The impact of biodiesel on air pollutant emissions: Northern Portugal case study

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Abstract

Biofuels are a favourable choice of fuel due to their renewability, biodegradability and, at the same time, can help in controlling air pollution, reducing particulate matter (PM), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOC) and carbon monoxide (CO) emissions. Nevertheless, nitrogen oxides (NOx) emissions may increase potentiating ozone (O_3) formation. The variability on emission is widely dependent on both fuel blends and vehicle technology. This study intends to clarify the questions concerning the impact of biodiesel use on road transport over the Northern Portugal (NP) on air pollutant emissions variation. Three different emission scenarios are considered within this study: diesel without biodiesel blend (B0) and two different biodiesel blends: 10% (B10) and 20% (B20).

Results point out that the B10 and B20 use in transportation will promote a positive effect on air pollutant emissions over NP, especially regarding SO_2 and PM10. They also show a slight trend towards higher NOx emissions with biodiesel blends. No significant variations were found for CO and NMVOC emissions.

1. Introduction

The increasing of industrialization and motorization of the world has led to a steep rise for the demand of petroleum-based fuels. Today, fossil fuels take up 80% of the primary energy consumed in the world, which 32% is consumed by the transport sector [1]. Furthermore, fossil fuels have a major contribution in greenhouse gas (GHG) emissions and global warming [2]. Progressive depletion of conventional fossil fuels with increasing energy consumption and GHG emissions, have led to a move towards alternatives based on renewable, sustainable, efficient and cost-effective energy sources with lesser emissions.

Over the last decade, the production and consumption of biofuels increased rapidly worldwide in an attempt to reduce GHG emissions, diversify transportation fuels, promote renewable energy and create employment, especially in rural areas and developing countries, Brazil being the most evident example. Several countries have adopted compulsory targets or financial incentives for promoting biofuels, but only some of them have accounted for sustainability certification schemes for those biofuels within their policy framework [URL1;2]. In the European Union (EU), environmental issues are one of the key challenges which oblige for investment in biofuels. Meeting the European commitment to the Kyoto Protocol and developing a low carbon economy are the keys of European Energy Strategy (Europe 20-20-20). The proposed scheme includes sustainability criteria for biofuels and a goal of 10% of renewable energy in the transportation sector by 2020, as described by the European Renewable Energy Directive (RED – 2009/28/EC). Portugal, as a Member State, intents not only to meet this target but to consider 10% at least using biofuels, especially biodiesel.

Diesel engines are the main power source in heavy-duty trucks and buses, and their share is rapidly growing in passenger cars as well. Almost half (48%) of new passenger cars in the European Union (EU) are sold with a diesel engine [3].

One of the most important differences between biodiesel and conventional diesel is the oxygen content. Biodiesel has 10-12% more oxygen than petroleum-based diesel that means lower CO, PM and NMVOC emissions, but higher NOx emissions and ozone-forming potential as well [4;5;6;7]. Moreover, biodiesel is better than diesel regarding sulphur content, flash point, aromatic content and biodegradability [8]. The emission variations are widely dependent on both fuel blends and vehicles technology [9]. Several research studies point out that even low blends of biodiesel on diesel, can help in improving air quality and ease the pressure on scarce resources without significantly sacrificing engine power and economy [10;11;7].

The present work intends to analyze the impacts derived by biodiesel use in road transports on air pollutant emissions and also its contribution to Europe 20-20-20. To achieve this objective, the Northern Portugal (NP) region was selected as a case study (Figure 1) and three emission scenarios were designed: the reference scenario (B0) reflecting the road transport emissions of 2008 and considering no biodiesel incorporation, and two prospective scenarios considering the same vehicles fleet distribution (VFD) of B0 and the use of a 10% biodiesel blend (B10) and a 20% biodiesel blend (B20), assuming two levels of fulfillment of the national transposition of RED.

