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Engine cold start analysis using naturalistic driving data: City level impacts on local pollutants emissions and energy consumption

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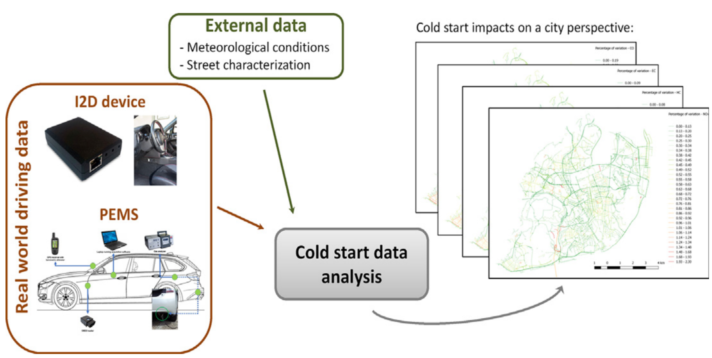
HIGHLIGHTS

- Extensive real world data collection to evaluate vehicle cold start running.
- Assess the impacts of cold start running on the city perspective.
- Lower average ambient temperatures increases the cold start running duration.
- Increase of 110% on energy consumption and up to 910% on emissions for cold start.
- The impact of cold start is higher on more densely populated areas.

GRAPHICAL ABSTRACT



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ABSTRACT

The analysis of vehicle cold start emissions has become an issue of utmost importance since the cold phase occurs mainly in urban context, where most of the population lives. In this sense, this research work analyzes and quantifies the impacts of cold start in urban context using naturalistic driving data. Furthermore, an assessment of the influence of ambient temperature on the percentage of time spent on cold start was also performed.

Regarding the impacts of ambient temperature on cold start duration, a higher percentage of time spent on cold start was found for lower ambient temperatures (80% of the time for 0 °C and ~50% for 29 °C). Results showed that, during cold start, energy consumption is >110% higher than during hot conditions while emissions are up to 910% higher. Moreover, a higher increase on both energy consumption and emissions was found for gasoline vehicles than for diesel vehicles. When assessing the impacts on a city perspective, results revealed that the impacts of cold start increase for more local streets.

The main finding of this study is to provide evidence that a higher increase on emissions occurs on more local streets, where most of the population lives. This kind of knowledge is of particular relevance to urban planners in order to perform an informed definition of public policies and regulations to be implemented in the future, to achieve a cleaner and healthier urban environment.

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1. Introduction

The cold start period typically corresponds to the beginning of trips, when the engine temperature is lower than its optimal value, influencing engine performance and emissions (Roberts et al., 2014). Considering this, emissions produced during cold running conditions are comparatively higher than those produced during hot running (Favez et al., 2009; Weilenmann et al., 2009). Therefore, over the last years, the cold start emissions have been extensively studied in order to improve the predictive capability of emission models and the estimates of emission inventories. Furthermore, the transport sector contributes significantly to the emissions of many air pollutants and the resulting air quality issues, particularly noticeable in urban areas with high traffic volumes (EEA, 2015). Air pollution is estimated to be responsible for over 400,000 premature deaths in Europe each year (EEA, 2014).

In this sense, more recently, the analysis of cold start emissions has become an issue of utmost importance since the cold phase occurs mainly in urban context, where most of the population lives (United Nations, 2016). From the driving trends of 55 vehicles, André (1991) found that most of the vehicle trips were of short duration, in terms of both time and distance, and that one third of the trips ended before the engine was fully warm.

Most of the existing research on the characterization of cold start has focused on the impacts of technology or emission standard (Dardiotis et al., 2013; Weilenmann et al., 2009), ambient temperature (Dardiotis et al., 2013; Laurikko, 1995; Ludykar et al., 1999; Weilenmann et al., 2009; Weilenmann et al., 2005), the drive cycle (average vehicle speed and travelled distance) (Bishop et al., 2016) or engine stop time (or parking time) (Favez et al., 2009).

For example, when addressing ambient temperature, Ludykar et al. (1999) used a three-way catalyst car to perform the European Driving Cycle (EDC) at 22 °C, −7 °C and −20 °C ambient temperatures in order to assess the impacts of ambient temperature on cold start emissions. Both regulated and unregulated exhaust components (CO, HC, NO_x, particulates, light aromatics, alkenes, greenhouse gases, aldehydes and polycyclic aromatic hydrocarbons) were assessed allowing concluding that lower ambient temperatures cause an increase of up to 19 times on emissions. The exceptions were NO_x, formaldehyde and acetaldehyde emissions which were not affected by lowering the temperature.

