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Spatial inter-comparison of Top-down emission inventories in European urban areas

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ABSTRACT

This paper presents an inter-comparison of the main Top-down emission inventories currently used for air quality modelling studies at the European level. The comparison is developed for eleven European cities and compares the distribution of emissions of NO_x, SO_2, VOC and $PPM_{2.5}$ from the road transport, residential combustion and industry sectors. The analysis shows that substantial differences in terms of total emissions, sectorial emission shares and spatial distribution exist between the datasets. The possible reasons in terms of downscaling approaches and choice of spatial proxies are analysed and recommendations are provided for each inventory in order to work towards the harmonisation of spatial downscaling and proxy calibration, in particular for policy purposes. The proposed methodology may be useful for the development of consistent and harmonised European-wide inventories with the aim of reducing the uncertainties in air quality modelling activities.

1. Introduction

Emission inventories represent one of the key datasets required for air quality studies, but they are often recognised as the most uncertain input in the modelling chain (Borge et al., 2014; Guevara et al., 2013; Thunis et al., 2016a; Viaene et al., 2013) as their accuracy greatly varies with the type of pollutant, the activity and the level of spatial disaggregation (Davison et al., 2011). In Europe, this is largely due to the fact that regional and local emission inventories are managed and compiled by several different agencies which rely on different standards, methods and categories. This may be understandable given the different background and scope of the inventories, however it may yield to a heterogeneous and inconsistent picture when collating these data for use in modelling at a larger scale (continental and national levels). Furthermore, it is known that, in emission inventories, different measurement methods are applied for the same sectors, e.g. residential combustion which may result in emissions different up to a factor 5 (Denier van der Gon et al., 2015).

For this reason, there exist several top-down implementations that compile EU wide inventories by downscaling national emissions data at a finer resolution: EDGAR (Crippa et al., 2016; Janssens-Maenhout et al., 2017), HTAP_v2 (Janssens-Maenhout et al., 2015), TNO-MACCII and MACCIII (Kuenen et al., 2014, 2015), E-PRTR (Theloke et al., 2009, 2012), JRC07 (Trombetti et al., 2017). These inventories are all comparable in spatial (i.e. between ~10 km x ~10 km and ~7 km x ~7 km) and temporal terms (i.e. annual), geographical extent (i.e. European continent) and thematic resolution (sectors and macro-sectors aggregation) but differences remain in terms of national total emission estimates and/or spatial gridding methodologies. The first type of difference can be caused by model settings, reporting of emission sources, gap filling approaches, assumptions or arbitrary choices and has already been discussed for some inventories (Kuenen et al., 2014; Granier et al., 2011).

For the second difference, spatial discrepancies mostly depend on methodological assumptions, proxies' availability and choice of the weighting methodology. The fact that all these inventories are developed at a high spatial resolution (~7–10 km x ~7–10 km) reinforces this factor. As shown by Zheng et al. (2017), the spatial mismatch between gridded inventories developed from different spatial proxies is largely diminished at coarse resolutions (i.e. 25 km × 25 km) but

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tends to increase as grid size decreases (i.e. 4 km × 4 km).

These differences have often been overlooked and only studied for regional (i.e. sub-national) inventories (Winiwarter et al., 2003; Vedrenne et al., 2016) while only a few cases at fine scale have been published (Ferreira et al., 2013). These studies clearly stressed the importance of the assumptions behind the underlying proxies, their level of detail and their accuracy, to explain the very low spatial correlations found between target inventories. It is important to note that these spatial variations have a strong impact on air quality modelling results (Geng et al., 2017; Zhou et al., 2017), especially when the results are considered for policy making and planning options. Top-down emission inventories are often being used as input data for modelling activities at urban scale (López-Aparicio et al., 2017); therefore, particular attention should be given before choosing a specific dataset for this kind of modelling activities.

To our knowledge, our study is the only existing spatial intercomparison between emissions inventories currently used at the European scale. Its novelty lies on defining the possible uncertainties in the spatial proxies behind the disaggregation and allocations of emissions in urban areas and, consequently, on reducing the propagation of errors to air quality models and their applications.

