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Impacts of Biofuels on Air Quality: Northern Portugal Case Study

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***Abstract*—**The increased use of biodiesel implies variations on both greenhouse gases and air pollutant emissions. Some studies point out that the use of biodiesel blends on diesel can help in controlling air pollution and promote a reduction of CO_2 emissions. Reductions on PM, SO_2, VOC and CO emissions are also expected, however NOx emissions may increase, which may potentiate O_3 formation.

This work aims to assess the impact of the biodiesel use on air quality, through a numerical modeling study, taking the Northern region of Portugal as a case study. The emission scenarios are focused on 2008 (baseline year) and 2020 (target year of Renewable Energy Directive-RED) and on three biodiesel blends (B0, B10 and B20).

In a general way the use of biodiesel by 2020 will reduce the CO_2 and air pollutants emissions in the Northern Portugal, improving air quality. However it will be in a very small extension.

***Keywords*—**air quality, biodiesel, emission scenarios, RED.

I. INTRODUCTION

THE increasing 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 58% is consumed by the transport sector [1]. To fulfill the energy demand, the sources of these fossil fuels are becoming exhausted. Increasing energy demand implies an increase in crude oil price, directly affected to global economic activity. Furthermore, fossil fuels have a major contribution in greenhouse gas (GHG) emissions and global warming, which leads to many negative effects including climate change, receding of glaciers, rise in sea level, loss of biodiversity, etc. [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 [3].

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 is the most evident example). Also, policy instruments focused on sustainable biofuels are being currently implemented in industrialized countries. Several countries have adopted compulsory targets or financial incentives for promoting biofuels, and only a few countries have accounted for sustainability certification schemes for those biofuels within their policy framework (e.g. Brazil, USA, Germany and France) [20-21].

In the European Union (EU), environmental issues are one of the key drivers for investment in biofuels. Meeting the European commitment to the Kyoto Protocol and developing a low carbon economy are the keys to Government targets. 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 do it only with biofuels, especially biodiesel.

Several studies have pointed out that emissions derived from biofuels use, namely particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOC) and carbon dioxide (CO_2), will have a lower impact on the environment than fossil fuels sources [4,5,6]. However, nitrogen oxides (NOx) emissions will increase as well as the ozone-forming potential [7]. The increased and decreased emission percentages are widely dependent on both fuel blends and vehicles tested [8]. Several research studies point out that even low blends of biodiesel on diesel, can help in air quality improvement and ease the pressure on scarce resources without significantly sacrificing engine power and economy [6,9,10].

The present work intends to analyze the impacts derived by biodiesel use in transportation on air quality and also its contribution to accomplish the Kyoto Protocol. To achieve this objective, the Northern Region of Portugal (NRP) was selected as a case study (Fig. 1) and three emission scenarios were designed: the baseline scenario (base) reflecting the road transport emissions of 2008 and considering no biodiesel incorporation (B0); the target scenario (2020B10) which considers a vehicle fleet evolution (VFE) by 2020 and the use of a 10% biodiesel blend (B10), assuming the fulfillment of the National transposition of RED; and finally the ambitious scenario (2020B20) to 2020 that considers the same VFE than 2020B10 scenario and the goal of last European directive (2003/30/CE): 20% biodiesel blend (B20) by 2020.

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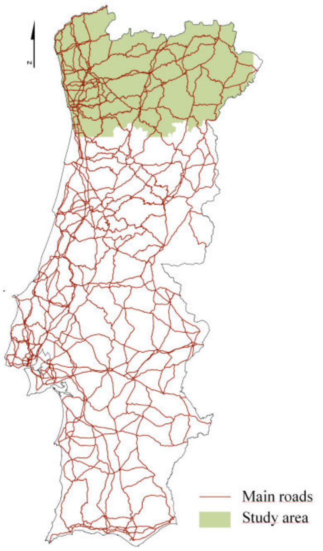

Fig. 1 Main roads of Portugal (red line) and the study area (NRP)

II. THE NORTHERN REGION OF PORTUGAL

The NRP (Fig. 1 and 2) has 21283.9 km^2 and 3.7 millions of inhabitants (24% of the total area and 35% of the population of Portugal) and is characterized by two different zones: the littoral with urban and industrial areas, and the inland predominantly rural with small cities/villages, aging population and agricultural based activities. As a consequence, the road network is denser in the littoral zone and also has more traffic than the inland roads (Fig. 2), especially in the surrounds of Porto, Braga and Guimarães municipalities.

