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Compilation of a road transport emission inventory for the Province of Turin: Advantages and key factors of a bottom–up approach

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ABSTRACT

Traffic is known to be a major source of air pollution, especially in urban areas and it is widely accepted that effectiveness of measures put into force to improve air quality was in the past limited by a partial knowledge of road transport emissions. In this work we have performed a comparison between the road transport pollutant emissions of Province of Turin calculated with a bottom–up approach and the corresponding emissions of the official Piedmont Inventory, based mainly on a top–down approach. The bottom–up inventory was obtained using the output of a traffic model referred only to private vehicles and integrating it with traffic survey data and mobility report studies. We were able to highlight the key factors liable for influencing the results. The traffic surveys can change the contribution of the vehicular categories while statistically–based annual mileages are crucial for determining the apportionment among Copert categories and the proxy variable used to estimate urban diffuse emissions (traffic models do not fully reproduce the amount of traffic flows) exerts a great influence on the total amount of emissions and on the spatial distribution. In bottom–up inventory we have obtained a different apportionment of emissions among vehicular categories: in example, for urban roads the CO_2 of passenger cars has risen from 52.7% in top–down inventory to 79.5% in bottom–up. Total emissions of road transport have significantly reduced in bottom–up inventory compared to top–down (NO_X–16%, CO–41%, NMVOC–66%) and the emissions of Turin have reduced more than in the other municipalities (CO_2–24%, NO_X–41%, CO–53%, NMVOC–71%). We have found that, if not unfeasible for lack of data, the bottom–up methodology should be preferred since it allows a more straightforward and transparent choice of input parameters.

Keywords: *Emission inventory, road transport, top–down, air quality*

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1. Introduction

Emission inventories are the basic information needed to guarantee a good understanding of ambient air pollution, to plan air quality measures and estimating their efficiency. Inventories are usually prepared using two different approaches, top–down (Progiou and Ziomas, 2011) and bottom–up (Wang et al., 2008; Borge et al., 2012), that sometimes can complement each other (Beevers et al., 2012). The top–down methodology is the most effective for the compilation of national databases of emissions as suggested by EMEP/EEA Inventory Guidebook (EEA, 2009), since it allows to obtain a geographically complete and methodologically homogeneous set of information. Starting from the national inventory, it is then possible to estimate emissions with a higher spatial resolution using proxy variables like, in the case of road transport (Borrego et al., 2000; EEA, 2009), the resident population, the fuel sold, the lengths of roads, etc. The choice of proxies proves often to be demanding, since it can easily causes the under/overestimation of emissions in different areas and the resulting inaccuracy in air quality management.

When it comes to air pollution assessment in local action plans, in fact, the spatial and temporal resolution of road transport emissions is very important and the bottom–up approach becomes preferable (Baldasano et al., 2010). This methodology requires more detailed input activity data and longer times are expected for the compilation, but it is recommended in particular for urban air quality assessment, where road transport is the most relevant source of pollution and traffic flows show high differences from area to area.

The lack or inaccuracy of input data can pose a risk in employing a full bottom–up methodology and a comparison between bottom–up and top–down is always recommendable (Borrego et al., 2000; EEA, 2009).

In Section 3 we present the comparison between the official emission inventory of road transport compiled by Piedmont Region for the territory of the Province of Turin using mainly a top–down approach (Regione Piemonte, 2008) and the road transport emissions that we have calculated for the same territory with a bottom–up approach, starting from traffic flow data, on site surveys and mobility report studies.

The Province of Turin territory, approximately 6 800 km^2, offers the opportunity to highlight strengths and weaknesses of the two approaches in a mixture of rural and industrial areas, with a spread out urban agglomerate (Turin metropolitan area) in the centre.

Expanding a previous work on the sole metropolitan area (Pallavidino et al, 2011), in the framework of AERA project we applied the bottom–up methodology to the full road network of the Province of Turin with the aim to obtain a more accurate estimate of the local road transport emissions relying, when available, on detailed and updated information. As a side consequence, the comparison between the two methodologies (top–down vs. bottom–up) could also be analyzed from the point of view of the sensitivity of input parameters.

2. Methodology and Data

2.1. Bottom–up approach

The calculation of emissions in the bottom–up approach has been performed by means of Trefic (Nanni et al., 2009; Denby, 2011), a software that implements Copert IV emission factors (EEA, 2009) for most of pollutants and emission factors provided by IIASA (Klimont et al., 2002) for PM_{10} and $PM_{2.5}$. Since the IIASA emission factors include exhaust and wear emissions but do not take into account the resuspension of PM_{10}, this contribution has been calculated by using the EPA formula published in 2011 (U.S. EPA, 2011) that takes into account the average weight of circulating fleet, the surface silt loading of the street and the numbers of hours of precipitation (see the Supporting Material, SM, S1). In Copert IV methodology the emission factors vary depending on the slope of the road, the mean travel speed and the vehicle category, identified by the vehicle type (passenger car, light duty), the vehicle technology (Euro 1, Euro 2), the engine displacement, the vehicle weight, and fuel. Given a road network and the other requested input data, for each link Trefic can calculate emission factors for all Copert classes.

For transport analysis, Province of Turin makes use of a traffic model describing private traffic flows on a detailed road network consisting of 13 690 links (C.S.S.T., 2001), which was recently updated (Torriani et al., 2012) considering the latest available mobility studies for the assessment of Origin–Destination matrix (Levinson et al., 2009), and new traffic measurements for a better calibration (see the SM, Figure S1).

