Summary

Experimental testing of Plug-in Hybrid vehicles

Impacts on CO_2-emission, energy consumption and pollution

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Two Plug-in Hybrid Vehicles (PHEVs) energy consumption, CO_2-emission and locally polluting emissions were tested in VTT's emission laboratory in Finland, at +23°C and -7°C and in different drive cycles and drive modes. Together with data on usage pattern extracted from a survey of PHEV owners in March 2016, the measurements enable an assessment of the environmental impacts of these vehicles in Norwegian traffic conditions. The general conclusion is that these vehicles provide substantial environmental advantages compared with comparable Internal Combustion Engine Vehicles (ICEVs). The CO_2-emission is reduced 30-50% depending on vehicle configuration, and local pollution does not seem to be an issue with these vehicles compared with ICEVs. They do however emit substantially more CO_2 and consume much more energy than the type approval values. The type approval value does not seem achievable in real traffic. Some specific usage modes, for instance driving in cold climates under heavy loads with an empty battery, can lead to excessive local emissions compared with the official type approval limits.

Background, method and analytical framework

The Hybrid Electric Vehicle (HEV) uses a battery and an electric motor/generator to capture brake energy. The motor is when braking turned into a generator producing electricity (and a braking torque) that is recharged into the batteries. This captured brake energy can subsequently be used in the electric motor to assist in the propulsion of the vehicle and thus save fuel. The batteries in these vehicles cannot be externally recharged. Plug in Hybrid Vehicles (PHEVs) can utilize grid electricity charged into the vehicle's larger batteries, for propulsion up to 20-80 km depending on the battery capacity and vehicle configuration. For longer distances and when the power in the electrical system is insufficient, the on-board Internal Combustion Engine (ICE) supports propulsion.

The duality of power sources and engine/motors in PHEVs introduce flexibility for the user, and the user can select different drive modes where the ICE is operating to a larger or lesser extent. The real traffic propulsion system usage patterns can therefore be much more diversified for these PHEVs than for ICEVs.

Little has been known about PHEVs real world energy consumption, emission and usage characteristics under Norwegian road and climate conditions, and typical usage patterns. EMIROAD set out to fill that knowledge gap following a two path approach:

1. Measurements were carried out in laboratories, to assess two PHEVs energy use and exhaust emissions, by simulating real world traffic and climatic conditions.
2. Current users of PHEVs (and BEVs and ICEVs) where surveyed about their usage pattern and charging behavior, to build a plausible Norwegian PHEV usage profile.

The combined results from the laboratory measurements and the survey enables estimation of possible reductions of emissions and energy consumption when PHEVs replace ICEVs.

Measurements and survey

Two PHEVs were tested extensively in the emission laboratory. Vehicle A was a compact sized vehicle which, according to the type approval, has an E-mode range of 50 km, emit 37 g CO_2/km with an average energy consumption of 117 Wh/km of electricity and 0.016 liter of gasoline/km. Vehicle B was a mid-sized plug-in hybrid vehicle, which according to the type approval, has an E-mode range of 31 km, emit 48 g CO_2/km with an average energy consumption of 110 Wh/km of electricity and 0.021 liter/km of gasoline.

These vehicles were tested in different combinations of input conditions in the NEDC, Artemis Urban and Helsinki-city tests, i.e. ambient temperatures of +23°C and -7°C, cold and warm starts, fully charged and fully discharged batteries, and in different user selectable drive modes.

The exhaust gravimetric emissions of carbon dioxide (CO_2), nitrogen oxide (NO_X), carbon monoxide (CO), hydrocarbon compounds (HC) and particulates (PM) as well as the total number of particulates (PN) and the electricity consumption from the grid, were measured.

The PHEV user survey of 2065 private owners is documented in Figenbaum and Kolbenstvedt (2016), and the methods used in the survey are therefore not repeated here.

Results

The tests of vehicle A were fairly repeatable. The CO_2-emission and energy consumption varied within 10% and electricity consumption within 4% over identical tests containing several drive cycles. The vehicle did not have a pure electric drive mode as the ICE started occasionally. In the hybrid mode the vehicle ran partly fully electric, but the ICE was switched on for more demanding driving and at low temperature or when the battery was empty. The type approval CO_2-emission level seems to be a very optimistic value for this vehicle. It seems only reachable for an optimum driving pattern with a very high share of driving in the E-mode. In favorable driving conditions and starting fully charged, the vehicle can however in some user selectable modes achieve 70% less CO_2-emission than a comparable diesel version of the vehicle. Over a year of average driving the advantage will be less.

The user survey showed that most PHEVs are charged at home every day and rarely elsewhere, and the typical average driving length is 15000-16000 km. That results in a CO_2-emission estimate of Vehicle A over a year of driving that is about 46% less than that of a comparable diesel vehicle. The average NO_X and particulates emissions can be below the type approval limits for this usage pattern over the year, and also for the winter season. Some specific usage conditions, such as heavy loads with an empty battery in cold climate, can however lead to elevated emission levels above type approval values.

Vehicle B functioned very differently from vehicle A. It was fully capable of driving in a pure electric mode both in warm and cold climates. However, when driving in cold climate the electric range was short, so trips longer than 10-15 km in cold climates will involve some operation of the ICE. The vehicle is apparently programmed to drive purely electrical in the hybrid mode when vehicle load, driving and climatic conditions make it possible. When driving in high load conditions, with 0% SOC or in cold climate, some of the local emissions were also for this vehicle above the type approval emission limits. Also the CO_2-emission can then be much higher than the type approval value. The average yearly CO_2-emission of the vehicle was estimated to be 27% less than with the 1.6-liter gasoline version of the vehicle, and 36% less compared with a 2.2-liter diesel version of the vehicle, when driven 16000 km per year.

The CO_2-emission level of these PHEVs varied much more between drive cycles and temperatures than for comparable ICEVs. User profiles are very diversified and will generate a large spread in the potential annual CO_2-emission of these vehicles.

Conclusion

The testing of these two vehicles demonstrates that PHEVs are a non-uniform category of vehicles. The amount CO_2 and local pollutants these vehicles emit will depend heavily on how the vehicles are designed, and how, when and where they are used. They are high performance vehicles and care should be taken when identifying vehicles to compare emissions with.

The CO_2-reduction benefit relative to comparable ICEVs, were proportional to the e-mode range, i.e. about 50% reduction for the vehicle with 50 km range and about 30% for the vehicle with 31 km E-mode range. The average yearly estimated CO_2-emission was about 2.5 times higher than the value stated in the type approval. That deviation is much larger than the 1.4 times larger on-road emissions Tietge et al (2016) found for 2015-yearmodel ICEVs.

Some driving conditions caused elevated local emission levels, but average driving in different drive modes should over the year lead to average emissions below the emission limit values.

The testing supports a conclusion that the users driving pattern needs to match the characteristics of these vehicles to reap the maximum benefits in terms of reduced CO_2-emission and less local pollution.