Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

ECOCHAMPS – Project Targets, their Tracking and the Evaluation of the Demonstrator Vehicles

Gunter Nitzsche [a,*], Simon Edwards [b], Eric White [b], Michele De Gennaro [c], Alessandro Tansini [c], Theodoros Grigoratos [c] and Eleni Avaritsioti [c]

[a] *Fraunhofer Institute for Vehicle and Infrastructure Systems IVI, Dresden, Germany*
[b] *Ricardo UK, Shoreham by Sea, UK*
[c] *European Commission – Joint Research Centre, Directorate for Energy, Transport and Climate, Ispra, Italy*

Abstract

The ECOCHAMPS project addresses the topic GV-04-2014 Hybrid Light and Heavy Duty Vehicles under the Horizon2020 programme (GA #653468) and is realized by a 26-member consortium. The overall objectives are to achieve efficient, compact, lightweight, robust and cost effective hybrid powertrains for both passenger cars and commercial vehicles, with increased functionality, improved performance, comfort and emissions levels below Euro 6/VI. In particular, an expected impact of 20% powertrain efficiency improvements and weight plus volume reductions with respect to the best-in-class vehicles on the market in the reference year 2013 is set, whilst having a maximum 10% cost premium. This paper presents the targets and the tracking of the developments of the OEMs and the approach for the final evaluation of the five demonstrator vehicles built by Q1-2018. Moreover the paper also looks towards the development of current and future CO_2 declaration methods for hybrid heavy duty commercial vehicles, supporting the deployment of next generation propulsion technologies for decarbonising freight transport.

Keywords: ECOCHAMPS; Hybridisation; Electromobility; Energy Efficiency; Decarbonisation; Emissions; Environmental Impact

* Corresponding author. Tel.: +49-351-4640-621; fax: +49-351-4640-803.
E-mail address: gunter.nitzsche@ivi.fraunhofer.de

Nomenclature

BIC	Best-in-Class	KPI	Key Performance Indicator
BOM	Bill of Material	LD	Light Duty
DCT	Dual Clutch Transmission	NVH	Noise, Vibration and Harshness
EUR	End User Requirement	OEM	Original Equipment Manufacturer
EV	Electric Vehicle	PHEV	Plug-in Hybrid Electric Vehicle
HD	Heavy Duty	SILS	Software in the Loop Simulation
HILS	Hardware in the Loop Simulation	SoA	State of the Art

1. Introduction

In the European Union (EU), transport contributes to nearly one-third of the CO_2 emissions and is the only major sector where emissions increased over the last decade (European Commission Website, 2013). The EU accounted for 35.3 billion tonnes CO_2-equivalent emissions in 2013 (European Commission Joint Research Centre, 2015), with more than 11 billion tonnes coming from transport, of which 72% from road transport. This shows the need to take action in CO_2-reducing technologies, especially in the transport sector. The ECOCHAMPS project incorporates a consortium that is collaborating to develop efficient, compact, lightweight, robust and cost effective hybrid powertrains for both passenger cars and commercial vehicles, with the aim of enabling a leading position in hybrid technology and increase the competitiveness of European road vehicle manufacturers. This project responds to the call GV-04-2014 Hybrid Light and Heavy Duty Vehicles under the Horizon2020 programme (GA No. 653468). This call has the expected impact of a 20% powertrain efficiency improvement and a 20% powertrain weight and volume reduction with respect to the 'best in class' full hybrid vehicles on the market in the reference year 2013, whilst having a maximum 10% cost premium over the models upon which the demonstrators are based. These have been used to derive 'Technical Targets' for the demonstrator vehicles. It should be noted that the specific targets and reference vehicles vary from one demonstrator to another, due to the wide range of vehicles considered. The vehicles range from small passenger cars to a medium duty truck, city bus and long haul truck. The achievements will be demonstrated at the end of the project (Q1 2018), with at least one vehicle per category delivered at Technology Readiness Level 7, i.e. "system prototype demonstration in operational environment".

The overall objective of the ECOCHAMPS project is to develop the knowhow, intellectual property rights and technical capabilities to adequately and cost-effectively achieve the targets mentioned above. The resulting powertrains will have increased functionality, improved performance and comfort relative to those in the market in 2013 and emission levels below Euro 6 or VI. Amongst other technologies, the powertrains will utilize advanced energy management systems, which are capable of optimally controlling the mechanical, thermal and electric energy flows in the vehicles, making maximum use of other installed features, e.g. thermal energy recovery systems.