Also, Weilenmann et al. (2009; 2005) investigated both the influence of emission standard and of ambient temperature on cold start emissions. Vehicles' ranging from pre-Euro 1 to Euro 4, both gasoline and diesel, were tested at three ambient temperatures (23 °C, −7 °C and −20 °C). Chassis dynamometer tests were carried out employing the INRETS urbain fluide court cycle repeated 15 times (IUFC15). Under low ambient temperatures, cold start CO and HC emissions from gasoline vehicles were found to increase by 15 times. In contrast, no evident trend could be identified for NO_x emissions of the same vehicles'. Overall cold start emission levels for diesel vehicles were found to be significantly lower than those for gasoline vehicles. For diesel vehicles up to Euro 2 emission standard, no clear dependence on ambient temperature was found.

More recently, Dardiotis et al. (2013) also studied the influence of emission standard and of ambient temperature on cold start emissions. The authors used thirteen late technology (Euro 4 to 6) vehicles, gasoline and diesel, to test the emission performance over the New European Driving Cycle (NEDC) at 22 °C and −7 °C. The obtained results are similar to those found by Weilenmann et al. (2005), (2009). CO and HC emissions of gasoline vehicles increased up to 11.3 times at the lower temperature when comparing to the ambient temperature. However, when considering NO_x emissions, the trend depended on the catalysts performance and engine injection strategy, with these emissions being either higher or lower at 22 °C. For diesel vehicles, in general, CO and HC emissions were found to be lower than those measured for gasoline vehicles. In contrast, NO_x emissions were higher for diesel cars. Moreover, NO_x emissions resulted to increase at −7 °C.

Laurikko (Laurikko, 1995, 2008; Laurikko and Nylund, 1993) has published several research works evaluating the cold-start emission performance of passenger cars. The vehicles were tested at −7 °C, according to the European low ambient temperature test procedure. The author found that, for gasoline Euro 4 vehicles, the average cold start CO emissions decreased by >50% when compared to Euro 2 vehicles. As for HC emissions, the decrease was lower, of circa 30%. Regarding diesel vehicles, they emitted less than the gasoline ones for both CO and HC emissions.

Regarding engine stop time, Favez et al. (2009) studied the relative cold start emissions as a function of stop times of 0, 0.5, 1, 2, 4 and 12 h. Furthermore, the authors compared the relative cold start emissions obtained for Euro 4 vehicles with those obtained 10 years before for Euro 1 vehicles. To perform this study all the cars were tested on a chassis dynamometer test bench with controlled temperature and humidity. Even with limited certainty, the authors claimed that for medium stop times of 0.5 to 4 h the average relative extra emissions of Euro 4 vehicles were significantly lower than the average relative extra emissions of Euro 1 vehicles.

Instead of analyzing the impacts of different parameters on cold start, Reiter and Kockelman (2016) have synthesized some current knowledge on cold start emissions and also quantified the cold start effect for U.S. light duty fleet conditions using the EPA's Motor Vehicle Emission Simulator (MOVES). From the performed simulations, the authors found that even though total vehicle emissions have dropped significantly in recent years, those associated with cold starts can still constitute up to 80% for some pollutant species.

Large amounts of data and research results are available in the cold start analysis. However, most of these studies use measurement procedures that are expensive and time consuming, and, therefore, existing research tends to focus on a single parameter or a small sample of vehicles. Additionally, most of these works investigate the impacts of cold start over certification tests such as the New European Driving Cycle (NEDC), which is known to underrepresent the real world driving conditions (Duarte et al., 2016; Pelkmans and Debal, 2006; Tzirakis et al., 2006; Weiss et al., 2011). Moreover, there is little knowledge about the locations where cold start mostly occurs, which is of particular relevance under urban context. In this sense, information and communication technologies (ICT) have emerged as a powerful tool allowing to unobtrusively monitor, on a large scale, driving behavior and vehicle dynamics on real world driving conditions (naturalistic driving data). These devices allow collecting data on several parameters simultaneously, which provide additional opportunities for performing an integrated analysis.

In this framework, the aim of this paper was to analyze and quantify the impacts of engine cold start in urban context using naturalistic driving data. The use of real world monitoring data in such context proves to be innovative by capturing real world dynamics particularly relevant in the characterization of cold start vehicle operation, applied in the specific case study of Lisbon, Portugal.

2. Methods and data

The methods applied and data collected for this work are described in the following sections, namely through a detailed characterization of the monitored drivers sample, the data collection methods and the data analysis performed. A generic overview of the methodological approach is presented in Fig. 1. Firstly, data was collected through two distinctive methods, using an on-board data logger (i2D device) and using a Portable Emission Measurement System (PEMS). The combination of the data from the i2D device (Sample A) and external data (meteorological data and street characterization) allowed building an integrated database. This database was used to characterize the city in terms of vehicle dynamics (by using the Vehicle Specific Power – VSP – methodology) and to obtain the percentage of time spent in cold start per street. Additionally, PEMS measurements (Sample B) provided data on fuel