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Real world CO_2 and NO_x emissions from 149 Euro 5 and 6 diesel, gasoline and hybrid passenger cars

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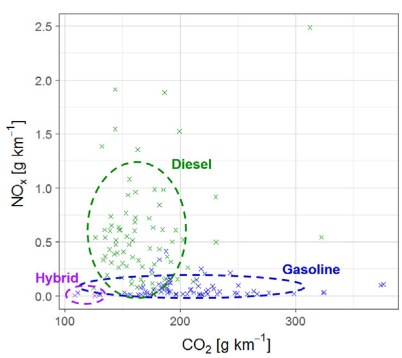
HIGHLIGHTS

- Largest PEMS study to date with 149 vehicles
- Detailed analysis of CO_2 and NO_x emissions
- Comparison of GDI and PFI gasoline vehicles
- Tests met dynamic boundary conditions of new European Real-Driving Emissions regulation

GRAPHICAL ABSTRACT



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ABSTRACT

In this study CO_2 and NO_x emissions from 149 Euro 5 and 6 diesel, gasoline and hybrid passenger cars were compared using a Portable Emissions Measurement System (PEMS). The models sampled accounted for 56% of all passenger cars sold in Europe in 2016. We found gasoline vehicles had CO_2 emissions 13–66% higher than diesel. During urban driving, the average CO_2 emission factor was 210.5 (sd. 47) g km^{-1} for gasoline and 170.2 (sd. 34) g km^{-1} for diesel. Half the gasoline vehicles tested were Gasoline Direct Injection (GDI). Euro 6 GDI engines <1.4ℓ delivered ~17% CO_2 reduction compared to Port Fuel Injection (PFI). Gasoline vehicles delivered an 86–96% reduction in NO_x emissions compared to diesel cars. The average urban NO_x emission from Euro 6 diesel vehicles 0.44 (sd. 0.44) g km^{-1} was 11 times higher than for gasoline 0.04 (sd. 0.04) g km^{-1}. We also analysed two gasoline-electric hybrids which out-performed both gasoline and diesel for NO_x and CO_2. We conclude action is required to mitigate the public health risk created by excessive NO_x emissions from modern diesel vehicles. Replacing diesel with gasoline would incur a substantial CO_2 penalty, however greater uptake of hybrid vehicles would likely reduce both CO_2 and NO_x emissions. Discrimination of vehicles on the basis of Euro standard is arbitrary and incentives should promote vehicles with the lowest real-world emissions of both NO_x and CO_2.

1. Introduction

Whilst passenger car emissions have improved with successive legislation there is substantial evidence of the growing discrepancy between type approval limits and real driving emissions (RDE) for

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both nitrogen oxides (NO_x) and carbon dioxide (CO_2) (Carslaw et al., 2011; Fontaras et al., 2017; Franco et al., 2014; Kågeson, 1998; O'Driscoll et al., 2016; Weiss et al., 2012). This creates the need for Portable Emissions Measurement (PEMS) studies to provide a true picture of real world emissions (Collins et al., 2007; Frey et al., 2003; Kousoulidou et al., 2013; Rubino et al., 2007; Weiss et al., 2011).

There is also a growing body of evidence relating to the adverse health effects of air pollution (COMEAP, 2010; EEA, 2015; RCP, 2016; WHO, 2016, 2013). Across Europe many major cities are unable to meet the annual mean concentration limit for nitrogen dioxide (NO_2), set for the protection of human health. Exceedances of the limit value occur mostly at roadside locations; this is largely attributed to the failure of the EU type approval procedure to reduce real world emissions, particularly NO_x from diesel vehicles (Beevers et al., 2012; Degraeuwe et al., 2015; DfT, 2016a; Franco et al., 2014). With an aim to address this the EU have introduced (from September 2017) a real driving component to the type approval process, Euro 6d-TEMP (EC, 2015).

CO_2 is the dominant greenhouse gas (GHG) causing global warming, which has severe impacts on climate, people and ecosystems around the world (IPCC, 2014). An international consensus has grown around the need to reduce emissions of GHGs though international summits such as the Paris Climate Accord (CCC, 2016). After the energy sector, the transport sector is the biggest emitter of GHGs in the European Union (EU), and more than two thirds of transport emissions come from road transport, making road transport responsible for ~20% of all GHG emissions in the EU (Europa, 2017). The EU is committed to reducing CO_2 emissions from road transport by introduction of fleet average CO_2 targets that aim to deliver a 40% decrease in emissions from new cars between 2005 and 2021. The current fleet average target of 130 g km^{-1} was introduced in 2015. Technological advancements in engine fuel efficiency have reduced vehicle CO_2 emissions but rising demand for fuel has outweighed fuel economy improvements. As a result, transportation is the only major sector in the EU for which greenhouse gas emissions continue to rise (CCC, 2015; Fontaras et al., 2017).

In Europe, the most prevalent passenger car fuels are diesel and gasoline. Differences between the two fuels and associated engines in energy density, combustion processes and after treatment technologies result in different exhaust compositions. Comparatively speaking, gasoline vehicles produce 20–30% more CO_2, whilst diesel vehicles emit many times more NO_x (Moody and Tate, 2017; Suzuki and Matsumoto, 2004; Weiss et al., 2012).