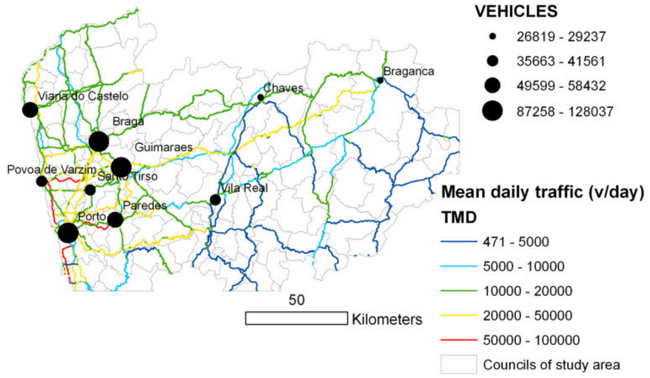

Fig. 2 The councils, number of vehicles in the main councils and main roads of NRP with mean daily traffic (vehicle/day)

The considered road network in this study was 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.

From the standpoint of atmospheric pollutants emissions, the NRP represents a very important contribution to the national emissions. According to [11], the NRP contributes with around 30% of the national air pollutants emissions, and both road transport and combustion processes are the sectors with higher emissions. Regarding the road transport sector, the NRP represents 38% of NOx, 40.9% of NMVOC, 44.2% of CO, 38.3% of PM10 and 38.3% of PM2.5 national emissions. The transportation sector is the main responsible for CO, NOx and NMVOC emissions. Spatially, the urban and industrial areas of *Porto*, *Braga* and *Guimarães* are those with higher emissions in the NRP.

III. EMISSION SCENARIOS

In order to estimate the impact of biofuels use in air quality and also on CO_2 emissions, three emission scenarios were build taking into account 2008 as the baseline year and 2020 as the target year, and also three different biodiesel blends. The baseline scenario translates the mean daily traffic, vehicle fleet (VF) and the emissions of the National Inventory Report (NIR) of 2008 [12]. In this year, the biodiesel share in diesel was 3.12% (v/v) [22]. However, since it is a very small percentage no blend was considered in this work for this scenario. The next two scenarios were projections for 2020: the 2020B10 scenario considers the accomplishment of the RED (10% share of energy from renewable sources in transports, bearing in mind that biofuels are the unique renewable energy sources, according to Portuguese transposition of the RED); the 2020B20 scenario is a more prospective scenario and considers the ambitious goal of 20% of biodiesel share in petroleum-based diesel. This third scenario was designed in order to understand what the impact on air quality is if an increase of the goal were implemented as it was foreseen in 2003/30/CE.

A. Vehicle fleet (VF)

According to the Automobile Association of Portugal [13], in 2008 the VF of the NRP represented 31.8% of Portugal's VF. Since there is no VF distribution by council, the distribution for the NRP was assumed to be equal to the national one (TABLE).

In order to build the prospective scenarios, is necessary to know the behavior of the trend curve of the VF from 2008 to 2020. In this sense, the variation rates curves of the number of vehicle categories from 2000 to 2008 were analyzed (Fig. 3).

