

ENVIRONMENTAL IMPACT MODELLING OF A HIGHWAY: A CASE STUDY

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Traffic pollution has serious implications on the atmosphere and human health. The present paper refers to the impact of traffic on the Italian A22 highway that crosses the region Trentino - Alto Adige. Based on information provided by ALPNAP (Air Pollution, Traffic Noise and Related Health Effects in the Alpine Space project) and iMonitraf (Monitoring of Road Traffic related Effects in Alpine Space and Common Measures), the variation of the emissions of NO_x and PM₁₀ was derived for the period 2005-2009 along the Bolzano North - Bolzano South stretch. By means of the COPERT IV model, emission simulations were performed and the results on the emission factors for the most polluting vehicles (heavy duty vehicles) were compared with the emission factors adopted by iMonitraf. The results show that the analysis of the main pollutants CO, CO₂, PM₁₀ and NO_x is more rigorous and accurate when performing simulations with COPERT.

Keywords: atmospheric pollution, highway, modelling, PM, NO_x.

1. Introduction

The emissive contribution of road traffic to air pollution has put environmental stress causing not only negative effects to human health but also climate change [1,2]. The air pollution related to transport, especially in urban sites has been widely investigated in the last decades, concentrating on: chemical composition, spatial temporal distribution of pollutants and effects on human health considering different traffic situations [3,4,5]. The pollutant emissions from mobile transport depend on type of fuel (diesel, biodiesel, compressed natural gas, hythane or liquefied natural gas), engine combustion technology, exhaust gas treatment (catalytic conversion, oxidative catalysis, gas recycling, selective catalytic reduction, particle filtration) and vehicle operating conditions (type, size, speed, age). Due to the technological progresses made in the last years, EURO 5 trucks emit twenty times less particulate matter (PM) compared to EURO 1 trucks

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[6]. Nevertheless, nitrogen dioxide (NO_2) is one of the most important traffic-related pollutant with 38.4% emissions in Europe coming from mobile source emissions [7]. A review [8] from different sites in Europe quantified the contribution to PM and concluded that road traffic contributes up to 55% for PM_{10} and up to 49% for $\text{PM}_{2.5}$.

In 2010, 44% of the European traffic stations registered a NO_2 exceedance with a maximal observed concentration 2.6 times higher than the limit value, while 33% of the traffic stations reported exceedance of the PM_{10} 24-hour limit value [9].

Road traffic in mountain regions is still in an early stage of research due to its characteristics such as topography, road type (flat or sloping), high-pressure conditions, atmospheric motions and distribution of temperature. The most critical period of air pollution is during winter, due to the long-lasting periods of high pressure, that are often accompanied by a state of thermal inversion that promote the accumulation of pollutants in the lower atmospheric layers [10,11]. Several projects have been completed in this regard; among the most notable there are ALPNAP (The Air Pollution, Traffic Noise and Related Health Effects in the Alpine Space project) and iMonitraf (Monitoring of Road Traffic related Effects in Alpine Space and Common Measures), both concerning the role of the Italian A22 highway in terms of local impact on air quality and emission control [12,13,14]. In order to perform realistic dispersion simulations, the emission sources of pollution have to be characterized properly considering also a monitoring sensor system network for real time data collection [15,16].

Moreover, different types of emission monitoring and inventorying tools can be used (*e.g.*, COPERT, MOBILE and MVEI MOBILE, HBEFA) if sufficient reliable input data for the models can be provided. The most used emission modelling tool is the COPERT 4 algorithm, which is part of the EMEP/CORINAIR emission inventory guidebook. This methodology has been developed by the European Environment Agency within the European Topic Centre on Air and Climate Change (ETC/ACC) activities, with the intention of providing a set of tools for the compilation of emission inventories to the European Countries [17].

The first aim of this study is a re-calculation of the emissive contribution of road traffic along the A22 highway, according to the changes of the traffic fluxes and the evolution of the vehicle fleet that occurred between 2005 and 2009. In addition, a comparison between the emission factors proposed by COPERT 4 and those adopted by iMonitraf will be performed, in relation to heavy duty vehicles (HDVs), the most polluting vehicle category.

2. Materials and methods

One of the main results of the ALPNAP project was the simulation of emission and dispersion of NO_2 and PM_{10} from the road traffic passing through the A22 highway. The results of the dispersion simulations were used in ALPNAP for the monetization of the health effects provoked by the human exposure to these pollutants, according to the ExternE (External cost of Energy) methodology [12,18].