'Dieselisation' of the European passenger fleet began in the mid-1980's, driven by improvements in fuel economy and supposed environmental benefits. Throughout the 2000's, government incentives promoted sales of diesel vehicles leading to a peak in EU passenger car sales of 52% in 2015 (ICCT, 2016). Recent trends in sales indicate the 2015 Volkswagen scandal along with evidence of the health effects relating to air pollution from diesel vehicles have caused consumers to move away from diesel (FT, 2016) (see supporting information). Total annual car sales continue to rise, and whilst some consumers are opting for alternative fuel vehicles instead of diesel, the majority are switching back to gasoline (SMMT, 2017).

In the UK over half of all alternative fuel vehicles sold are gasoline-electric hybrids. Previous studies have found average emissions from two Euro 5 Toyota Prius gasoline-electric vehicles were (0.009 ± 0.005 g NO_x km^{-1}) and (136 ± 21 g CO_2 km^{-1}) (Wu et al., 2015) with fuel economy savings of 40–60% compared to an equivalent conventional gasoline vehicle (Fontaras et al., 2008).

In this study, we compare the real-world emissions of NO_x and CO_2 from 149 Euro 5 and 6 diesel, gasoline and hybrid passenger cars and 2 gasoline-electric hybrids. We analyse and compare the real world CO_2, NO_x and primary NO_2 emissions and how these relate to type approval limits and manufacturer's official estimates. We investigate the CO_2 savings delivered by Gasoline Direct Injection (GDI) engines, and compare urban and motorway emissions. We also extend the discussion to the significance of cold start emissions in the supporting information. Our aim is to present an accurate representation of CO_2 and NO_x emissions from the current Euro 5 and 6 European fleet in order to inform policies that protect both air quality and climate change objectives.

2. Materials and methods

PEMS measurements of 149 vehicles were conducted in the Greater London area between 2012 and 2016. The test fleet contained 37 Gasoline Euro 5 (G5), 35 Gasoline Euro 6 (G6), 36 Diesel Euro 5 (D5), 39 Diesel Euro 6 (D6), 1 Euro 5 Hybrid (H5) and 1 Euro 6 Hybrid (H6) vehicle(s). The models sampled accounted for 56% of all passenger cars sold in Europe in 2016 and included vehicles made by 27 manufacturers.

2.1. Test vehicles

The goal of this study was to provide a broad characterisation of the fleet, as opposed to identifying issues specific to a manufacturer, therefore vehicles were anonymised and assigned a vehicle ID. The characteristics of the vehicles are provided in the supporting information.

Engine displacements of the test fleet followed the wider European trend, with diesel engines being larger and gasoline engines smaller. The average engine displacement was 1.9ℓ for diesel and 1.5ℓ for gasoline. The distribution of engine sizes in the test fleet was representative of the UK and European fleet (see supporting information). As engine displacement relates closely to CO_2 emissions, the vehicles were split into categories for analysis as follows; <1.4ℓ = Extra Small [XS], 1.4ℓ − ≤1.55ℓ = Small [S], 1.55ℓ − ≤2ℓ = Medium [M] and >2ℓ = Large [L].

The most represented euro car segments in the test fleet were B (Small), C (Lower Medium), D (Upper Medium) and H (SUV). Segments B, C, D and H are the most common in the passenger car market, in the UK in 2015 they made up 83% of new vehicles registered (SMMT, 2015).

Vehicles in the test fleet had relatively low start mileages with an average of 4105 (standard deviation, sd. 3000) km. Therefore, deterioration of the emissions control systems as a result of ageing, usually observed after ~50,000 km (Borken-Kleefeld and Chen, 2015), is not a factor in this study. As it is too early for substantial evidence of emissions degradation from Euro 5 and 6 vehicles, it cannot be assumed emissions stated in this study will remain constant over the lifetime of the vehicle (Chen and Borken-Kleefeld, 2016). Some of the vehicles have driven <3000 km and may not have fully de-greened, however, these are representative of vehicles on European roads. The vehicles in the test fleet include Euro 6 classified vehicles manufactured from 2013 to 2016. The Euro 6 regulations are currently undergoing rapid changes, and vehicle manufacturers are likely to be modifying vehicles in response. As a result, the real-world performance of Euro 6 vehicles has become a moving target, again however, this sample can still be seen as representative of vehicles currently on the road.

2.1.1. After treatment

All gasoline vehicles in the test fleet were fitted with three-way catalysts (TWCs) which control NO_x, carbon monoxide (CO) and hydrocarbon emissions. All diesel vehicles were fitted with a Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF) and Exhaust Gas Recirculation (EGR), as are all diesel cars Euro 5 or after (BMVI, 2016; DfT, 2016a). The D6 vehicles had a mixture of NO_x aftertreatments, 7 used only EGR, 19 used EGR + Lean NO_x Trap (LNT), and 13 used EGR + Selective Catalytic Reduction (SCR). This reflects the 2014 sales mix (ICCT, 2015). All three abatement technologies were previously found to reduce diesel NO_x emissions to a similar degree (O'Driscoll et al., 2016).

Half of the vehicles in the test fleet were equipped with fuel saving stop-start technology. 60% of new cars sold in Europe have stop-start technology (Gross, 2015). It is thought to deliver fuel savings of between 3 and 5%, making any potential benefit within the natural