [agree]:
j9.…will foster innovation in HDV efficiency at the *vehicle* level [agree]:
j10. …is likely to be adopted in other regions of the world [agree]:

Option M1…
j11. …will be easy to implement in the EU legislation [agree]:
j12. …will increase the administrative burden for my organization [agree]:

Option M1 …
j13. …is a costly option for my organization [agree]:
j14. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (*e.g.* dedicated server, software) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
j15. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
j16. …will require hiring additional staff [Y/N]:
please indicate current number of staff in my organization [open]:
if relevant, indicate estimated additional number of staff in my organization (*1* is equivalent to one full-time staff member) [open]:
j17. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
j18. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:
j19. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:

Option M2
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option M2…
k1. …will produce reliable results [agree]:
k2. …will produce transparent results [agree]:
k3. …will improve stakeholder trust in the reported results [agree]:
k4. …will improve the availability and quality of public data on CO_2 emissions from HDVs [agree]:

Option M2…
k5. …is a technically sound option [agree]:
k6. …is future-proof [agree]:
k7. …will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
k8. …will foster innovation in HDV efficiency at the *engine* level [agree]:
k9. …will foster innovation in HDV efficiency at the *vehicle* level [agree]:
k10. …is likely to be adopted in other regions of the world [agree]:

Option M2…
k11. …will be easy to implement in the EU legislation [agree]:
k12. …will increase the administrative burden for my organization [agree]:

Option M2 …
k13. …is a costly option for my organization [agree]:
k14. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (*e.g.* dedicated server, software) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
k15. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
k16. …will require hiring additional staff [Y/N]:
please indicate current number of staff in my organization [open]:
if relevant, indicate estimated additional number of staff in my organization (*1* is equivalent to one full-time staff member) [open]:
k17. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
k18. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:
k19. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:

Option M3
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option M3…
I1.…will produce reliable results [agree]:
I2.…will produce transparent results [agree]:
I3.…will improve stakeholder trust in the reported results [agree]:
I4.…will improve the availability and quality of public data on CO_2 emissions from HDVs [agree]:

Option M3…
I5.…is a technically sound option [agree]:
I6.…is future-proof [agree]:
I7.…will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
I8.…will foster innovation in HDV efficiency at the *engine* level [agree]:
I9.…will foster innovation in HDV efficiency at the *vehicle* level [agree]:
I10. …is likely to be adopted in other regions of the world [agree]:

Option M3…
I11. …will be easy to implement in the EU legislation [agree]:
I12. …will increase the administrative burden for my organization [agree]:

Option M3 …
I13. …is a costly option for my organization [agree]:
I14. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (*e.g.* dedicated server, software) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
I15. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
I16. …will require hiring additional staff [Y/N]:
please indicate current number of staff in my organization [open]:
if relevant, indicate estimated additional number of staff in my organization (*1* is equivalent to one full-time staff member) [open]:
I17. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
I18. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:
I19. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:

Option M4
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option M4…
m1. …will produce reliable results [agree]:
m2. …will produce transparent results [agree]:
m3. …will improve stakeholder trust in the reported results [agree]:
m4. …will improve the availability and quality of public data on CO_2 emissions from HDVs [agree]:

Option M4…
m5. …is a technically sound option [agree]:
m6. …is future-proof [agree]:
m7. …will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
m8. …will foster innovation in HDV efficiency at the *engine* level [agree]:
m9. …will foster innovation in HDV efficiency at the *vehicle* level [agree]:
m10.…is likely to be adopted in other regions of the world [agree]:

Option M4…
m11.…will be easy to implement in the EU legislation [agree]:
m12.…will increase the administrative burden for my organization [agree]:

Option M4 …
m13.…is a costly option for my organization [agree]:
m14.…will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (*e.g.* dedicated server, software) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
m15.…will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
m16.…will require hiring additional staff [Y/N]:
please indicate current number of staff in my organization [open]:
if relevant, indicate estimated additional number of staff in my organization (*1* is equivalent to one full-time staff member) [open]:
m17.…will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
m18.…will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:
m19.…will impose additional *variable* costs (per certified vehicle) to my organization [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:

Option M5
Please consult the summary document for a description of this option and evaluate the following statements from 1 (strongly disagree) to 5 (strongly agree) **[agree]** or by indicating *yes* or *no* **[Y/N]**. Questions marked **[open]** encourage you to elaborate on your answers.

