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HOW DOES THE BIODIESEL USE AFFECT THE URBAN AIR QUALITY?

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Abstract: This study aims to assess the influence of the use of a B20 fuel instead of pure diesel on road-transports in urban air quality. For this purpose two emission scenarios were designed through the TRansport Emission Model for line sources with Hazardous Air Pollutant extension (TREM-HAP) application: a reference scenario considering no use of biodiesel (REF) and a scenario that reflects the use of a B20 fuel (B20). Both regulated and non-regulated pollutant emissions from B20 fuels were examined and their impacts on air quality were assessed using the WRF-EURAD modelling system applied over the Porto urban area (the second largest in Portugal), with 1× 1 km^2 of horizontal resolution.

This work revealed that the use of B20 fuels may help in controlling air pollution in Porto urban area promoting reductions on PM, CO, O_3 and total NMVOC concentrations. However, a slightly increase on formaldehyde, acetaldehyde and acrolein emissions, studied as HAP, may potentiate the O_3 formation at urban areas and its surrounds.

In spite of these pollutants are toxic and carcinogenic, the dominant VOCs of pure diesel engine exhausts (typically present in reduced amounts in biodiesel blends) have the highest chronic hazard quotients and hazard indices than VOC from B20. Thus, the use of pure diesel is more injurious for human health than B20 fuel, contributing to improve air quality levels as well.

Key words: *Biodiesel, urban areas, regulated and non-regulated pollutant emissions, air quality.*

INTRODUCTION

Due to global concerns on climate change, air pollution and energy supply, biofuels are seen as alternative fuels in the transport sector, over the last years, being biodiesel the most important biodegradable fuel over the Europe. Due to its biodegradability and its higher oxygen content (10-12%) in comparison with diesel, several recent studies have been reveal that blend fuels with small content of biodiesel (≤ 30%v/v) in place of petroleum diesel can help in controlling air pollution, generating lower exhaust gases emissions, without significantly sacrificing engine power and economy (Xue, J. et al., 2011).

According to European and Portuguese statistics, the number of passenger vehicles has been increasing over the last decade (ACAP, 2010; ACEA, 2010), with direct consequences on fuel consumption and atmospheric pollutant emissions, especially in urban areas. In fact, road transports have been pointed out as the main air pollution source in European cities, largely contributing to high levels of PM10 (mainly from diesel engines) and NOx concentrations measured in traffic monitoring stations. Lisbon and Porto (the two main cities in Portugal) are not exceptions of this (Borrego, C. et al., 2010; EEA, 2013).

Previous works conducted for the Northern region of Portugal (Ribeiro, I. et al., 2011, 2012, 2013) revealed that the use of diesel fuel blended with biodiesel up to 20%v/v (B20) has negligible impacts on atmospheric regulated emissions and on the air quality. Beyond NOx, PM, non-methane volatile organic compounds (NMVOC), CO, SO_2 and O_3, taken into account in these studies, several measurements on non-regulated pollutants emitted by road transports have been recently performed, focused on the composition and quantification of hydrocarbon and PM (Peng, C.-Y. et al., 2012). These include quantification of VOC and carbonyl compounds (CC) from gaseous exhaust and measurements of aromatic and polyaromatic hydrocarbons (PAH) from both gaseous and particulate emissions. The

