Flexible calculation approaches to support the European CO2 emissions regulatory scheme for road vehicles

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Abstract:
The thesis presents the activities carried out, in collaboration with the Sustainable Transport Unit (STU) of the European Commission's Joint Research Centre (JRC), for the development and validation of calculation tools to quantify the CO_2 emissions from road vehicles, both Light-Duty Vehicles (LDVs) and Heavy-Duty Vehicles (HDVs). In Europe, calculation tools take part in the certification process of CO_2 emissions from road vehicles. Additionally, calculation tools are used to support studies for the development of the regulations. The Vehicle Energy Consumption calculation Tool (VECTO) was adopted in Europe to quantify the CO_2 emissions from HDVs (only trucks currently, buses and coaches to be included in the future). The CO_2 Model for PAssenger and commercial vehicles Simulation (CO_2MPAS) was adopted to handle the so-called correlation process, calculating the NEDC-equivalent CO_2 emissions for all the LDVs certified in Europe in the transition period between the NEDC and WLTP procedures (2017-2020). These two calculation tools constituted the foundations of the research activities of the PhD Programme, on top of which further assessments, validations and developments are carried out. Additionally, other CO_2 emissions evaluation approaches were derived based the two calculation tools. The first activity regarded extension of the VECTO-based certification procedure. Following the adoption of Commission Regulation (EU) 2017/2400 regarding the CO_2 determination methodology for trucks, DG CLIMA and DG GROW requested to launch a test campaign to investigate the validity, accuracy and plausibility of the application of the methodology to buses and coaches. Experiments were conducted on one interurban bus and one coach, both on the chassis dynamometer and on the road. Vehicle air drag physical determination through experiments, and the use of the specific calculation tool (VECTO Air Drag), were the aspects for which this PhD Programme gave substantial contribution. Air resistance, which is one of the aspects with higher impact on fuel consumption for HDVs, is evaluated through the constant speed test as described in Commission Regulation (EU) 2017/2400 and is mandatory to produce VECTO input data. The study confirmed the accuracy and applicability of the methodology for air drag and overall CO_2 emissions evaluation to buses and coaches. During year 2017, DG CLIMA asked the STU to create a baseline of CO_2 emissions for the regulated vehicles of the HDVs fleet (groups 4, 5, 9 and 10). The activity provided valuable input for drafting the regulation on HDVs CO_2 emissions standards (EU 2019/1242). For this purpose, the STU was provided with VECTO simulation data of vehicles registered in the year 2016. The exercise produced a database of about 1.7 million rows and 120 columns. The activity included four main phases:

1. Database preparation
2. Statistical market analysis
3. Input data quality analysis and components losses characterisation
4. Creation of the HDVs CO_2 emissions baseline

The main outcome of the activity consists of the distributions of CO_2 emissions per vehicle group and cycle-loading combination. Furthermore, the approach developed for obtaining the fleet CO_2 emissions, normalised for input data quality, constitutes a solution for controlling and possibly normalise the data obtained from manufacturers through the monitoring and reporting scheme. Based on this approach, a new fleet normalisation approach is being developed by the STU for the creation of the baseline for year 2020 that will be used to check CO_2 emissions compliance in the years 2025 and 2030.
In addition to the normalisation approach, other two CO_2 emissions calculation methodologies were developed that can be used for verification purposes. The first one consists of an input-data generation model (components losses maps and engine fuel consumption map) that produces fleet-representative cases for VECTO simulation. The second one rather relies on correlation formulas, derived from VECTO data, to calculate directly the overall energy consumption with no use of simulation.
The activities carried out in the framework of LDVs CO_2 emissions regarded Hybrid Electric Vehicles (HEVs) exclusively. Due to the uptake of electrified vehicle powertrains, CO_2MPAS needed to be extended in order to capture the operation and the associated fuel savings. For this reason, a generic simulation strategy needed to be developed and implemented into the model of CO_2MPAS. A generic simulation strategy for HEVs was also needed for other applications, e.g. traffic simulations or studies (impact assessments, creation of scenarios, etc.). To increase the level of understanding and create a

database for validation, several vehicles with different hybrid powertrain architectures (serial, parallel and powersplit) and electrification levels (mild, full, plug-in and range extender) were tested. The tests were carried out at vehicle-level, without tearing down the vehicle to individually test the components for their characterisation. A combination of vehicle signal logging and physical measurements was adopted to obtain a detailed picture of the powertrain operation and reconstruct the energy flow. Lastly, a generic simulation strategy was developed which finds the optimal solution for operating the powertrain according to the Equivalent Consumption Minimisation Strategy (ECMS) principle. A modelling approach for a generic electrical power system (EPS), which includes the batteries, the DC/DC converter, the electric loads and the electric machines was also developed. The governing equations for all the hybrid powertrain architectures were obtained. The strategy was first implemented in the hybrid controller (hycon) and, at a later stage, into CO_2MPAS model. Hycon is a simple tool that was developed to test the performances of the simulation strategy on parallel HEVs; this tool requires that specific input data of the vehicle considered is provided. The results obtained with hycon demonstrated that the simulation strategy is appropriate for obtaining representative values for the instantaneous operation and the overall vehicle energy efficiency. A similar simulation strategy was then implemented into CO_2MPAS, covering all HEVs architectures and electrification levels. It requires a smaller amount of input data than hycon, comparable to that needed for the correlation procedure from the certification of LDVs. Additionally, it is able to self-calibrate the ICE fuel consumption map as for conventional vehicles, although this comes with a lower accuracy with respects to conventional vehicles due to the more challenging calibration process (less calibration points in a restricted area of the ICE map). The outcomes of this PhD programme are a set of experimental observations, analyses and calculation approaches constituting valuable tools for the evaluation of the CO_2 emissions from road transport.