2. Case study: Northern Portugal (NP)

The NP region (Figure 1) has 21283.9 km^2 and 3.7 million inhabitants (24% of the total area and 35% of the Portuguese population) and is characterized by two different zones: the coastal region with urban and industrial areas, and the inland region, predominantly rural, with small towns/villages, aged population and agricultural based activities. As a consequence, the road network is denser in the littoral and with more traffic than in the inland roads (Figure 1b), especially in the surrounds of Porto, Braga and Guimarães municipalities.

The road network considered in this study is from the *Tele Atlas® MultiNet®* database and it takes into account the main roads of the case study area, such as the motorways, other major roads, secondary roads and principal local connecting roads.

Regarding air pollutants emissions, the NP represents an important contribution to the national emissions (30%), in which both road transport and other combustion processes are the sectors with higher emissions. Concerning the road transport sector, the NP represents 38% of NOx, 40.9% of NMVOC, 44.2% of CO, 38.3% of PM10 and 38.3% of PM2.5 national emissions. Spatially, the highest emission regions in the NP are the urban and industrial areas of Porto, Braga and Guimarães [12].

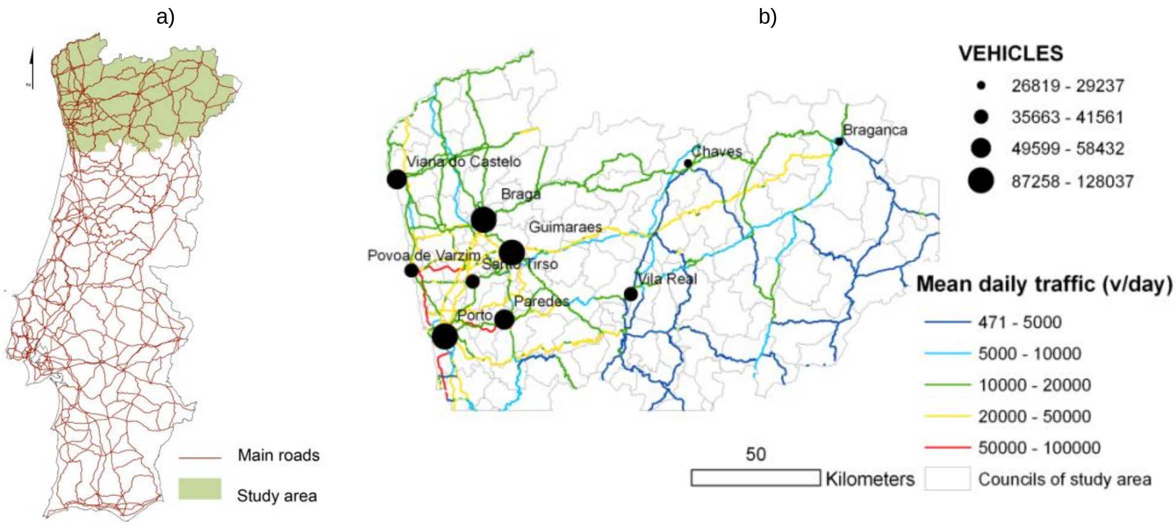

Figure 1 Portugal and study area: a) main roads of Portugal (red lines) and the study area; b) the councils, number of vehicles in the main councils and main roads of NRP with mean daily traffic (vehicle.day^{-1}).

3. Emissions scenarios

3.1. Scenarios description

To estimate the impact of biodiesel use on air pollutant emissions and also on CO_2 emissions, three scenarios were built taking into account the VFD of 2008 (Table 1) and three fuel types. The reference scenario (B0) emissions reproduce the mean daily traffic, VFD of 2008 and no biodiesel blend. Despite the biodiesel share in diesel was 3.12% (v/v) [URL3] in that year, no blend was considered in the B0 emissions scenario, since detailed data on biodiesel effects is scare regarding this blend. The B10 scenario reflects the accomplishment of the RED (10% share of energy from renewable sources in transports, considering that biofuels are the unique renewable energy sources, according to Portuguese transposition of the RED) and no changes on VFD. The B20 scenario is similar to the B10, but it considers that the RED will be accomplished only by biodiesel, and therefore a 20% biodiesel blend is assumed.