Within the ALPNAP project, emission simulations for 2004 were carried out by means of the COPERT algorithm, by considering the vehicle fluxes for that year and using the information on the vehicle fleet supplied by the census of the Automobile Club d'Italia (ACI) [12]. An average speed of 130 km h^{-1} was adopted for passenger cars and light duty vehicles, whilst for HDVs an average speed of 80 km h^{-1} was assumed. PM_{10} and nitrogen oxides (NO_x) emissions, together with orographic and meteorological data pre-processed with the CALMET diagnostic model, were used as input data for CALPUFF, the dispersion model adopted by ALPNAP. As a result of the simulations, maps of the annual average concentration of PM_{10} and NO_2 were generated by ALPNAP for 2004.

To study the evolution of the emissive framework during the years following the conclusion of the ALPNAP project, PM_{10} and NO_x emissions were re-calculated on the basis of updated data on the vehicle fleet and of the information on the vehicle fluxes supplied by iMonitraf. The project iMonitraf, ended in June 2012, was intended to implement strategies, actions and innovative measures for traffic in the Alpine region, in order to build a political network between the countries involved and to get to a sustainable regional development [13].

PM_{10} and NO_x emissions were calculated for the years 2007 and 2009. The evolution of the emissive scenario has obvious effects on the pollutant concentrations that can be achieved in ambient air. To keep homogeneity in the visualization of the new concentration maps with the results of ALPNAP, the same maps obtained for 2004 were used and re-calibrated. More specifically, the scale of concentration was changed according to the new maximal and minimal concentrations of PM_{10} and NO_2 . The latter were estimated by a proportion between the emissions of PM_{10} and NO_x calculated by ALPNAP for 2004 and the new emissions. For the new calculations, since COPERT calculates emissions for total NO_x , the ratio between the emissions of NO_2 and NO_x was assumed to be constant and equal to that obtained by ALPNAP for 2004.

As previously mentioned, the secondary aim of this study is a comparison between the emission factors developed by COPERT IV and those proposed by iMonitraf for HDVs. Emission factors were calculated with COPERT IV with regards to rigid trucks belonging to the EURO 1 to EURO 5 European emission

standards. The emission factors proposed by iMonitraf are derived from the Handbook of Emission Factors for Road Transport developed by INFRAS [19]. For each EURO class, iMonitraf provides an average emission factor for HDVs. To make the comparison reasonable, for each EURO class the average emission factor provided by iMonitraf was compared with the emission factors calculated with COPERT that refer to the heaviest (gross weight up to 32 tons) and the lightest group (gross weight less than 7.5 tons).

3. Results and discussion

The results of the dispersion simulations consist in the annual average concentrations of NO_x and PM_{10} for 2004, referring to a particular stretch of the A22 highway between the towns of Verona and Bolzano (Fig. 1). On the basis of the updated emissions, the concentration maps were re-calibrated and the results are reported in Fig. 2 and Fig. 3 for 2007 and 2009, respectively. As it is visible from the scale, NO_2 concentrations have continuously decreased since 2004, due to the introduction of more and more restrictive emission standards and, consequently, to the evolution of the vehicle fleet. The maximal concentration changed from $53 \mu\text{g m}^{-3}$ in 2004 to $37 \mu\text{g m}^{-3}$ in 2009. Conversely, PM_{10} shows the opposite behavior: the maximal air concentration increased from $45 \mu\text{g m}^{-3}$ in 2004 to $55 \mu\text{g m}^{-3}$ in 2007 and decreased to $47 \mu\text{g m}^{-3}$ in 2009. Thus, PM_{10} concentrations in 2009 are slightly higher than 2004. One possible explanation is that, unlike HDVs, a decrease of the NO_x emission limit for gasoline passenger cars was not accompanied by any regulation on PM_{10} [20]. Moreover, in 2007 the vehicle fluxes were higher than 2004, especially for passenger cars and light duty vehicles (about +5% variation) [12,13].

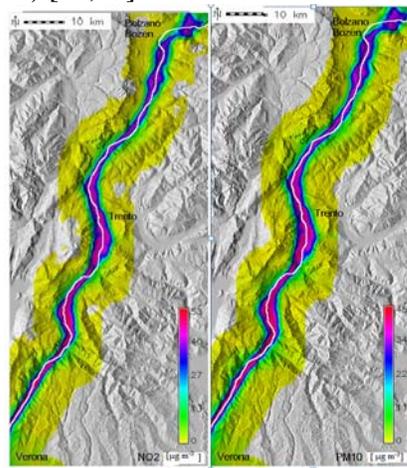


Fig. 1. Annual average concentrations of NO_x and PM_{10} along the A22 highway calculated in the ALPNAP project for 2004.