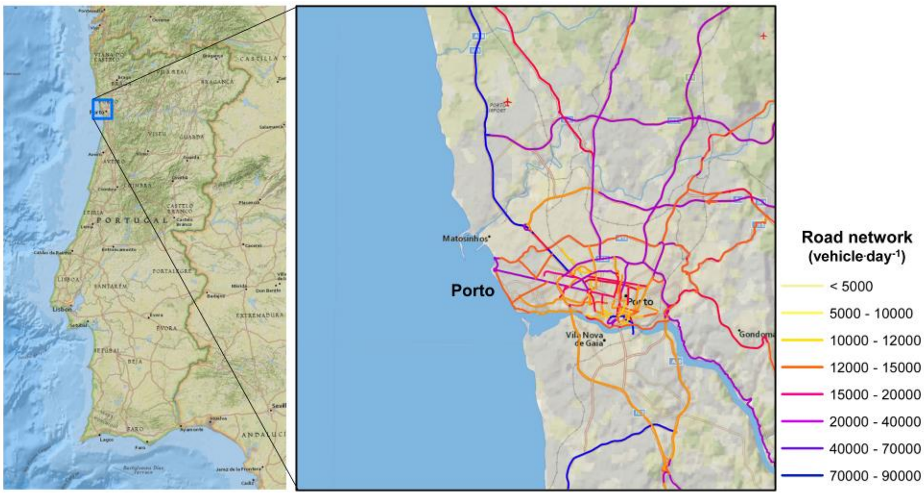
interest on these pollutants are mainly because they are hazardous for human health and environmentally dangerous (Peng, C.-Y. et al., 2008).
The impacts from the biodiesel use on regulated and non-regulated pollutant emissions and on air quality over the Porto urban area will be address in this study. To achieve this objective, emission scenarios were built considering (or not) the use of a B20 fuel on road-transport, and the WRF-EURAD numeric modelling system was used to investigate the influence of this fuel on the air quality over the Porto urban area.

EMISSION SCENARIOS

To assess the impact of the use of biodiesel on road-transport sector, two emission scenarios were designed for the Porto urban area (Figure 1):

- The REFerence scenario (REF) considering that biodiesel is not used as fuel by road-transport sector, considering the atmospheric emissions from the use of pure petroleum-based fuels (mainly diesel and gasoline);
- The B20 scenario (B20) assuming that all diesel engines are fuelled with diesel blended with 20%(v/v) of biodiesel.

REF and B20 emission scenarios were calculated using the TRansport Emission Model for line sources with Hazardous Air Pollutant extension (TREM-HAP, Borrego, C. et al., 2003; Tchepel, O. et al., 2012), taking into account the most recent data available on the Portuguese vehicle fleet distribution (ACAP, 2010) and the road network of the study domain (Figure 1).



a) b)

Figure 1. Porto urban area domain: a) its location in mainland Portugal and b) its road network with respective mean daily traffic (vehicle·day^{-1}).

TREM-HAP estimates road traffic emissions with high temporal and spatial resolution, considering roads as line sources and the emissions induced by vehicles are estimated individually for each road segment based on detailed information on traffic fluxes, vehicle fleet distribution and road segment length. This emission model uses the state of the art emission factors from the EMEP/EEA (2013) air pollutant emission inventory guidebook for regulated pollutants, and updated emission factors from ARTEMIS methodology for benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, naphthalene and PM2.5 (Tchepel, O. et al., 2012). The B20 emissions scenario data was calculated based on REF values and on variations of the emission factors estimated by Di, Y. et al. (2009), Bakeas, E. et al. (2011), Karavalakis, G. et al. (2011) and Lopes, M. et al. (2014), for B20 fuel under the New European Driving Cycle (NEDC) or Common Artemis Driving Cycle (CADC).

According to the results in Figure 2, three pollutant groups can be identified: the 1st group, composed by acrolein, formaldehyde and acetaldehyde, with an estimated increase on emission in more than 20% when using B20 fuel instead of pure diesel; NOx, C_6H_6, CO_2 and NMVOC belong to the 2nd group which emissions vary in a small range [-3.98 ; 3.65]%; and a 3rd group including CO, PM2.5 and PM10 which emissions are reduced in more than 10% when B20 is used instead of pure diesel.

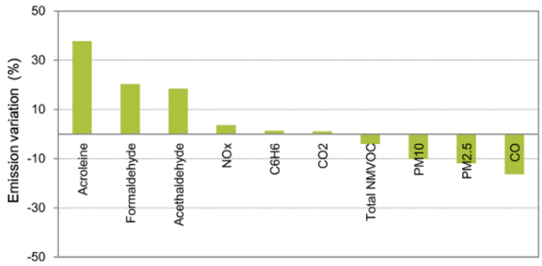


Figure 2. Emission variations (%) between B20 and REF scenarios.