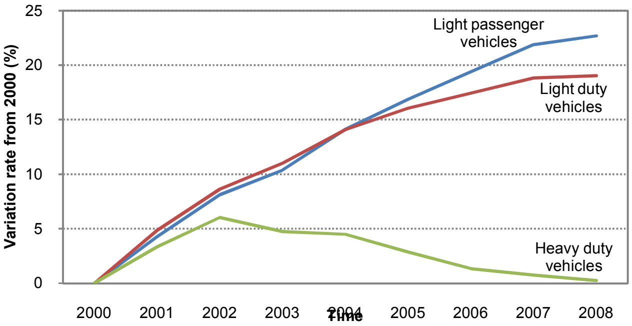

Fig. 3 Variation rates of vehicles from 2000 to 2008 [13]

According to the trends shown by Fig. 3, a 25% increase of light vehicles and a 1% decline of the number of heavy duty vehicles are expected in 2020. This corresponds to an increase of 24% of total number of vehicles by 2020. Moreover, it is expected that the VF by 2020 is more efficient than VF of 2008, which means, in a general way, a reduction on pollutant emissions.

The VF distribution for the NRP, in 2008 and in 2020, is compiled in Table .

TABLE I
VEHICLE FLEET DISTRIBUTION FOR THE NRP TO 2008 AND THE ESTIMATED DISTRIBUTION TO 2020 [13]. NOTE THAT DISTRIBUTION WAS ASSUMED TO BE THE SAME AS PORTUGAL

Vehicle type	2008	2020
Light passenger vehicles	69.6 %	72.0 %
Light duty and all-terrain vehicles	19.0 %	18.0 %
Heavy duty vehicles	2.0 %	1.0 %
Coaches and urban buses	0.3 %	0.2 %
Motorcycles < 50cc.	6.8 %	6.6 %
Motorcycles > 50cc.	2.3 %	2.1 %
Others	0.1 %	0.1 %

B. Emission scenarios

The road traffic emissions used to the baseline scenario were provided from the 2008 Emission Inventory of the NRP [11], which were calculated through the TRansport Emission Model for line sources (TREM) [14]. Both the inventory and the TREM comprise emissions of CO, CO_2, NO, NO_2, PM10, SO_2 and VOC.

The TREM (Fig. 4) estimates road traffic emissions with high temporal and spatial resolution. This model describes the vehicle emissions based on the average speed approach proposed by MEET/COST319 projects, which considers aggregated information for various driving patterns that are represented by average speed. The emission factors suggested by the methodology were derived from the data collected during several European experiments and based on best-fit curves that correlate emission measurements with speed [14].

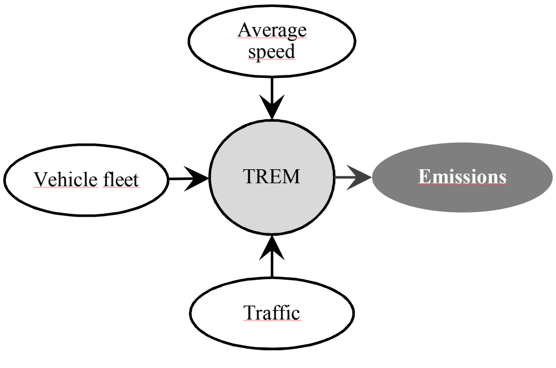

Fig. 4 Inputs and outputs of the TREM.

Parameters such as ambient temperature (Table) and fuel properties (TABLE) were defined to determine the emissions with TREM.

TABLE II
THE MEAN VALUES OF MINIMUM, AVERAGE AND MAXIMUM TEMPERATURE FOR JANUARY AND JULY, 2008 [15]

	Temperature (ºC)		
	Min.	Avg.	Max.
January	4	6	12
July	12	18	26

TABLE III
FUEL PROPERTIES [16,17]

Parameters	Gasoline	Diesel	B10	B20
Max. Sulphur content (ppm)	50.0	50.0	15.0	15.0
Pb ($g.l^{-1}$)	0.0	0.005	0.005	0.005
Volatility	0.1	0.2	0.2	0.2

To calculate the road traffic emissions, regarding prospective scenarios to 2020, the estimated VF and changes on emission factors suggested by EMEP/EEA air pollutant emission inventory guidebook-2009 [18] were taken in account (TABLE). These changes on emission factors were related to different biodiesel shares in diesel and different vehicle categories (passenger cars, light duty vehicles and heavy duty vehicles). In this work the same variation for heavy duty vehicles, coaches and urban buses, was assumed. The variations on annual emissions, calculated through TREM, of each considered pollutant, between each scenario and the baseline situation, and between 2020 scenarios are represented in Fig. 5.