In the project, three Light Duty (LD) OEMs (CRF, Renault and Daimler) take part and will build two small passenger car demonstrator vehicles. On the Heavy Duty (HD) side, IVECO builds a small delivery truck, MAN a city bus and DAF a long haul truck. This wide variety of demonstrator vehicles made it necessary to have an independent work package spanning the individual work packages of each OEM, in order to ensure as much consistency as possible and also provide an independent tracking and evaluation. This horizontal work package includes the work of target setting, the tracking of progress and the final evaluation of the demonstrator vehicles against the targets. It is carried out by independent assessors within the ECOCHAMPS project – the so called Golden Engineers. They are technical experts working very closely with the OEM during each stage of the project, nevertheless ensuring an unbiased assessment. The Golden Engineers for LD are provided by Ricardo and for HD by the JRC. Fraunhofer IVI coordinates between LD and HD as independent work package leader.

This paper describes the work carried out by the Golden Engineers. The process is depicted in Fig. 1, in which the main blocks serve as a guideline through this paper. The final evaluation of the vehicle demonstrator is planned for the last part of the project, and the results are not available at the time of the submission of the present manuscript.

In addition, the horizontal work package also includes a review of SoA methods for CO_2 declaration for hybrid heavy commercial vehicles. This activity was carried out by the JRC and is presented in Section 5.

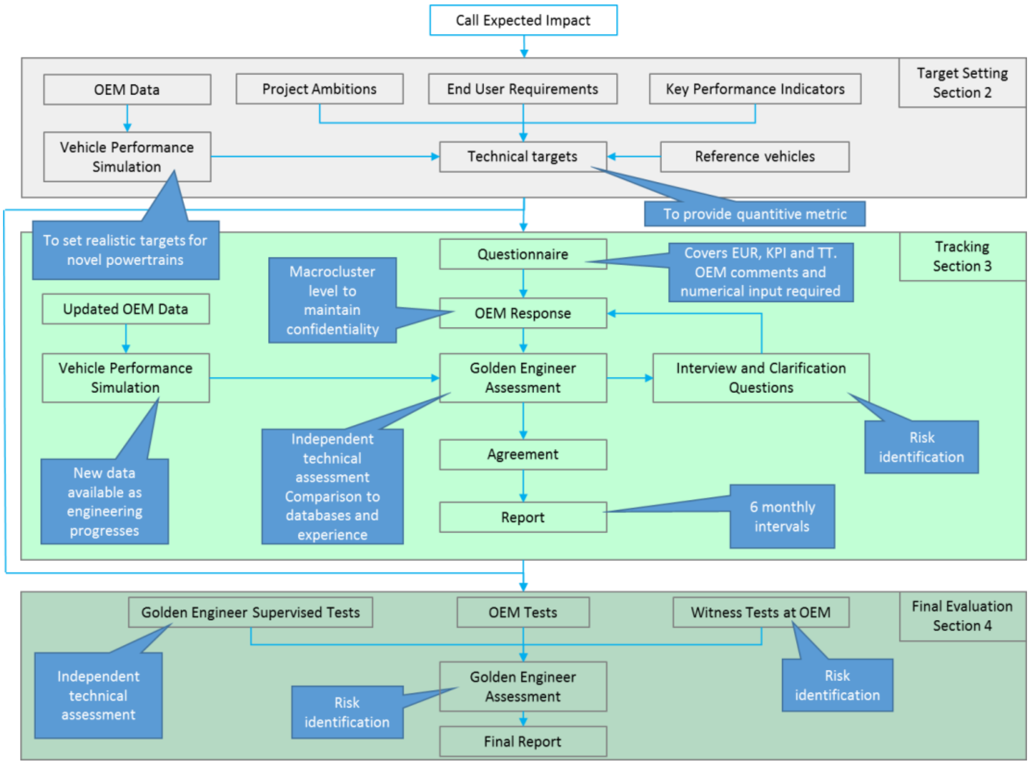

Fig. 1 Process chart of target setting, their tracking and the final evaluation.

2. Target Setting

The project ambition was geared to the expected impact, as per the GV-04-2017 call text. In the starting phase of the project the task of a specific target setting was carried out in order to get to consistent definitions of the targets and corresponding specific targets. For this the ambitions were further refined into End User Requirements (EUR), Key Performance Indicators (KPI) and Technical Targets for each demonstrator, in order to aid the evaluation, see Fig. 1 and in detail Fig. 2. Supporting simulations were used to set feasible yet challenging targets.

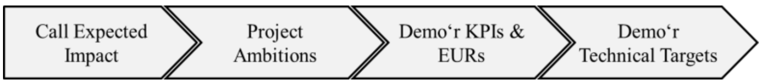

Fig. 2 The process of setting technical targets for the five demonstrator vehicles, based on the call text expected impacts

These three sets of requirements are defined as follows: EURs are taken to represent the consumers’ desires at a mostly qualitative level. In the case of the LD vehicles, the end users are taken to be customers who buy and use the cars, which could also include fleet management companies. In the case of commercial vehicles, the end users are taken to be customers who buy the vehicles for commercial use. KPIs are a technical representation, mostly on quantitative level, for those EURs that require them. The Technical Targets are related to the call expected impacts set by the European Commission and the project ambitions. The Technical Targets are used repeatedly as the reference when tracking the technical progress of the demonstrators. All targets are defined carefully, in order to have, the same understanding over the broad range of vehicles in the ECOCHAMPS project. Nevertheless, the actual target values are distinctive for each demonstrator.