Road traffic emissions were estimated using the TRansport Emission Model for line sources (TREM) [13], which comprise emissions of CO, CO_2, NO, NO_2, PM10, SO_2, NMVOC and other trace pollutants such as heavy metals, dioxins, furans, PAH and POP. This emission model uses information on traffic fluxes, obtained from [14], VFD from [15], road segment length and state-of-the-art emission factors from [16;17]. The latter are function of the average speed and vehicle class (based on engine age, type, and capacity, vehicle weight, fuel type, and emission reduction technology).

According to the Portuguese Automobile Association [15], in 2008 the NP represented 31.8% of Portugal's VFD. Table 1 shows the assumed VFDs calculated using available information of traffic counts from the NP network traffic counters in 2008 [14]. VFD is presented in intervals due to the different distributions estimated for each road analyzed.

Parameters such as minimum, maximum and mean ambient temperature, July 2008 [18], and fuel properties [16;17] were also defined for the emissions estimates using TREM.

Table 1 Vehicle fleet distribution for the NP to 2008 year.

Vehicle type	VFD (%) [min-max]
Passengers Gasoline	[26.18-65.76]
Passengers Diesel	[13.37-33.57]
Passengers Liquefied Petroleum Gas	[0.26-0.65]
Light Duty Vehicles Diesel	[0.0-53.01]
Heavy Duty Vehicles	[0.0-16.94]
Bus	[0.0-0.42]
Coaches (inter urban buses)	[0.0-1.67]
Motorbikes	[0.0-8.9]

Assessing the results provided by these three scenarios enables understanding the influence of the incorporation of 10% and 20% of biodiesel in diesel on air pollutant emissions (PM10, NOx, CO, SO_2 and NMVOC) and also on CO_2 emissions.

3.2. Emissions estimation

To calculate road traffic emissions, namely for both B10 and B20 scenarios, the changes on emission factors suggested by [17] were taken in account for TREM simulations. These changes on emission factors were related to different biodiesel blends and vehicle categories (passenger cars, light duty vehicles and heavy duty vehicles), for post-Euro 3 diesel technologies. The emissions variation between each prospective scenario and the B0 scenario are represented in Figure 2.

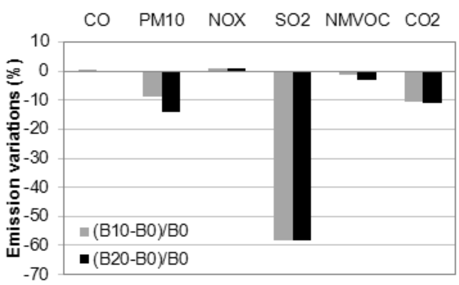

Figure 2 Annual emissions variation between each scenario and the baseline scenario, based on effect of biodiesel share on diesel vehicle emissions of [17].

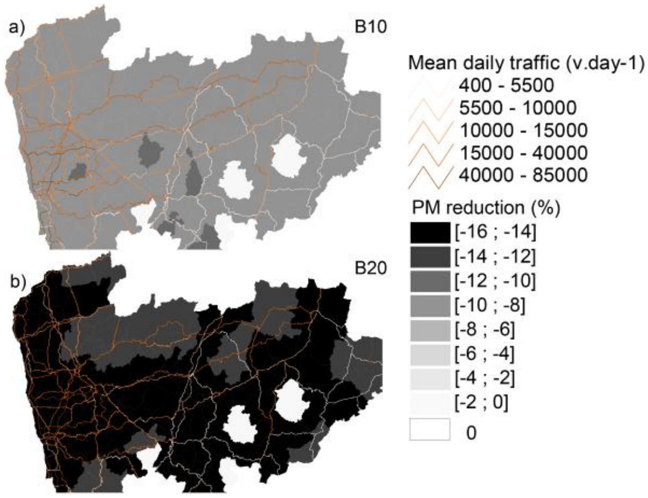

Figure 3 Spatial mean daily traffic distribution differences (%) of PM10 daily emissions (a) B10-B0 and (b) B20-B0.