According to [18] and the majority of published studies [e.g. 5,6], an increase in NOx emissions with the percentage of biodiesel blended was expected. However, in this study that was not verified due to the VFE that induces changes on vehicles performance by 2020. The emission reductions, verified in both future scenarios, for all the selected pollutants, are an outcome of two factors: (1) the reduction on emission factors described on Table (except for NOx) and (2) the VFE differences, namely regarding vehicle performance improvement from 2008 to 2020. On the other hand, the reductions on SO_2 emissions are a result of the lower sulphur content value of B10 and B20 when compared to diesel (Table).

TABLE IV
EFFECT OF BIODIESEL BLENDS ON DIESEL VEHICLE EMISSIONS [18]

Pollutant	Vehicle type	B10	B20
CO_2	Passenger cars	-1.5%	-2.0%
	Light-duty vehicles	-0.7%	-1.5%
	Heavy-duty vehicles	0.2%	0.0%
NOx	Passenger cars	0.4%	1.0%
	Light-duty vehicles	1.7%	2.0%
	Heavy-duty vehicles	3.0%	3.5%
PM10	Passenger cars	-13.0%	-20.0%
	Light-duty vehicles	-15.0%	-20.0%
	Heavy-duty vehicles	-10.0%	-15.0%
CO	Passenger cars	-0.0%	-5.0%
	Light-duty vehicles	0.0%	-6.0%
	Heavy-duty vehicles	-5.0%	-9.0%
HC/VOC	Passenger cars	0.0%	-10.0%
	Light-duty vehicles	-10.0%	-15.0%
	Heavy-duty vehicles	-10.0%	-15.0%

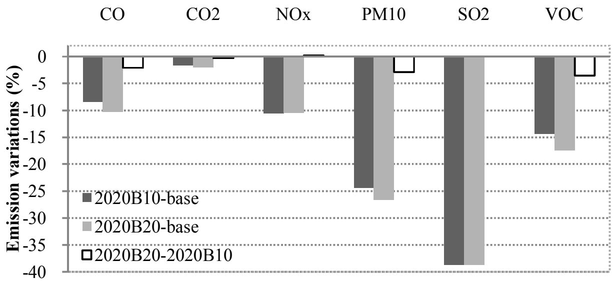

Fig. 5 Variations on annual emissions between each scenario and the baseline scenario and between both future scenarios, based on effect of biodiesel share on diesel vehicle emissions of [18]

IV. AIR QUALITY MODELING

A. Modeling approach

In order to investigate the impact of the biodiesel use on air quality, The Air Pollution Model (TAPM) [19] was applied over the study area. TAPM is a 3-D Eulerian model, with nesting capability, which predicts meteorology and air pollution concentrations in a Graphical User Interface. The model has two components: the meteorological prognostic component, and the air pollution concentrations component. The meteorological module of TAPM is an incompressible, optionally non-hydrostatic, primitive equation model with terrain-following coordinates for 3D simulations. The results from the meteorological module are one of the inputs to the air pollution component of TAPM. The air pollution component includes various sub-modules: Eulerian Grid Module (EGM), Lagrangian Particle Module (LPM), Plume Rise Module (PRM) and Building Wake Module (BWM). In this study the EGM submodule was applied and consists of nested grid-based solutions of the Eulerian concentration mean and optionally variance equations representing advection, diffusion, chemical reactions and emissions; the dry and wet deposition processes are also included.

Fig. 6 presents the scheme followed in order to perform these air quality simulations. The input emissions database to TAPM was composed by EMEP emissions from 2005, for all activity sectors except the road transport, whose emissions were determined using TREM, following the methodology describe in section III.B.