One of the concerns on non-regulated pollutant (acroleine, formaldehyde, acethaldehyde and benzene) emissions rising on urban areas is related to human exposure to these toxic and carcinogenic pollutants and also because they potentiate the tropospheric ozone formation. The equivalent ozone production (EOP) from these pollutants, calculated based on the product of measured hydrocarbon emission factors and maximum incremental reactivity (MIR) (Peng, C.-Y. et al., 2008), is presented in Figure 3 expressed as the difference between B20 and REF scenarios. Due to the MIR and emission values, formaldehyde and acetaldehyde are the most critic pollutants among the non-regulated pollutant studied, contributing to 85% of the EOP over the entire domain.

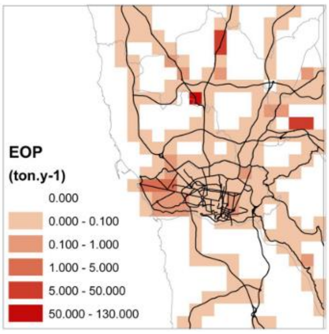


Figure 3. Difference between REF and B20 annual emissions (ton·y^{-1}) regarding the Equivalent Ozone Production (EOP).

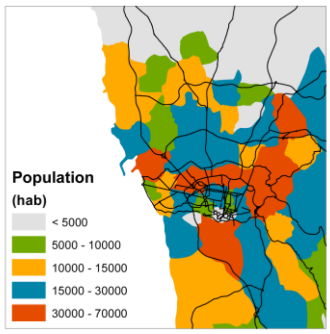


Figure 4. Population distribution of the Porto urban area.

Figure 3 also reveals that there are hot spots located in the West side of the Porto city, which is especially critic due to the population density of this area and in its surrounds (Figure 4). There are some additional hot spots in the North of the city, where the road traffic is extremely higher, contributing to a deterioration of emission levels over the entire domain. However, according to Peng, C.-Y. et al. (2012) the dominant VOC of pure diesel engine exhausts have the highest chronic hazard quotients and hazard indices than VOC from B20. Thus, the use of pure diesel is more injurious for human health than biodiesel blends, in terms of VOC emissions.

IMPACTS OF BIOFUELS USE ON AIR QUALITY

In order to investigate the impact of the biodiesel use on air quality over Porto urban area, the WRF-EURAD numerical modelling system was applied. This is an Eulerian mesoscale system in a non-hydrostatic configuration, composed by three main models:

- The Weather Research & Forecasting (**WRF**) model (Skamarock, W.C. et al., 2008) acting as meteorological driver in the modelling system;
- The EURAD Emission Model (**EEM**) (Memmesheimer, M. et al., 1991) delivering emission fields for the specific grid considering seasonal, weekly and diurnal cycles;

- The EURopean Air pollution Dispersion – Chemistry Transport Model (**EURAD-CTM**) (Hass, H., 1991; Elbern, H. et al., 2007) that computes transport, chemical reactions and deposition of gas-phase and aerosol-phase species.

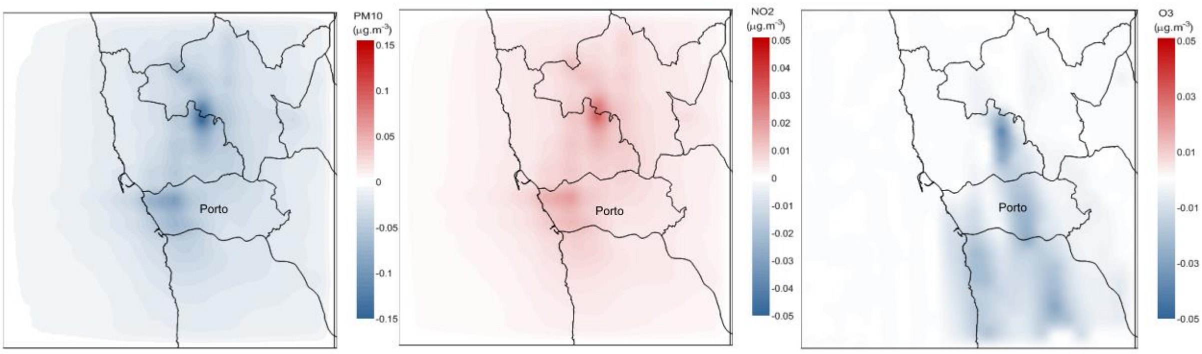
Using a nesting ratio of 5, simulations were conducted throughout four domains, from a low horizontal resolution of 125×125 km^2 over an European scale, followed by a domain covering the Iberian Peninsula, Portugal and finally the Porto urban area with a fine horizontal resolution of 1×1 km^2 (Figure 1b).