Option M5…
n1. …will produce reliable results [agree]:
n2. …will produce transparent results [agree]:
n3. …will improve stakeholder trust in the reported results [agree]:
n4. …will improve the availability and quality of public data on CO_2 emissions from HDVs [agree]:

Option M5…
n5. …is a technically sound option [agree]:
n6. …is future-proof [agree]:
n7. …will foster innovation in HDV efficiency at the *vehicle component* level [agree]:
n8. …will foster innovation in HDV efficiency at the *engine* level [agree]:
n9. …will foster innovation in HDV efficiency at the *vehicle* level [agree]:
n10. …is likely to be adopted in other regions of the world [agree]:

Option M5…
n11. …will be easy to implement in the EU legislation [agree]:
n12. …will increase the administrative burden for my organization [agree]:

Option M5 …
n13. …is a costly option for my organization [agree]:
n14. …will require additional capital investments [Y/N]:
if relevant, indicate the nature of these investments (*e.g.* dedicated server, software) [open]:
if relevant, indicate the approximate monetary value of these investments (in EUR) [open]:
n15. …will require training staff in my organization [Y/N]:
if relevant, indicate the estimated person-days of training required [open]:
n16. …will require hiring additional staff [Y/N]:
please indicate current number of staff in my organization [open]:
if relevant, indicate estimated additional number of staff in my organization (*1* is equivalent to one full-time staff member) [open]:
n17. …will increase the number of activities that are outsourced by my organization [agree]:
if relevant, indicate briefly which activities will likely be outsourced [open]:
n18. …will impose additional *fixed* costs to my organization (excluding additional staff) [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (in EUR) [open]:
n19. …will impose additional *variable* costs (per certified vehicle) to my organization [agree]:
if relevant, indicate the nature of these costs [open]:
if relevant, indicate the approximate monetary value of these costs (per certified vehicle, in EUR) [open]:

Additional questions about monitoring and reporting
o1. The monitoring and reporting of CO_2 values should follow a basic approach using a similar system as for M1 and N1 passenger cars (option M1) and monitor a limited set of data from the CoC [agree]:

o2. The monitoring and reporting of CO_2 values should follow an extended approach using a similar system as for M1 and N1 passenger cars and vans, but use CO_2 determined by VECTO and monitoring more entries or parameters. [agree]:
o3. Which parameters do you think should be monitored? [open]:
o4. Please discuss the added costs of monitoring/reporting these additional parameters [open]:
o5. Technical data from trailers (category O vehicles) should also be monitored [agree]:
o6. Please discuss the added costs of monitoring/reporting data from trailers [open]:
o7. The monitoring should be done as in the current system for LDVs [agree]:
o8. The monitoring should be done by the OEM [agree]:
o9. The monitoring should be done by the OEM and Member States working in combination [agree]:
o10. The monitoring of CO_2 values and additional vehicle parameters should be done using a network of online CoC databases [agree]:
o11. What functionality would you expect from such a database? [open]:
o12. Only basic information should be reported (option R1) [agree]:
o13. Extended data should be reported to follow technical trends more closely (option R2) [agree]:
o14. The reporting should follow the current procedure (option R3) [agree]:
o15. The reporting should follow a light weight procedure (option R4) [agree]:
o16. Please, discuss the benefits/cost relief of a lightweight reporting procedure [open]:

Questions about conformity of production
Options P1/P2/P3
sp.P.1. The determination of conformity of production (CoP) should be done on the basis of individual component testing alone (only the inputs to the simulation are checked, option P1). [agree]:
sp.P.2. The determination of conformity of production (CoP) should be done on the basis of individual component testing *and* a new simulation run (the inputs to the simulation *and* the simulation itself are checked, option P2). [agree]:
sp.P.3. The determination of conformity of production (CoP) should be done on the basis of comparing the results of a simplified track test (or, alternatively, a PEMS test) to a simplified simulation run, option P3). [agree]:

Stakeholder type-specific questions
Please answer the questions for the stakeholder-type that best describes your organization (only answer **one question set**).
Vehicle OEM
sh.A1. Please discuss how the different CO_2 determination options (D1 to D5) would affect the number of vehicle types that you would need to type-approve in a given model year. [open]:
sh.A2. Please discuss previous relevant experience you have had with costs associated with emissions certification and monitoring and reporting. [open]:
sh.A3. Please discuss advantages and disadvantages of the proposed options for monitoring and reporting. [open]:
sh.A4. Please discuss advantages and disadvantages of using CFD simulations instead of the air drag test. [open]:

sh.A5. Would you like to be contacted for a *brief telephone interview* to discuss any other aspects not covered in the questionnaire? [Y/N]:

Component supplier

sh.B1. Please discuss how the different CO_2 determination options that rely on testing (D1 and D5) would affect the costs of supplying input information, and how these costs would be passed on to manufacturers [open]:

sh.B2. Would you like to be contacted for a *brief telephone interview* to discuss any other aspects not covered in the questionnaire? [Y/N]:

Technical service

sh.C1. Please discuss the costs for witnessing the tests within the certification procedure, for accompanying the complete certification process and for the initial assessment [open]:

sh.C2. Please discuss advantages and disadvantages of the proposed options for monitoring and reporting. [open]:

sh.C3. Please discuss advantages and disadvantages of using CFD simulations instead of the air drag test. [open]:

sh.C4. Would you like to be contacted for a *brief telephone interview* to discuss any other aspects not covered in the questionnaire? [Y/N]:

Type approval authority

sh.D1. *If relevant*, please discuss your experience with the type approval of multi-stage vans (MSVs). [open]:

sh.D2. How could information regarding the CO_2 emissions from HDVs be passed on to the Members States vehicle registration? [open]:

sh.D3. Are there additional administrative or legal burdens associated with the certification procedures? [open]:

sh.D4. Please discuss advantages and disadvantages of the proposed options for monitoring and reporting. [open]:

sh.D5. Please discuss advantages and disadvantages of using CFD simulations instead of the air drag test. [open]:

sh.D6. Would you like to be contacted for a *brief telephone interview* to discuss any other aspects not covered in the questionnaire? [Y/N]:

Regulatory agency

sh.E1. Please discuss any problems that may have been encountered in monitoring CO_2 emissions from cars and vans? [open]:

sh.E2. What was the quality of the monitoring of cars and vans in recent years? [open]:

sh.E3. Please discuss advantages and disadvantages of the proposed options for monitoring and reporting. [open]:

sh.E4. Would you like to be contacted for a *brief telephone interview* to discuss any other aspects not covered in the questionnaire? [Y/N]:

Other stakeholder types

sh.F1. Please discuss advantages and disadvantages of the proposed options for monitoring and reporting. [open]:

sh.F2. Please discuss advantages and disadvantages of using CFD simulations instead of the air drag test. [open]:

sh.F3. Would you like to be contacted for a *brief telephone interview* to discuss any other aspects not covered in the questionnaire? [Y/N]:

End of the questionnaire

Thank you very much for your participation! Your feedback is very much appreciated. If you would like to make any further comments or ask questions about this survey or the stakeholder consultation exercise, please provide them below. We will get back to you as soon as possible. [open]:

C Implementation

The following options and sub-options are considerable as basis for a legal implementation:

C1. 2007/46/EC => Type Approval Framework (baseline option, Lot3)

1.1 Amendment to Commission Regulation (EU) No 582/2011 which is an implementing act under Regulation 595/2009 (legal basis Article 5(4)(e)).

- sub-option 1(i): amendment to Annex VIII on CO_2 emissions and fuel consumption;
- sub-option 1(ii): new Annex.

1.2 New Commission implementing act (Regulation) under Regulation (EU) No
595/2009 (Euro VI) (legal basis Article 5(4)(e) of the latter).

1.3 New co-decided Regulation parallel to Regulation (EU) No 595/2009

C2. Standalone Directive

2.1 "New Approach "

2.2 New independent Regulation/Directive

In any case, the certification procedure shall be able to cope with the following exemplary requirements which build the basis for an assessment:

- Certification of the CO_2 determination process or certification of input data to VECTO
- Possibility to introduce simulation to the certification process
- Measures to ensure conformity of production
- Clear definition of responsibilities
- Provisions for all possible HDV configurations (e.g. multi-stage / non-standard bodies, trailers, semi-trailers)
- Measures to validate the CO_2 value after certification
- Build a basis for registration and monitoring of the CO_2 value and other needed information (information documents, Certificate of Conformity (CoC), etc.)
- Third party control

Option C1: Type Approval Framework (baseline option)
Since almost all motor vehicle[31] related EC requirements are regulated by the framework directive 2007/46/EC[32] this well-established Type Approval scheme was considered for the future greenhouse gas certification of heavy-duty vehicles (HDV) with respect to their CO_2 emissions and fuel consumption.