2.1. Choice of Reference Vehicles

When analysing the expected call impacts repeated in the introduction, one notices that some are defined in reference to the best-in-class hybrid vehicle in the market in 2013, whilst others are defined in reference to the conventional vehicle on which the demonstrator is based. Whilst this sounds trivial, a careful choice of the reference vehicles is necessary, taking into account the availability of such, the increased functionality of the demonstrator vehicles and the various peculiarities of the different vehicle classes. The choice of the reference vehicles enables a comprehensive assessment of the advantages for the end customer, compared to the vehicles available in 2013, as well as ongoing development of previous research projects. Some other requirements, e.g. available capacity, are defined relative to a comparable vehicle of the manufacturer.

The donor vehicle for the CRF demonstrator is a FIAT 500X 1.4l MultiAir, MY2015. For this vehicle class, the Toyota Yaris HEV is identified as best-in-class (BIC) powertrain in 2013. However, technology has moved on towards Plug-in Hybrids (PHEV), as the CRF demonstrator will be in order to give a substantially increased powertrain efficiency and vehicle functionality. The increased PHEV battery size, though, also leads to higher costs, weight and volume than in the Yaris. Thus, the battery needs to be differentiated in the comparative analysis.

The donor vehicle for the Renault/Daimler demonstrator is a Renault Megane 1.3l GDI, 6 gear DCT, MY2014. In 2013, the VW Jetta hybrid, 1.4l GDI, 7 gear DCT was the only DCT hybrid vehicle available, hence, it was chosen as the state of the art (SoA) reference. However, this reference hybrid powertrain is at high voltage, whilst the development of the demonstrator is concentrating on the benefits of 48V DCT hybridisation as a cost-effective means for powertrain efficiency improvement. This lower voltage will reduce the amount of hybridisation possible, so a comparison of the benefits and compromises needs to be made. However, when also compared to the conventional powertrain of the donor vehicle, the development may still provide a cost-effective solution.

The donor vehicle for the IVECO demonstrator is an IVECO Daily 7 tonne, 170CV/125 kW, MY2014, based on which a PHEV is developed with a substantially increased performance compared to the donor vehicle. No suitable reference vehicle in this vehicle class could be identified as available in the market in 2013. Thus, two other references have been chosen to show the improvements achieved in the ECOCHAMPS project. The increase in powertrain efficiency is shown relative to the donor vehicle itself, whilst the weight and volume reduction of the electrical components are compared to the pure electric Daily 5 tonne, MY2014, being the conventional one not applicable in this case.

The donor vehicle for the MAN demonstrator is a MAN Lion's City Hybrid, MY2016. The 2013 version of the same city bus is considered to be the best-in-class and is, therefore, chosen as the reference vehicle. As the donor vehicle already is a hybrid vehicle, the cost target will be compared to this, showing a cost decrease.

The donor vehicle for the DAF demonstrator is a DAF XF FT, MX-11 320 kW, MY2017. No hybrid long haul truck was available in the market in 2013, hence other suitable references needed to be chosen. Similarly to IVECO, the conventional fuel DAF XF FT, MX-13 340 kW, MY2013 was chosen to show the increase in powertrain efficiency. A suitable reference for powertrain weight and volume was found in the DAF XF FT demonstrator from the FP7 CONVENIENT project[1]. Due to ongoing developments in hybrid technology, a decrease in powertrain weight and volume was likely on the basis of this previous EU project.

2.2. Target Definition

2.2.1. End User Requirements

As described above, the EURs are mostly qualitative customer's desires given in general descriptions, because end users are not considered to be technical experts. Examples for those requirements are given in Table 1. Some requirements, such as reliability, are included to ensure consideration of those topics. Nevertheless, they are not investigated in detail in this project, because this is not feasible at a demonstrator vehicle level, which has not the maturity level of a serial production vehicle.