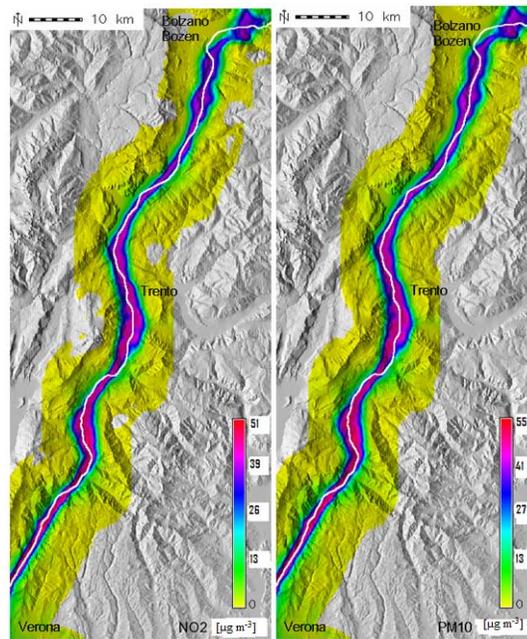


Fig. 2. Annual average concentrations of NO_x and PM₁₀ along the A22 highway calculated for 2007, after recalibration of the modeling results of ALPNAP on the basis of updated emissions.

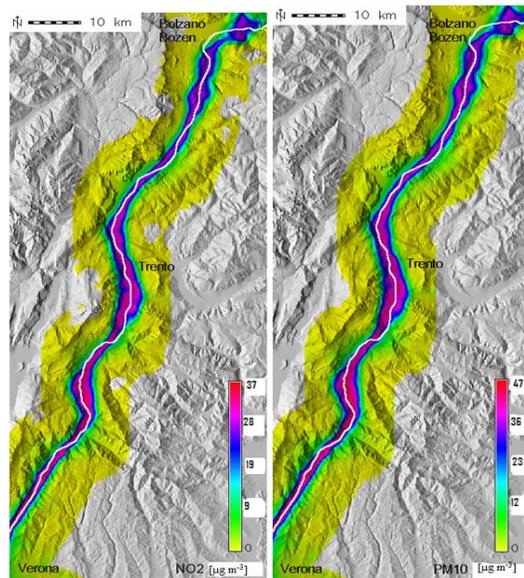


Fig. 3. Annual average concentrations of NO_x and PM₁₀ along the A22 highway calculated for 2009, after recalibration of the modeling results of ALPNAP on the basis of updated emissions.

The introduction of the diesel particulate filter (DPF) can also play an important role, since the regeneration phase (the burning and the release of the particles trapped) occurs when the vehicle is running at constant speed and high load [21,22]; such kind of situation is typical for highways, although it is not clear whether the emission factors provided by COPERT take the regeneration process into account.

The results of the comparison between the emission factors of iMonitraf and COPERT are reported in Fig. 4, Fig. 5, Fig. 6, Fig. 7, for carbon monoxide (CO), NO_x, carbon dioxide (CO₂) and PM₁₀, respectively. There is substantial agreement between the range of emission factors used by COPERT and the average emission factors proposed by iMonitraf for CO, NO_x and CO₂, with some exceptions for the EURO 5 class: the emission factor for CO proposed by iMonitraf is lower than the emission factor adopted by COPERT for the lightest EURO 5 HDVs (Fig. 4); on the other hand, the emission factor for NO_x by iMonitraf is higher than the emission factor used by COPERT for the heaviest EURO 5 HDVs (Fig. 5). A general disagreement between the two methodology can be observed for PM₁₀ (Fig. 7): for EURO 3, EURO 4 and EURO 5 HDVs, the emission factors proposed by iMonitraf are higher than the maximal emission factors adopted by COPERT. This aspect can lead to an overestimation of the PM₁₀ emissions calculated by iMonitraf in comparison with COPERT.

Considering the importance of the relationship between outdoor and indoor pollutant concentrations [23,24,25], a next step of the research has been planned to this concern for a complete vision of the impact of the highway.

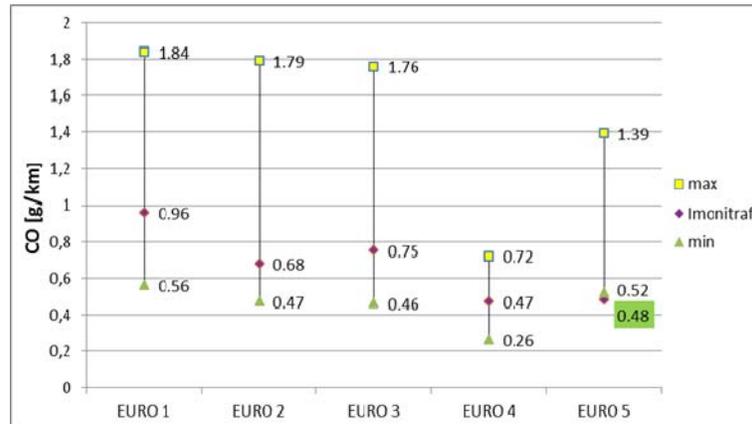


Fig. 4. Comparison between the emission factors for CO proposed by iMonitraf and the ranges of emission factors adopted by COPERT for EURO 1 to EURO 5 HDVs.