[31] 'motor vehicle' means any power-driven vehicle which is moved by its own means, having at least four wheels, being complete, completed or incomplete, with a maximum design speed exceeding 25 km/h

[32] framework for the approval of motor vehicles and their trailers and of systems, components and separate technical units intended for such vehicles

Beside the fact that the framework directive 2007/47/EC is used since a very long time (its predecessor was directive 70/156/EEC) and for that reason allocated to long-term experiences within the motor industry other reasons are evident for hosting the HDV CO_2 issue under the umbrella of the current framework. Those reasons are:

- Article 3.32 of 2007/46/EC allows making use of simulation based on virtual testing (*virtual testing method*). Since the determination method (VECTO model) considered for the HDV CO_2 explained in the following is based on a calculation model, the *virtual testing method* reference in 2007/46/EC gives adequate freedom for this approach.

- Article 3.27 of 2007/46/EC indicates clearly the responsibility of a *manufacturer* which is considered being the accountable entity for the CO_2 value to be generated. This adds certainty to the procedure and gives clarity to the process which is responsible for the nomination of a particular CO_2 value. It is also clearly stated that it is not essential that the manufacturer need to be involved in all stages of the construction of the vehicle, system, component or separate technical unit. This opens the way to delegate certain tasks of necessary verifications and analysis to supplier and component manufacturer.

- In accordance with Article 12 the manufacturer (as responsible and accountable entity) is obliged to carry out conformity of production (*COP*) measure in order to ensure that production vehicles, systems, components or separate technical units conform to the approved type. This provides an additional requirement within the process to ensure that all vehicles produced are in conformity with the product characteristics specified and certified.

Furthermore, the framework directive 2007/46/EC requires in Article 18 that the manufacturer shall deliver a certificate of conformity (*CoC document*) to accompany each vehicle, whether complete, incomplete or completed, that it is manufactured in conformity with the approved vehicle type. This document (*CoC*) provides an already existing basis for the indication of the HDV CO_2 value.
For passenger cars and light-duty vehicles where a CO_2 declaration procedure is already in force, the CO_2 value is also indicated in the *CoC*. The European type approval scheme for motor vehicles (such as passenger cars, trucks and buses and their trailers) is based, as already mentioned, on the framework directive 2007/46/EC and a large number of technical regulations. The currently applicable Framework Directive on type approval of motor vehicles makes a whole vehicle type approval (WVTA) possible for all categories of motor vehicles and their trailers. For that reason a third party approval is needed for testing, certification and production conformity assessment by a Type Approval Authority (TAA), respectively Technical Service (TS). Each Member State is required to appoint an Approval Authority to issue the approvals and Technical Services to carry out the testing to the applicable EC or ECE regulations (UN). An approval issued by one Authority is accepted in all other Member States. A comparable procedure is given for the applicable ECE regulations where the Contracting Parties are put into a similar role as the EC Member States.

The Framework Directive requires the Member States to take appropriate measures at two stages:

- before granting type approval, the approval authority must verify that the type to be approved complies with the relevant safety and environmental requirements and that adequate arrangements for ensuring conformity of production have been taken by the manufacturer;

- after having granted type approval, the approval authority must verify that the conformity of production (CoP) arrangements of the manufacturer continue to be adequate. This verification must be carried out in accordance with the procedures set out in the Directive, and, where appropriate, with the specific provisions of the relevant Regulatory Acts listed in the Framework Directive. This procedure may be carried out with manufacturers' technical equipment and control programs, but may also be extended to the actual testing of selected production samples.

The type approval approach is based on the proposition that new types of components, systems or vehicles are tested and checked prior to their placing on the EU market. This means the overall approach of approval is based on “prototype stage” testing and verification. Nonetheless, the type approval legislation does not refer only to the prototype stage, but also to the production process through conformity of production (CoP) and registered vehicles through in-service conformity (ISC).
The granted type approval is then applied to such types of vehicles without the need of any confirmation check for each vehicle produced within the type approved specifications. The manufacturer must however certify that each vehicle conforms to the type approved by issuing a certificate of conformity for the individual vehicle. The CO_2 / fuel consumption approach for HDVs as described above is intended to generate a specific CO_2/FC value for each vehicle produced. In this sense the approach differs from the determination of CO_2 emissions from light duty vehicles, where emissions are tested and considered representative for a vehicle type or pre-defined vehicle families. This difference will also have implications for how the certification procedure can be implemented in the type approval framework.