Table 1 Examples of EURs for the different demonstrator vehicles

EUR	CRF	Renault/Daimler	IVECO	MAN	DAF
Costs	Cost of ownership lower than donor vehicle	Max. 10% premium over donor vehicle (cost of acquisition)	Cost of ownership lower than donor vehicle	Lower than SoA vehicle	Cost of ownership lower than donor vehicle
Fuel Consumption	Lower than SoA	Lower than SoA	Lower than donor vehicle	Lower than SoA	Lower than SoA
Emissions	--------- Below Euro 6b --------			--------------- Below Euro VI ---------------	
Performance	------------------------------ Equal or better than donor vehicle ------------------------------				
Available Capacity	--- Sufficient ---				
Reliability	----------------------------- Equal or better than industry practice -----------------------------				

[1] http://cordis.europa.eu/project/rcn/105749_en.html

2.2.2. Key Performance Indicators

KPIs are defined to quantify EURs as needed. They provide actual metrics to evaluate against, where those are not given by the EURs alone, as can be seen from Table 1. Whilst some EURs only needed to be defined with a specific value to become a KPI, some EURs needed to be split in separate KPIs. E.g., Available Capacity was defined with clear numbers, which are considered to be 'sufficient'. The Performance EUR was divided further, e.g. into maximum speed, acceleration, charging time (where applicable), gradeability and pure electric range (where applicable).

Table 2 Examples of KPIs for the different demonstrator vehicles that are not discussed as Technical Targets

KPI	CRF	Renault/Daimler	IVECO	MAN	DAF
Electric Range	25 km	n/a	20-40 km	5 km	1.5 km
Available Capacity	<0.1 m^3 loss	<0.1 m^3 loss	> 80% of SoA	≥ 78 passengers	< 300 kg decrease compared to donor vehicle

2.2.3. Technical Targets

The starting points for setting the Technical Targets were the call expected impacts. The impacts were reviewed and put in perspective related to powertrain and vehicle development trends. This was done for all mentioned targets, but for the sake of brevity only powertrain efficiency vs. vehicle cost is depicted in Fig. 3. It can be clearly seen that the expected impact lies well ahead of the curve of general development trends. So achieving all expected impacts at once seems unachievable. Therefore, the demonstrators have different focus areas of improvement. Simulations were already used during this stage to define realistic targets for the demonstrator vehicles. They were carried out by the Golden Engineers, e.g. Ricardo, the OEMs themselves or other project partners, e.g. ika.

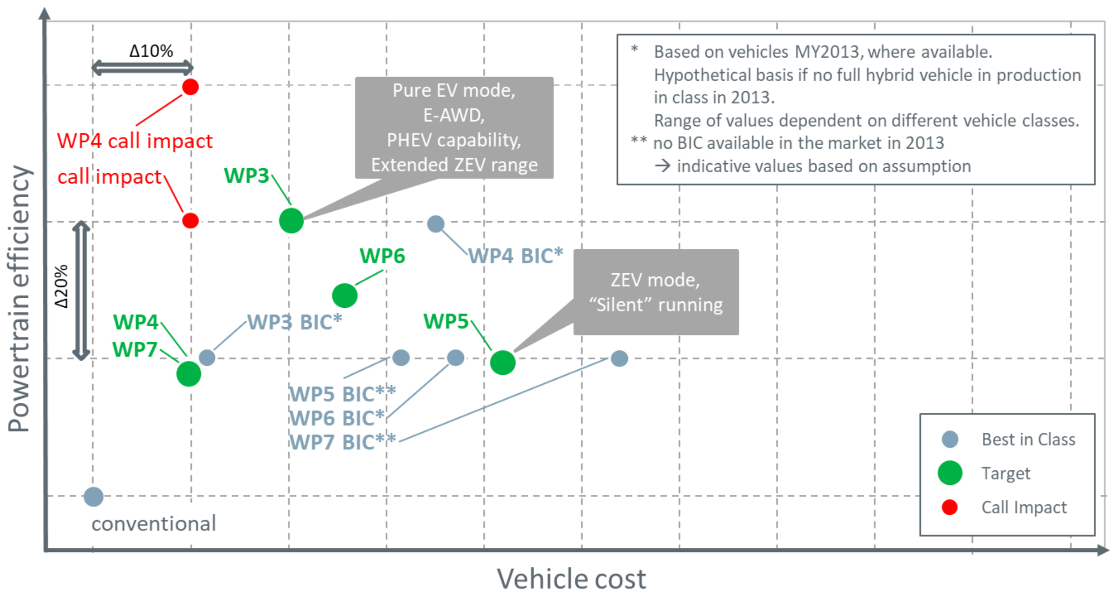

Fig. 3 Powertrain efficiency versus vehicle cost trade-off

The **CRF** plug-in demonstrator focusses on the improvement of powertrain efficiency and additional functionality like pure electric driving, whilst limiting cost to current best in class (BIC) hybrid vehicles. The selection of a plug-in powertrain concept leads to higher mass and volume compared to mild hybrid solutions, but provides substantially higher powertrain efficiency and pure electric range. Those two aspects are more highly appreciated by the typical end customer of a small passenger car than the mass and volume of the powertrain, as long as it does not impair passenger and luggage space, which is ensured by an appropriate KPI.

The **Renault/Daimler** 48V demonstrator focusses on equivalent powertrain efficiencies as BIC hybrids, but at lower cost. The lightweight 48V technology will help to meet the powertrain weight and volume target.

The **IVECO** plug-in delivery van demonstrator focusses on an improved powertrain efficiency and additional functionality, like pure electric driving, whilst not giving up the flexibility of the vehicle, which is needed for daily delivery business – both urban and extra-urban. The drawback of the necessary high battery capacity are costs on the high end of the BIC spectrum.

The **MAN** city bus demonstrator takes powertrain efficiency and costs as equal targets. As a result, a homogeneous progress from the current SoA vehicle towards the call expected impacts is pursued. Furthermore, a modular powertrain concept is introduced, which allows for an easy adaptation for different fuels.

The **DAF** long haul demonstrator targets CO_2 emissions by an increased powertrain efficiency compared to the conventional vehicle. Besides the environmental effect, the total cost of ownership is reduced by limiting the hybrid cost premium with the used powertrain concept. This is of great importance for the typical customer. The resulting Technical Target values are compiled in Table 3.

Table 3 Overview of the Technical Targets for the five demonstrator vehicles

Technical Target	CRF	Renault/Daimler	IVECO	MAN	DAF
Powertrain Efficiency	+20% vs. SoA	+20% vs. Megane gasoline	+20% vs. Daily Diesel	+10% vs. SoA	+20% vs. DAF XF Diesel
Powertrain Weight/Volume	+5% vs. SoA w/o battery	-20% vs SoA	-20% vs. Daily Electric	-10% vs. SoA	-5% vs. FP7 Convenient
Hybrid Cost Premium	15-20%	10%	40%	-10% vs. SoA	10%
Emissions	< Euro 6b	< Euro 6b	< Euro VI	< Euro VI	< Euro VI

3. Tracking

As part of the project risk mitigation strategy, the development of the demonstrator vehicles was tracked by the Golden Engineers, who used questionnaires and interviews with the OEM. In parallel, vehicle powertrain efficiency simulations were used to recognize deviations from the project targets as early as possible, see Fig. 1. The tracking process focused on the technical targets, but compliance to the project KPI and EUR was assessed too.

A questionnaire was developed to enable efficient exchange of technical and progress information including numerical grading from the OEM per each project semester. Questions were based on the established EUR, KPI and Technical Targets and designed to report the technical progress against these metrics. Further to this, for each question posed, the OEM was asked to indicate their confidence in achieving their progress claims and to provide evidence to support those claims.

To provide guidance for completing the questionnaire, and ensure a fair and even scoring system between each OEM, a numerical scoring structure was devised based on generic engineering activities normally associated with delivery of a prototype road vehicle demonstrator. Different scoring criteria were developed for different technical aspects as the technical gateways differed. This approach enabled the OEM to align their progress with an appropriate scoring value, to be used in the questionnaire response. An example of this is provided in Table 4.

Table 4 Example of scoring guidance used in questionnaire

Certainty (%) [For categories where initial simulation leads to proving tests]		
1	= untested	No data available / start of the project
20	= 1D simulation	e.g. model of motor at one operating point
40	= Full simulation	e.g. model of motor simulated over full drive cycle
60	= Robust simulation	e.g. real drive cycle for complete powertrain
80	= Verified on a test rig	e.g. gearbox and motor on a test rig and tested over a real cycle
100	= Verified in vehicle	e.g. complete powertrain built into vehicle and tested over a real cycle

The Golden Engineers analysed the OEM responses to the questionnaires and consulted internally with their company technical specialists, to ensure a robust assessment. This inevitably led to a list of further questions, to clarify any uncertain points and obtain further information.

To manage sensitive information, it was necessary that the OEM approved shared information. In the majority of cases this was successful as information was shared at macrocluster level, effectively concealing the confidential detail. However, in practice cost information could not be shared despite signed confidentiality agreements between the companies. So, the Golden Engineer resorted to use a database of known costs for similar hardware, developed independently of ECOCHAMPS, to compare to the technical target and the OEM claim.

Simulation models developed at the target setting stage were updated and used throughout the tracking task as new data became available, through physical tests such as transmission bench tests for example. In this way, the accuracy of the predictions evolved throughout the project, which, in turn, managed the technical risk as the project progressed. Ricardo conducted simulation for the LD powertrains; ika for DAF; while MAN and IVECO conducted simulation for their own vehicles.

In order to visualize the data and protect confidentiality in the wider audience, “spider web’’ diagrams depicting OEM progress relating the five technical targets were created, one per demonstrator vehicle. The diagrams represent the grade of target fulfilment where the inner blue pentagon represents the State of the Art for each target; the red outer pentagon represents the ECOCHAMPS targets; the green pentagon the assessment of the demonstrator vehicle at that time. If the green pentagon coincides with the red one, all targets are (expected to be) fulfilled on completion of the project. Fig. 4 provides an example.

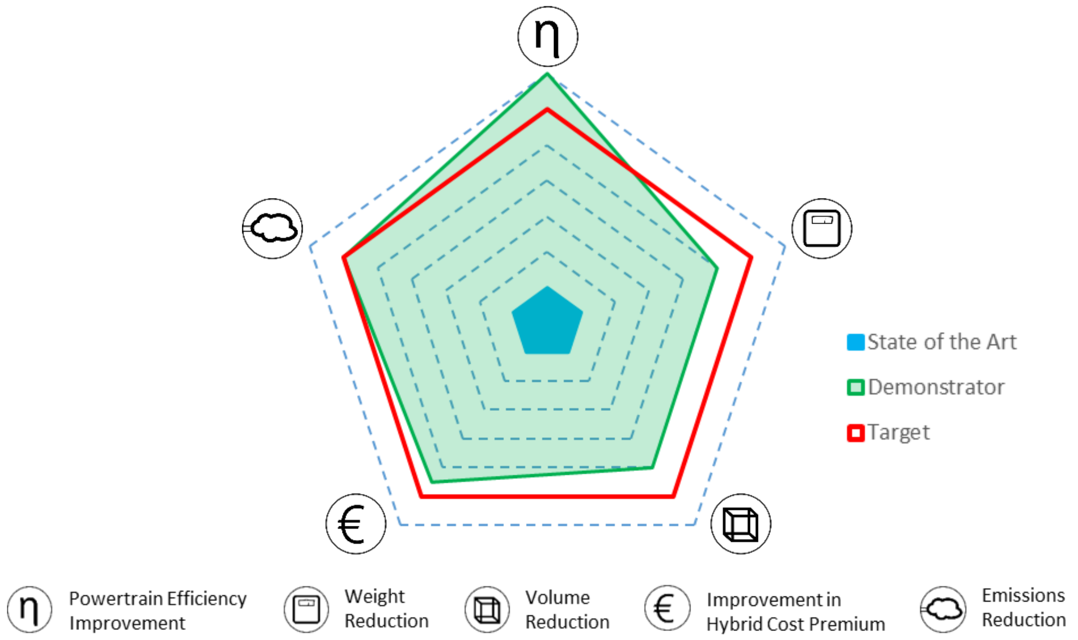

Fig. 4 Example Spider Web Diagram for the tracking of the five Technical Targets for an individual OEM demonstrator

Originally, it was planned to include certainty in these graphs, to show the reduced project risk as engineering progressed. However, this idea was abandoned, because it made the diagram difficult to interpret. Nevertheless, the Golden Engineers still included certainty in their assessments, and provided a written statement on the confidence associated with achieving the project targets with the demonstrator vehicles in the reports. Assessing also the certainty is a crucial thing in the tracking process to highlight the level of maturity of the data, especially in the beginning of the project, where certainty is low. During the course of the project both the changing projected outcome of the targets and the increasing certainty in those projections can be presented.

Although, the tracking task caused additional effort, it helped to collect information on the demonstrator vehicles on a regular basis (six months). The resulting discussions also laid the basis for setting up the final evaluation. The tracking approach, including the Golden Engineer concept, proved effective for the ECOCHAMPS project and was a valuable method to report on the status of the development of the five demonstrator vehicles to the project management and to the European Commission.

4. Final Evaluation

The final evaluation is an assessment by the Golden Engineers based on the results from a series of tests designed to assess compliance against the Technical Targets, KPI and EUR, see Fig. 1. The OEM will perform their own tests as part of their individual project deliverables, while the Golden Engineer has specific tests required to provide evidence of compliance, where not covered by OEM tests. The Golden Engineer attends some of these tests as an independent witness. The objective is to compile sufficient evidence to independently confirm the demonstrator vehicle performance relative to project targets. Some of the test results also serve to enable validation of the simulation models used throughout the project.

A method to obtain evidence was either established very early in the project or prepared by the Golden Engineer prior to the evaluation exercise. This information was shared with the OEM in advance of the final evaluation, to ensure sufficient visibility and preparation time. The evaluation methods consisted of standard engineering tests (measurement of powertrain efficiency over the NEDC (New European Driving Cycle) for example); qualitative measurements (performance; volume; mass assessments though measurement) and some subjective (NVH, comparison to base vehicle for example).

Confidentiality was a major concern during the preparation phase of the final evaluation. A compromise needed to be found between sufficient information provided to the Golden Engineer for the assessment, and existing confidentiality requirements. This resulted in agreements, which data is going to be shared, which can be checked on-site and for which tests only the methodology can be assessed, e.g. by witnessing of the test. This information was included in the description of the evaluation method, which in the end served as a guide and checklist through the final evaluation process.

The results of the final evaluation will be completed in the months immediately preceding TRA 2018. Therefore, these results will be presented at the conference.

5. Enhancement of CO_2 declaration methods for Hybrid Heavy Commercial Vehicles

One third of the CO_2 emissions in the transport sector originates from HD vehicles (European Commission, 2015), representing 9.2% of total inland surface passenger transport and 74.9% of total inland surface freight transport. Recent data shows that over the last years the energy demand and CO_2 emissions of the HD vehicle sector increased, possibly overtaking LD vehicles in the next decade (Fontaras, et al., 2016). In order to move towards the full sustainability of the transportation system, new technologies with fuel saving potential need to be developed. Hybrid powertrains (hybrid-electric, plug-in hybrid-electric, hybrid-hydraulic) are one step in this direction and may help to significantly reduce the carbon footprint of the commercial vehicle fleet in the future. However, commercial powertrains face unique regulatory challenges due to the wide range of vehicle sizes, configurations and in-use duty cycles that characterize HD vehicles. In fact, in order to represent this diversity best, current regulations for conventional powertrains focus on engine test procedures to prescribe the allowable mass of emissions per unit of engine work (g/kWh), rather than the emissions mass per driven distance, as for light duty vehicles. In this framework, hybrid powertrains introduce even more diversity by employing an additional energy source with interactions between the conventional engine and the hybrid components. Thus, the solutions for declaring carbon emissions adopted for conventional fuel vehicles may not return a representative picture for hybrid powertrains, calling for the development of alternative methods for CO_2 declaration.

Within the horizontal activities of the ECOCHAMPS project, the JRC embarked on a preliminary technical screening of possible methods to enhance CO_2 declaration of hybrid heavy duty vehicles. This activity has been carried out in parallel with the study commissioned by DG CLIMA to the Technical University of Graz (TUG), i.e. "Feasibility assessment regarding the development of VECTO for hybrid heavy-duty vehicles", and considering the input from the simulation approaches used by ECOCHAMPS partners. These two contributions are acknowledged, although the results of this technical screening presented below constitute the JRC's independent opinion on the subject. Within this task, three groups of methods for CO_2 declaration for Hybrid Heavy Commercial Vehicles have been identified:

- virtual methods, i.e. crediting scheme, VECTO (stand-alone) and VECTO enhanced with SILS/HILS;
- physical tests (on the bench), i.e. engine and powertrain in-the-loop;
- full-vehicle tests, i.e. chassis-dyno and on-road testing.

The results of the technical screening carried out at the JRC are summarised in Table 5. Here qualitative ratings have been assigned to each criteria, with "+" meaning "low" and "+++++" meaning "high". Note that "low" and "high" might assume a positive or negative meaning depending on the context, therefore this information is enriched with colours according to the legend below the table.

Table 5 Results of the JRC technical screening of possible methods for enhancing CO_2 declaration methods for Hybrid Heavy Commercial Vehicles.

	Method	Simulation-based	Hybrid part simulated	Effort for development of certification procedure	Capital investment for test facilities	Effort for certification test	Expected accuracy
Virtual Methods	Crediting scheme	yes	no	+++ (neutral)	+ (positive)	+ (positive)	++ (negative-to-neutral)
	VECTO (stand-alone)	yes	yes	+++ (neutral)	+ (positive)	++ (neutral-to-positive)	++++ (neutral-to-positive)
	VECTO with Software-in-the-Loop (SILS)	yes	yes	++++ (negative-to-neutral)	++ (neutral-to-positive)	+++ (neutral)	+++++ (positive)
	VECTO with Controllers-in-the-Loop (HILS)	yes	yes	++++ (negative-to-neutral)	++ (neutral-to-positive)	+++ (neutral)	+++++ (positive)
Physical Tests (on-the-bench)	Engine-in-the-Loop	mixed	Depends on architecture	+++++ (negative)	+++ (neutral)	++++ (negative-to-neutral)	++++ (neutral-to-positive)
	Powertrain-in-the-Loop	mixed	no	++++ (negative-to-neutral)	++++ (negative-to-neutral)	++++ (negative-to-neutral)	++++ (neutral-to-positive)
Full Vehicle	Chassis dyno testing	no	no	++ (neutral-to-positive)	+++++ (negative)	+++++ (negative)	+++++ (positive)
	On-road testing	no	no	++ (neutral-to-positive)	++ (neutral-to-positive)	++++ (negative-to-neutral)	+++++ (positive)

Legend

negative (red)	negative-to-neutral (orange)	neutral (yellow)	neutral-to-positive (light green)	positive (green)

The results indicate that the virtual methods might be a valuable candidate for CO_2 declaration purposes of hybrid heavy duty vehicles, with increasing accuracy from VECTO stand-alone to VECTO enhanced with SILS/HILS, despite an increase in effort for development and execution of the certification tests. Software-In-the-Loop testing (SILS) is, in particular, a very promising method, implying the use of a tool for full vehicle simulation that allows for the inclusion of OEMs-proprietary software. This software can be provided by the OEM under a non-disclosure agreement for the type-approval test. Hence SILS can be, ultimately, more desirable than HILS, allowing for a leaner procedure which does not include major hardware components. On the other hand, physical tests on the bench demand high efforts for development and certification, thus resulting less attractive. These, in fact, are not viable due to limited time available for their implementation, high effort needed for the development of the testing procedure and small benefit to the accuracy of the method in comparison to other solutions. Moreover, in the case of Engine-in-the-Loop testing, some engines will be type-approved equipped together with their hybrid components while some others are not, depending on the architecture of the hybrid system. This would make this option the least desirable. Additionally, full vehicle tests require relatively low efforts for development, higher efforts for certification and good accuracy too. The on-road testing is, in general, more desirable than chassis-dyno due to the lower capital investment, and it can be a valuable candidate for the validation of the virtual methods, although some scattering of the results can be expected due to the variability of the on-road conditions.

Therefore, based on the analysed data, the best solution for CO_2 declaration points in the direction of VECTO enhanced with SILS/HILS combined with full vehicle on-road testing for validation of the simulation results and for in-service conformity check purposes. Noticeably both methods could be used together, and each of them does not exclude the other. VECTO enhanced with SILS/HILS can be used in tandem with on-road full vehicle testing for vehicle certification, while on-road full vehicle testing can be sufficient for in-service conformity checks.

Note that the contents of this report are purely explorative: they are not intended to be considered conclusive, neither as an indication nor a position from the JRC, on the methods that need to be applied in future certification of Hybrid HD vehicles. However, they aim at informing future regulatory processes on the subject, in view of supporting the development of future hybrid heavy duty market. More details are provided in the full report, (Tansini, Grigoratos, & De Gennaro, 2017).

6. Conclusions

Adding a horizontal work package within the ECOCHAMPS project and assigning Golden Engineers to independently track the progress of the OEM has been successful; the questionnaires and OEM interviews collated sufficient information for the Golden Engineer to confidently report on the status of the OEM work packages. These regular updates helped to report the development status within the project and to the European Commission. In addition, the process ensured and improved where needed the common understanding of the project targets.

Simulation played a key role during target setting, but also in monitoring progress. In addition, simulation proved a valuable tool for assessing the likely impact of various technical choices available to the OEM, from gear ratios to optimise energy recovery to the contribution of thermoelectric generators fitted to exhaust systems. Nevertheless, physical testing of the developed demonstrator vehicles, e.g. on chassis dynamometers, was used for the final evaluation of the targets as well as simulation model validation.

One of the challenges of the tracking has been the ability of the OEM to share data, even at macrocluster level – especially cost data. This limited the tracking effort to comparisons conducted by the Golden Engineer for this particular metric. The issue is further complicated as the technical target for this is based on price to the end customer. As such, company accountancy and marketing influence the magnitude of the '10% premium' target, which contributes to confidentiality aspect.

Concerning the heavy commercial vehicles, hybrid technology adds new challenges for CO_2 declaration. Within the ECOCHAMPS framework, the JRC embarked in a preliminary technical screening of possible methods to overcome these challenges, analysing pros and cons of virtual methods, physical tests and full-vehicle tests. The results, although not conclusive, highlights that virtual methods offer indisputable benefits in terms of low capital investment and effort for certification, and that they could be an effective solution to pair up with full vehicle tests, that provide, ultimately, the most accurate outcomes. On the contrary physical tests on the bench, i.e. engine and powertrain in-the-loop, seem to be the least attractive solution.

The ECOCHAMPS project as a whole, with its particular OEM work packages, increased the competitiveness of European road vehicle manufacturers through the development of efficient, compact, lightweight, robust and cost effective hybrid powertrains. The developments span the vehicle range from small passenger cars to a medium duty truck, a city bus and a long haul truck – all with its particular challenges.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme und grant agreement No. 653468.

References

European Commission. (2015). *Climate Action: Road transport: Reducing CO2 emissions from vehicles.* Retrieved November 2015, from http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm

European Commission Joint Research Centre. (2015). *EDGAR Home Page: Emission Database for Global Atmospheric Research*. Retrieved November 2015, from http://edgar.jrc.ec.europa.eu/

European Commission Website. (2013). Retrieved October 2016, from http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm

Fontaras, G., Grigoratos, T., Savvidis, D., Anagnostopoulos, K., Luz, R., Rexeis, M., & Hausberger, S. (2016). An experimental evaluation of the methodology proposed for the monitoring and certification of CO emissions from heavy-duty vehicles in Europe. *Energy*, 354-364.

Tansini, A., Grigoratos, T., & De Gennaro, M. (2017). *Proposal on the enhancement of CO2 declaration methods to support Hybrid Commercial Vehicles.* ECOCHAMPS Deliverable 1.4 (public).