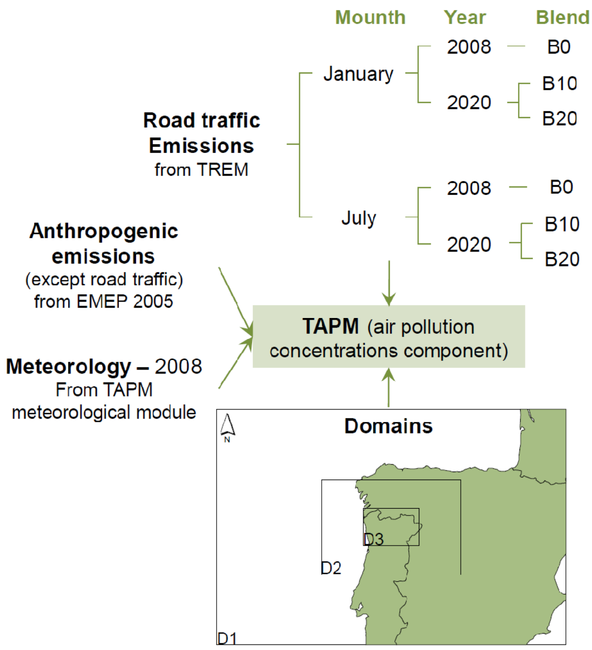

Fig. 6 The TAPM simulations scheme used.

This study implied six TAPM simulations for two periods (January and July), for each of the three scenarios, with the intention *to know the impacts over winter and over summer periods*.

Towards achieving clear outcomes of the meaning of the biofuels impact on air quality, the 2008 meteorological data was used not only for 2008 but also for 2020 simulations. In this way the external factors (such as climate) which have influence on air quality were neglected.

On the TAPM simulations three domains through the nesting approach were considered: the outer domain (D1) covers an area of 1350×912.5 km^2 with a spatial resolution of 12.5×12.5 km^2, the D2 has an area of 540×365 km^2 with a special resolution of 5×5 km^2 and the inner domain (D3) has an area of 216×146 km^2 with a resolution of 2×2 km^2.

As a result, concentrations of NOx, SO_2, PM10 and O_3 are obtained to the NRP (D3) for each scenario and study period. The simulation results will be analyzed on the section IV.

1) Modeling results

The simulation results are presented in Table and also in Fig. 7: the ranges of differences of pollutant concentrations for each scenario, in absolute value, are compiled in Table ; Fig. 7 shows the spatial differences (in percentage) of daily mean concentrations of NOx, PM10 and SO_2 and also daily maximum concentration of O_3 between each scenario, for January and July.

In general, the results show that concentrations of selected pollutants are lower for the target scenarios than for the baseline scenario, except for O_3. However, it does not mean that the introduction of biofuels on transportation is beneficent to air quality, since VFE is an important factor which promotes a significant influence on results.

TABLE V
DIFFERENCES ON MONTHLY MEAN CONCENTRATION OF NOX, O_3, PM10 AND SO_2, AND DIFFERENCES ON MONTHLY MAXIMUM CONCENTRATION O_3, BETWEEN THE 2020 SCENARIOS (2020B10 AND 2020B20) AND THE BASE SCENARIO CONCERNING ABSOLUTE VALUES (μG/M^3)

	January	July
2020B10 – base (μg/m^3)		
NOx	-4.77;-0.01	-3.49;0.00
O_3	0.01;0.59	0.00;0.91
O_3 (max.)	-0.15;1.09	-0.75;1.07
PM10	-1.04;0.00	-0.83;0.00
SO_2	-0.59;0.00	-0.48;0.00
2020B20 – base (μg/m^3)		
NOx	-4.68;-0.01	-3.42;0.00
O_3	0.01;0.57	-0.01;0.90
O_3 (max.)	-0.15;1.06	-0.75;1.02
PM10	-1.15;0.00	-0.92;0.00
SO_2	-0.59;0.00	-0.48;0.00
2020B20 – 2020B10 (μg/m^3)		
NOx	0.00;0.09	0.00;0.06
O_3	-0.01;0.00	-0.02;0.00
O_3 (max.)	-0.10;0.00	-0.13;0.01
PM10	-0.10;0.00	-0.08;0.00
SO_2	0.00	0.00