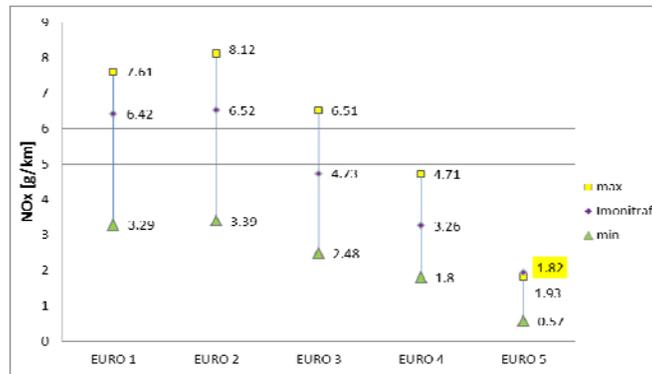


Fig. 5. Comparison between the emission factors for NO_x proposed by iMonitraf and the ranges of emission factors adopted by COPERT for EURO 1 to EURO 5 HDVs.

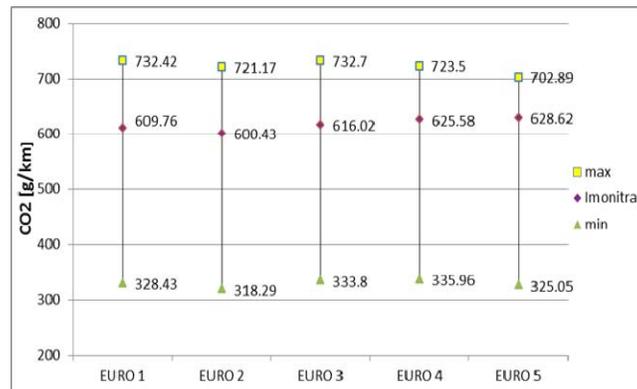


Fig. 6. Comparison between the emission factors for CO₂ proposed by iMonitraf and the ranges of emission factors adopted by COPERT for EURO 1 to EURO 5 HDVs.

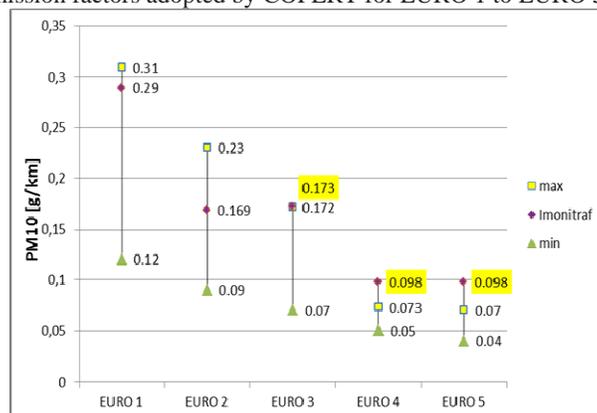


Fig. 7. Comparison between the emission factors for PM10 proposed by iMonitraf and the ranges of emission factors adopted by COPERT for EURO 1 to EURO 5 HDVs.

6. Conclusions

The Alpine region is a vulnerable environment from the point of view of air pollution, since many factors (orography and road type above all) are responsible for conditions of atmospheric stability and high emissions, which tend to be trapped at ground level. In this frame, the results obtained by ALPNAP represent a useful term of comparison for the evolution of the emissive framework generated by road traffic along the A22 highway between 2004 and 2009. A clear decrease of NO_x emissions, due to improvements in the legislation and technology, translates into a 30% reduction of NO_2 concentrations in ambient air. On the other hand, PM_{10} shows the opposite behavior, since the ambient air concentration slightly increased (+4% variation) between 2004 and 2009. Possible explanations can be found in the operation of the DPF, whose regeneration usually occurs along high-speed roads, but also in the misalignment of the emission limits for gasoline cars.

The results presented in another project (iMonitraf), aimed at planning actions and innovative solution for a sustainable development of the Alpine region, allowed a comparison between the emission factors proposed in it and the emission factors used by the European reference model to calculate emissions from road traffic (COPERT). Although a general agreement between the two models can be observed for some pollutants (CO , NO_x and CO_2), the emission factors for PM_{10} proposed by iMonitraf for EURO 3, EURO 4 and EURO 5 HDVs fall out of the range of the emission factors estimated by COPERT. As a consequence, iMonitraf tends to overestimate PM_{10} emissions.

It is clear from this paper that a unique reference approach is lacking in the sector. Apart from that, the study of the impact of a highway should be completed by an additional analysis of the relationship between induced outdoor pollutant concentrations and indoor air concentrations.

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