In the road network, motorways are the minority of links (with a total of 621 km), while urban roads sum up to 6 331 km and rural roads to 2 232 km. Inside the metropolitan area, the motorway links are part of a Ring Road that encloses Turin on the west. The Origin–Destination matrix takes into account the mobility of people among 636 zones and 1 493 963 one–way movements in a mean working day, describing a high fraction of the whole mobility since 2 200 000 people reside in the Province of Turin. The Origin–Destination matrix refers only to people using a private vehicle, so that traffic flows calculated by the traffic model can be assigned only to private cars and two–wheelers.

In order to evaluate the yearly traffic from the working day traffic and to split the private traffic between cars and two–wheelers it was necessary to estimate the factors to apply to the model data, deriving them from the analysis of local traffic counts (for two–wheelers factors see the SM, Table S1).

The emissions of public transport buses have not been considered as included in the traffic flow data and have been treated separately, since the local public transport company made available accurate data about the fuel consumption, Copert classes and the average travelling speed (GTT, 2008).

The traffic model doesn't give any information about commercial vehicles. For the assessment of commercial traffic flows more than 390 traffic measurements were used. On the motorways, where traffic data are accurate and spatially dense, a rough conservation of traffic flows of commercial vehicles could be considered, while for urban roads we found out an average 9.2% of Average Daily Traffic (ADT) for commercial vehicles with respect to private vehicles. Rural roads exhibit a variety of behaviors, depending on many factors (proximity to a motorway or an industrial area, access to a bordering tunnel, etc.). On the basis of traffic counts, it was assumed a fixed percentage of commercial vehicles flow with respect to private vehicles ADT with three options: 10% inside Turin Metropolitan Area and 15% or 5% outside it. The map reporting the percentages of commercial vehicles circulating on the streets of the Province of Turin is represented in Figure S2 (see the SM).

The commercial vehicle flows were further split into light duty vehicles (LDV) and heavy duty vehicles (HDV) on the basis of traffic surveys for rural and urban roads and of payment toll data for motorways (see the SM, Table S2).

After the estimation of traffic flows of two–wheelers, passenger cars, light duty vehicles and heavy duty vehicles, each value had to be divided into Copert classes identified by fuel, environmental Euro category, engine displacement, and vehicle weight in order to apply the proper emission factors. This splitting procedure must be carefully performed because it is known to have a great influence on calculated emissions. In principle, the composition of the circulating fleet could be simply derived from the vehicle Public Register data without any manipulation, but for a more accurate estimate of emissions it is convenient to take into account that some Copert classes, usually the oldest, travel much less kilometers than others and the relative contribution on the vehicle category emissions is much lower (Andre et al., 1999; Caserini et al, 2007a; LAT/AUTh, 2008; Wang et al., 2008). One common way to consider the "age factor" is to define a set of yearly mileages driven on average by each Copert vehicle on urban roads and rural/motorways, based on statistical data and using them as weighting factors.

In this study, we applied annual mileages estimated by Caserini et al. (2011, 2013) to the vehicle register data of Piedmont Region for year 2008. The mileage, divided between urban and rural/motorways, gives two different fleet compositions, shown in the Supporting Material in terms of environmental "Euro" categories (see the SM, Figures S3 and S4).

Since the road network does not account for all roads, CO_2 emissions calculated from traffic flow data don't match CO_2 emissions estimated by official Piedmont Region Inventory in the Province of Turin on the basis of the fuel sold. The missing CO_2 was chosen to be allocated to urban diffuse emissions and split among all municipalities using the population as proxy variable (Carletti et al., 2013). The amount of pollutants associated to urban diffuse emissions was calculated on the basis of specific ratios derived from the amounts of CO_2 and other pollutants already calculated for all the urban roads of network. The procedure is simply described by three equations:

$$CO_{2\,diff} = CO_{2\,tot} - CO_{2\,lin} \tag{1}$$

$$CO_{2\,diff,\,k} = CO_{2\,diff} \times POP_k \tag{2}$$

$$POLL_{i,k} = CO_{2diff,\,k} \times POLL_{lin\text{–}urb,\,i} \,/\, CO_{2\,lin\text{–}urb} \tag{3}$$

where, $CO_{2\,diff}$ is the quantity of diffuse CO_2, not directly associated to the road network; $CO_{2\,tot}$ is the quantity of CO_2 associated in Piedmont Inventory (IREA) to road transport; $CO_{2\,lin}$ is the quantity of CO_2 calculated with the bottom–up approach for the whole road network; $CO_{2\,diff,\,k}$ is the quantity of CO_2 associated to diffuse traffic of the k^{th} municipality; POP_k is the population of the k^{th} municipality; $POLL_{i,k}$ is the quantity of pollutant i^{th} (NO_X, SO_2, PM_{10}, etc.) associated to the k^{th} municipality; $POLL_{lin\text{–}urb,\,i}$ is the quantity of pollutant i^{th} emitted from all urban links in the whole road network; $CO_{2lin\text{–}urb}$ is the quantity of CO_2 emitted from all urban links in the whole road network.

2.2. Piedmont region inventory

The emission inventory about road transport that we obtain using the bottom–up approach was compared with the official inventory compiled by the local authority, the Piedmont Region (Regione Piemonte, 2008).

The Piedmont Region Inventory was compiled using Inemar database (Arpa Lombardia, 2008), which combines both bottom–up and top–down approaches mainly referring to Copert