From 2008 to 2020 the reductions on NOx concentrations may reach to [-6.58;-0.11]% in January and [-6.62;-0.03]% in July using B10, and [-6.46;-0.11]% in January and [-6.50;-0.03]% using B20. The verified reductions for this pollutant by the target year are mainly explained by the improvement on vehicle performance. Moreover, no significant variations were detected when both 2020's scenarios are compared (Table and Fig. 7a). On the other hand, the O_3 concentrations will increase by 2020 (Table and Fig. 7b), while NOx and VOC emissions will decrease. This fact may help to justify the decreasing on NOx concentrations: NOx is likely to be consumed to produce O_3. This phenomenon takes place principally in urban areas of the NRP, where NOx and VOC are emitted. Regarding maximum O_3 concentrations, Fig. 7b evidences a slight increase from 2008 to 2020 (for both B10 and B20 scenarios), specially during January. The differences of the ozone concentrations reaches to +2.96% (+1.09μg/m^3) in January and +1.12% (+1.07μg/m^3) in July. Nevertheless, these values are very low concerning the observed O_3 base year concentrations (mean values: 61.21μg/m^3 and 89.19μg/m^3 for January and July, respectively). For PM10 (Fig. 7c), there are a slight decrease of ambient concentrations, which can reach to -2.05% in January and -1.78% in July for 2020B10 and -2.30% in January and -1.93% in July for 2020B20 scenario. In spite of the differences between PM10 concentrations of both simulated scenarios to 2020 are nearby zero ([-0.21;-0.001]% and [-0.18;0.00]% for January and July, respectively), it is possible to conclude that the reductions of PM10 concentrations are mainly provided by the biodiesel use introduction in transport sector, since the differences on emissions from baseline scenario to both 2020's scenarios are significant (see Table). Nevertheless, these reductions that are around 24-26% are translated in concentrations reductions around 0-2%.