The differences verified in both prospective scenarios are an outcome of two main factors: (1) the effect of biodiesel blends on diesel vehicle emissions reduction (except for SO_2) [17] and (2) the fuel properties, particularly sulphur content. In fact, the decreasing of SO_2 emission decrease verified by both prospective scenarios (58%) is entirely derived from the reduction on sulphur content from diesel (40 ppm) to B10 and B20 (9 ppm) [16;17].

When diesel engines are considered, the NOx and PM10 emissions are of major interest. Figure 2 shows a slight trend toward higher NOx emissions with biodiesel blends and the opposite for PM10. NOx variation emissions are ranging between [0.7;1.5]% and [0.9;1.5]% for B10 and B20, respectively. The increasing of NOx emissions may be related to premixed combustion, injection timing (bulk modulus effects) and fuel chemistry namely the oxygen content of the biodiesel. Other reasons for the increase NOx emissions with the biodiesel blends are described and discussed in [7].

As shown in Figure 2, PM10 emission variations range between [-9.7;-7.8]% for B10 and [-15.1;-13.2]% for B20, respectively. The benefit of biodiesel use in road transport over NP road network, regarding PM10 emissions is clearly shown in Figure 3. These results are consistent with the conclusions of other published studies [19] and show that the use of high biodiesel blends usually has a positive effects on PM10 emissions and consequently on air quality, since PM10 is one of the most critical pollutants in urban areas. The principal reasons for the reduction of PM emissions are related to the higher oxygen content in biodiesel (more complete combustion) [7] and the lack of aromatic and sulphur compounds [20;21]. The reduction in NMVOC emissions, ranging between [-2.8;-0.9]% for B10 and [-5.4;-2.0]% for B20 may be related to the increasing in oxygen content with the biodiesel blend as well.

The variation on CO emissions determined in this work can be considered insignificant ([0.0;1.4]% for B10 and [-0.5;0.0]% for B20), reflecting the marginal effect of biofuel use on CO emissions, discussed by [17]. However, the most of the literature points out that CO emissions are improved with the addition of biodiesel, namely under high engine loads [7;22]. It is important to review the effects of biodiesel blends on CO emissions from diesel vehicle presented in [17].

The reduction of CO_2 emissions is one of the most important arguments found for the use of biofuels in road-transport. With the TREM application over NP it was possible to verify that CO_2 emissions decrease in about 10% with the increasing of biodiesel blend ([-13.8;-9.0]% for B10 and [-13.9;-9.3]% for B20). This decreasing reflects the fact that biodiesel is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel [20].

4. Conclusions

Biofuels are a favorable choice of fuel consumption due to their renewability, biodegradability and at the same time generating an acceptable quality of exhaust gases. However, this is an issue that has been discussed scientifically and politically. Thus, this study aimed to verify if the use of biodiesel (the only biofuel being used in Portugal) in road-transportation actually has benefits impacts in terms of air pollutants emissions. It is shown that the introduction of biodiesel in road-transport (B10 and B20) will promote a positive effect on NP's road traffic emissions, especially concerning SO_2 and PM10. On the other hand, the increasing of NOx emissions with biodiesel blends is expected, potentiating the tropospheric ozone formation. In order to predict the effects of biodiesel use on air quality over NP, it is important to further simulate the three emission scenarios here presented. Only in this way will be possible to analyze if biodiesel use implies deterioration or an improvement on air quality, especially concerning PM10, SO_2 and O_3.

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