Towards achieving clear outcomes on the impact of the B20 fuel use on Porto urban area air quality, both scenario simulations were driven by meteorology for 2012 and the same emission data regarding all the activity sectors with exception for the road-transport sector, which emissions vary according to each scenario (REF or B20) as described in the previous section. The ranges of differences of pollutant concentrations for each scenario are compiled in Table 1, expressed as annual mean concentrations of NO_2, PM10, PM2.5, CO and total NMVOC, and maximum daily 8-h running average concentration for O_3 (O_3 max-8h), following the current 2008/50/EC European directive on ambient air quality and cleaner air for Europe. The spatial distribution of such differential concentrations are present in Figure 5.

In general, the results show that concentrations of the studied pollutants decrease when B20 fuel is used instead of pure diesel, with exception for $NO_{2,}$ which annual mean concentrations have a slightly increase. The concentration patterns are similar for both scenarios as well as the annual mean differential patterns for all the pollutants (PM10 and NO_2, shown in Figure 5a,b as well as CO, NMVOC and PM2.5). Nevertheless, the O_3 26th max-8h differential pattern (Figure 5c) illustrates the influence of the advection by the dominant wind (NW) contributing to a reduction on O_3 levels at South and South-East of the Porto city (identified in Figure 5 as 'Porto'). However, this reduction on O_3 concentrations could be even less if the influence of formaldehyde, acetaldehyde and acrolein emissions is considered.

Table 1. B20 and REF differential pollutant concentrations (μg·m^{-3}), for the Porto urban area.

Pollutant	**Parameter**	**Concentration range (μg·m^{-3})**
PM10	Annual mean	[-0.14 ; 0.00]
PM2.5	Annual mean	[-0.15 ; 0.00]
NO_2	Annual mean	[0.00 ; 0.03]
O_3	26th Max-8h	[-0.04 ; 0.00]
CO	Annual mean	[-33.30 ; 0.00]
Total NMVOC	Annual mean	[-0.91 ; 0.00]



a) b) c)

Figure 5. Spatial differences (μg·m^{-3}) between B20 and REF, of annual mean concentrations of PM10 (a), NO_2 (b) and O_3 max-8h (c), over the Porto urban area.

CO levels (not shown here) are improved on about 10%, reaching a reduction of more than 30 μg·m^{-3} on the most Northern hot spot (also identified in Figure 5 with highest differentials for PM10, NO_2 and O_3).

On the other hand, the reductions estimated for total NMVOC and PM2.5 levels (also not shown) are very small, achieving to 1.6% and 1.3%, respectively, on the above-mentioned hot spot.

FINAL REMARKS

The results of this study suggest that the use of a B20 fuel instead of pure diesel in road-transports promotes a reduction in PM10, PM2.5, total NMVOC and CO emissions over the Porto urban area. In general, these emission variations revealed a positive effect, however small, on the air quality of this urban area. However, it was estimated that NOx emissions may increase with B20 fuel (as well as NOx concentrations), which together with the estimated decrease on NMVOC levels, promotes a slight reduction on O_3 concentrations over the entire domain.

Besides NOx emissions, an increase on non-regulated pollutants emissions (acrolein, formaldehyde and acetaldehyde) were estimated as well, potentiating tropospheric O_3 formation and causing adverse effects on human health. However, these are not the dominant VOC on pure diesel engine exhausts. The dominant VOC on diesel have the highest chronic hazard quotients and hazard indices than VOC from B20. Thus, the use of pure diesel is more injurious for human health than B20 fuel, in terms of VOC emissions. Regarding O_3 concentrations, a more detailed study should be done in order to understand the truthful effect from the increase of non-regulated pollutants and NO_2 together with the reduction of total NMVOC emissions at regional and urban areas.

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