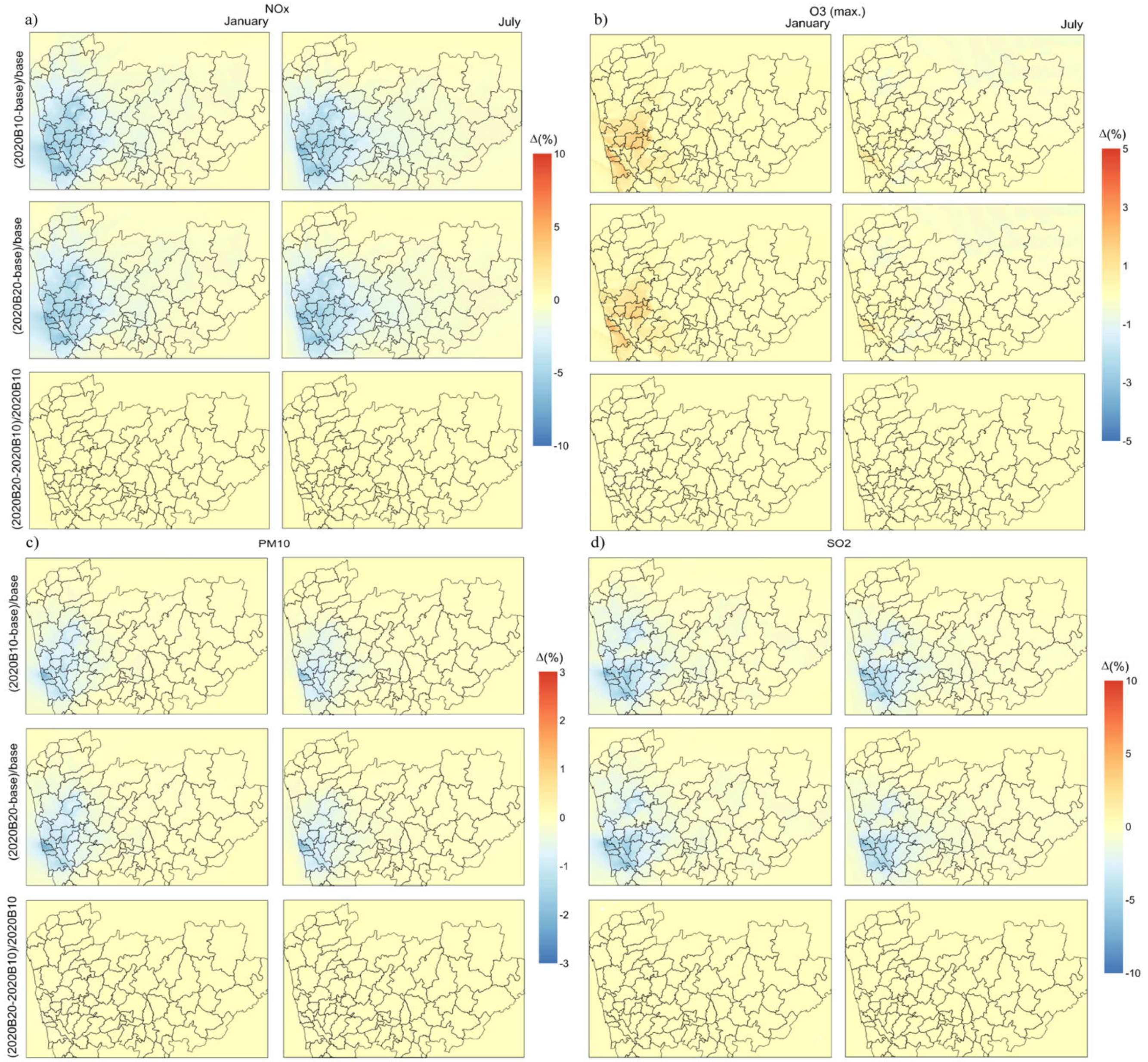

Fig. 7 Spatial differences (%) of month mean concentrations of NOx (a), month maximum concentrations of O_3 (b), month mean concentrations of PM10 (c) and SO_2 (d), between the 2020 scenarios (2020B10 and 2020B20) and the base scenario, and also between both 2020's scenarios

Regarding SO_2 (see Fig. 7d), the TAPM simulations point out to SO_2 concentration reductions of [-6.85;-0.05]% (-0.59 $\mu g/m^3$) in January and [-6.28;-0.01]% (-0.48$\mu g/m^3$) in July, from baseline to target scenarios. Moreover, when 2020B10 is compared with 2020B20 the difference on concentrations is null. This fact is explained by the difference on the sulphur content of the fuel (see Table). Thus, the introduction of biodiesel in diesel to transportation might have a positive impact on SO2 ambient concentrations.

The results of Table and Fig. 7 illustrate insignificant differences between both studied period (January and July).

V.CONCLUSION

With the growing concern about global warming, increasing energy demand and depletion of fossil fuels, the interest in biofuels as possible replacers of fossil fuels has increased as well. According to several studies, 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 caused major differences of opinion in the scientific and political worlds. In this way, this study aimed to verify if the use of biodiesel in transportation actually has benefits for the air quality.

This study shows that the introduction of biodiesel in transportation (biodiesel blends of 10% and 20%) will promote a positive effect, however small, on NRP's air quality, concerning SO_2 and PM10. Regarding O_3 the NRP's air quality may slightly deteriorate, especially during January (O_3 concentrations are expected to increase by about 3% over the littoral/urban zone). With respect to NOx, the positive impact on air quality expected by 2020 is mainly derived from the improvements on vehicle fleet.

Reduce CO_2 emissions is one of the most important arguments found for the use the biofuels in transportation. However, the reduction expected from the introduction of biodiesel in transportation seems like to be a very small contribution in order to reduce CO_2 emissions: it may reach to -1.68 or -1.95% if B10 or B20 be in use, respectively.

This study comprehends the first step of the assessment of the impacts provided by biofuels on air quality in Portugal. In this sense, this study will be extended to all over Portugal.

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