The objective of this study is to analyse whether or in which respects the existing type approval legislation offers an appropriate framework for the implementation of the CO_2 certification procedure outlined above.
Inter alia, this will require consideration of the CoP issue, noticing it is one of the cornerstones of the type approval framework. CoP describes the measures and provisions to be introduced by the applicant for type approval to make sure that his products are produced in accordance with the type approved qualities and performance criteria. The CoP process is typically applied to a type approved value or criteria (by means of a finalised product) to be checked during / after production. The same circumstances are obvious for the CoC. This document usually contains values, characteristics and properties originated from type approval.
To account the above described difficulties and make use of the 2007/46/EC framework two, respectively three options can be considered.

C1 Sub-option 1
Amendment to Commission Regulation (EU) No 582/2011 which is an implementing act under Regulation 595/2009.
In 582/2011, Annex VIII describes already the fuel consumption and CO_2 emission measures to be applied for HDV engines. A new annex could be introduced dealing with the whole HDV vehicle. Nonetheless such a proceeding would cause an engine only regulation to deal with whole vehicle aspect.

C1 Sub-option 2
New Commission implementing act (Regulation) under Regulation (EU) No 595/2009 (comitology)
This would be a new stand-alone technical implementing act (Regulation) dealing with fuel consumption / CO_2 emission of the whole HDV.
It needs to be verified if the legal basis, Article 5(4)(e) of Regulation (EC) No 595/2009, provides the necessary scope.

C1 Sub-option 3
Option 3 deals with a complete new, and for that reason, Regulation adopted under the ordinary legislative procedure, i.e. as a parallel act to Regulation (EU) No 595/2009.
In chapter 2 the possibility of a regulation" adopted under the ordinary legislative procedure (co-decision) was mentioned. This would be the way forward should the legal basis provided in Regulation (EC) 595/2009 not be appropriate for the implementation of the whole HDV CO_2 procedure.

Option C2: Stand-alone directive
The working assumption under this option should thus be to establish such a new regulation outside the type approval framework in order to be able to define new boundary conditions customised to the particular needs of HDV CO_2 certification. There are already existing examples which can be considered. One example for such standalone legislative requirements is Directive 94/25/EC (2003/44/EC) for recreational crafts (also limiting the exhaust gas criteria pollutant for engines to be used on such boats) or Regulation 1222/2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters. Directive 94/25/EC is based on the new approach making use of the CE sign and includes elements similar to the type approval (Notified Body vs. Technical Service).

Option C2.1: New approach
Another possibility to be considered is a regulation under the "New Approach" scheme in accordance with the EC conformity assessment criteria. "New Approach" directives were designed to streamline the certification / approval process for the European market. Such regulations can be configured from labelling of a product by a manufacturer to very challenging provisions similar to the established type approval procedures.

An example for such regulation is Directive 94/25/EC based on the new approach making use of the CE sign. Directive 94/25/EC includes elements very similar to the type approval procedures such as a third party involvement. The inspection bodies involved are so called Notified Bodies and act somehow similar to the Technical Services in the Type Approval framework.

Option C2.2: New independent Regulation/Directive
The possibility of a regulation adopted under the ordinary legislative procedure (co-decision) was mentioned. This would be the way forward, should the legal basis provided in Regulation (EC) 595/2009 not be appropriate for the implementation of the whole HDV CO_2 procedure.

A complete new regulation can be considered also being applied under the type approval framework. The working assumption under this option should thus be to establish such a new regulation in order to be able to define new boundary conditions customised to the particular needs of HDV CO_2 certification.
By detaching the HDV CO_2 certification completely from the type approval framework, which means to create a separate act outside the framework, further work is necessary to define appropriate general conditions. Nonetheless, numerous of the doubtlessly very well established type approval specifications and requirements can be transferred to such a new act. Accountability and responsibility of the applicant as well as the incorporation of Type Approval Authorities and Technical Services are only a few of these well-developed type approval principles. The earlier mentioned need to integrate a CoP process and to make use of the CoC (or similar procedure) can be solved by creating appropriate new provisions for these tasks. Furthermore, the framework of 2007/46/EC need to be slightly adjusted anyhow as long as the mentioned indication of the CO_2 value in the CoC remains necessary. If an additional document for the CO_2 value is contemplated such a slight adjustment is not necessary.
An example for such a “stand-alone regulation” outside an existing framework is Regulation 1222/2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters.