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Fuel and Recharging Effects on Regulated and Unregulated Emissions from a Gasoline and a Diesel Plug-In Hybrid Electric Vehicle

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Abstract

As passenger cars are progressively moving towards more electrification, Plug-in Hybrid Electric Vehicles (PHEVs) may play a greater role. Several questions arise regarding their performance in real-world conditions, their optimal configuration - in terms of battery capacity, fuel and powertrain used - and their pollutant emissions. In this context, two PHEVs complying with Euro 6d standards were evaluated on a chassis-dyno and on-road using the same road profile, complying with RDE requirements. The two vehicles differ only by their powertrain, one being diesel-fueled, and the other being gasoline-fueled. The vehicles were tested under various conditions, including charge depleting and charge sustaining modes (i.e., tests respectively starting with a fully charged battery and a discharged battery), with various fuel compositions including traditional fossil-based fuels, 100% renewable Hydrotreated Vegetable Oil (HVO) and 100% renewable gasoline, blended with 20% v/v ethanol (E20). The vehicle weight was also artificially varied on the chassis-dyno to assess the difference of performance between a PHEV and a Hybrid Electric Vehicle (HEV), having a lower-capacity battery. The set of measurements included fuel and electricity consumptions, CO_2 and regulated pollutant emissions (NOx, CO, HC, PN23, PM) as well as non-regulated pollutant emissions such as PN10, CH_4, NH_3 and N_2O. The results show that the two vehicles have regulated pollutant emissions levels well below the Euro 6d limits under all testing conditions, and unregulated pollutant emissions in the range of Euro 7 proposals. For the PHEVs and operating conditions tested, switching from a traditional fossil-based fuel to a 100% renewable fuel, for both gasoline and Diesel powertrains, does not have statistical significant impact on the pollutant emissions. Regarding fuel and powertrain aspects, it is observed that switching from a gasoline- to a Diesel-PHEV enables a reduction of CO_2 emissions whilst also lowering pollutant emissions except for NH_3 and N_2O. However, on-road tests results show significantly higher fuel consumption than chassis-dyno tests, although being driven on the same test-cycle.

Introduction

Transport related greenhouse gases (GHG) emissions represent approximately a quarter of total EU GHG emissions [1]. In the context of targeting carbon neutrality in 2050 as set by the EU Green Deal [2], reducing transport related GHG emissions represents both an important stake and challenge. The present study focuses on passenger cars only. When considering each vehicle individually, there are several ways to consider their GHG emissions:

- The Tank-to-Wheels (TtW) approach focuses only on the tailpipe emissions;
- The Well-to-Wheels (WtW) approach is more complete and considers the GHG emissions related to the production of the energy carriers;

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2.0% the TtW CO_2 emissions and increases the volumetric fuel consumption by 8.4% on CS.

Reducing the mass of the vehicle surprisingly does not change the consumption or the pollutant emissions: despite weighing 120 kg less, the HEV configuration presents results in emissions and energy consumption very close to the PHEV configuration in CS mode.

The measurements performed on-road show higher fuel consumption and CO_2 emissions. In CS mode, the Diesel vehicle showed a 29% higher fuel consumption and CO_2 emissions on the road compared to the laboratory tests. The gasoline vehicle showed a difference of 13.6%. This gap was investigated using a calibrated simulator (not shown in this article) and explained by a different road law between the roller test bed and the on-road.

Perspectives

The data generated in this study, from RDE driving in the laboratory and on-road, will allow to calibrate a vehicle simulator. It will aim at extending the findings to more varied conditions: trip distance, driving profile, ambient temperature, battery capacity, recharging frequency, etc. By combining these different parameters extensively, statistically representative use cases can be generated and evaluated regarding their fuel and electricity consumption, utility factor and CO_2 emissions. This will be the subject of another article.

Furthermore, TtW CO_2 emissions do not offer a complete picture of the GHG emissions emitted during the life of a vehicle. For this, a broader analysis of the vehicle's life cycle must be determined by considering not only the TtW emissions of the vehicle during its use, but also the WtT emissions related to the energy sources (electricity and fuel productions) and finally the production and end of life of the vehicle itself, including the battery. This assessment is based on many parameters: the CO_2 intensity of electricity production, the CO_2 WtT emissions of different fuel production pathways, the CO_2 emissions related to the production of the vehicles, particularly the battery, the lifetime of the vehicles, etc. These LCA and WtT aspects will be the subject of future work. Additionally, given the quantity of assumptions and their variability, a dynamic LCA GHG tool will be developed, allowing to configure any possible combinations of parameters and to compare PHEVs life-cycle emissions with other levels of vehicle electrification: HEVs and BEVs.

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Definitions/Abbreviations

AFTS - Aftertreatment System

BEV - Battery Electric Vehicle

Bx - Diesel fuel containing max. x% v/v of FAME

CD - Charge Depleting

CH_4 - Methane

CI - Compression Ignition

CN - Cetane Number

CO - Carbon monoxide

CO_2(eq) - Carbon dioxide (equivalent)

CPC - Condensation Particle Counter

CR - Compression Ratio

CS - Charge Sustaining

CVS - Constant Volume Sampling

DOC - Diesel Oxidation Catalyst

DPF - Diesel Particulate Filter

Ex - Gasoline containing max. x% v/v of ethanol

EFM - Exhaust Flow Meter

EGR - Exhaust Gas Recirculation

FAME - Fatty Acid Methyl Ester

FBP - Final Boiling Point

FC - Fuel Consumption

GHG - Greenhouse Gas(es)

GPF - Gasoline Particulate Filter

GPS - Global Positioning System

GWP - Global Warming Potential

(T)HC - (Total) Hydrocarbons

HEV - Hybrid Electric Vehicle

HV - High Voltage

HVO - Hydrotreated Vegetable Oil

ICE - Internal Combustion Engine

IPCC - Intergovernmental Panel on Climate Change

LCA - Life-Cycle Assessment

LV - Low Voltage

NH_3 - Ammonia

N_2O - Nitrous Oxide

NOVC-HEV - Not Off-Vehicle Charging Hybrid Electric Vehicles, simply called HEVs

NO_x - Oxides of Nitrogen

OBD - On-board Diagnostics

OEM - Original Equipment Manufacturer

OVC-HEV - Off-Vehicle Charging Hybrid Electric Vehicles, simply called PHEVs

P2 - Hybrid configuration where the electric machine is integrated between the internal combustion engine and the transmission

PEMS - Portable Emissions Measurement System

PHEV - Plug-in Electric Vehicle

PM - Particulate Matter/Mass

PN - Particle Number

PNx - Particulate Number with a diameter greater than x nm

RDE - Real Driving Emissions