This study assesses how a set of six EU wide emission inventories (i.e. EDGAR, TNO_MACCII, TNO_MACCIII, INERISinv, EMEP, JRC07) behave in selected European urban areas in terms of sectorial shares and regional allocation also through the application of a novel approach, namely the diamond analysis (Thunis et al., 2016b), in order to estimate systematically the spatial variability between them. This approach aims to contribute to increasing the reliability of emission inventories. We first describe the methodology and the emission datasets used, before identifying the main differences for the selected urban areas. Finally, recommendations to improve credibility for air quality modelling applications and reduce the level of uncertainty are provided for each inventory.

2. Methodology

We focus our analysis on the way emissions of NO_x, SO_2, VOC and $PPM_{2.5}$ are spatially distributed by different European scale top-down inventories. For this reason, the comparison is not made in terms of absolute, but rather in terms of normalised emission values. The values attributed to each grid cell of coordinates i and j for the variable $E^*_{s,p}$ represent the percentage of the total national emission for each emission pollutant "p" and sector "s", i.e.:

$$\forall\, s\,,\ \forall\, p\colon\ E^*_{s,p}(i,j) = \frac{E_{s,p}(i,j)}{E^{tot}_{s,p}}$$

where $E^{tot}_{s,p}$ represents the country total emission for a given sector and pollutant. With this normalisation, observed differences between inventories at a given grid cell do not depend on the original national emission value, but instead depend on the downscaling methodology and ancillary data used (Hiller et al., 2014).

The spatial analysis is performed for specific urban areas and for the main emission macro sectors: non-industrial combustion (SNAP02), industrial activities (SNAP03 and SNAP04, which are kept together in order to facilitate the comparison within inventories: SNAP34) and road transport (SNAP07). See the Supplementary Information (SI) for a description of the SNAP Macro Sectors (Table 1, SI).

The SNAP02 macro-sector consists of i) commercial/institutional stationary combustion; ii) residential combustion; iii) stationary combustion associated with agriculture, forestry or fishing; iv) other stationary. Given that the sector "ii) residential combustion" is the dominant one, the discussion in this paper focuses only on this subsector, hereafter referred to as 'Residential'.

Eleven cities (Barcelona, Bucharest, Budapest, Katowice, London, Madrid, Milano, Paris, Sofia, Utrecht and Warsaw) were selected across Europe to represent the diversity of environmental and anthropogenic factors (i.e. meteorology, economic activities, energy system, population density and land use) over the continental domain; in particular, the differences in Land Use cover reported in Table 2, SI, will affect the sectorial shares of emissions in each study site. For each city, the study area covers approximately 35 × 35 km^2, including only whole grid cells without having to split or resample them. With the exception of EDGAR, all inventories have similar spatial resolution and grid alignment, so it was possible to define common study areas. The EDGAR inventory has a different spatial resolution and so an alternative definition of the study areas was created resembling the original one, while preserving the integrity of the selected grid pixels. The standard study site and the adjusted EDGAR one for each urban area are shown in the SI with the considered land use pattern (Figs. 1 and SI).

The assessment is supported by the analysis performed by means of the diamond approach (Thunis et al., 2016b), a novel method which, by using total emission ratios, allows the comparison of emission inventories and the identification of the likely cause (activity level or activity share) of differences between them. Given the normalisation by the country totals, the differences seen among inventories in terms of activity levels and share can be directly attributed to the spatial disaggregation methodology.

2.1. Downscaled inventories

We consider six European scale top-down inventories, with 2010 as reference year, unless mentioned otherwise. The selected emission inventories cover a wide and important range of applications, including regulatory purposes (e.g. EMEP), monitoring services (e.g. TNO-MACC, EDGAR) and integrated assessment (e.g. INERISinv, JRC07).

- EDGAR version v4.3.1, January 2016 (European Commission, 2016a; Crippa et al., 2016), hereafter referred to as EDGAR. This inventory provides global emissions for gaseous and particulate air pollutants (BC, CO, NH_3, NMVOC, NO_x, OC, PPM_{10}, $PPM_{2.5}$, SO_2) per IPCC sector (Intergovernmental Panel on Climate Change) covering the whole time-series 1970–2010 at the global scale. Emissions are provided in tons of substance at 0.1 × 0.1° resolution. A highly detailed re-mapping of the sectors from the IPCC to the SNAP nomenclature has been made to allow comparing with the other databases. The simplified version of the mapping scheme from IPCC to SNAP codes is included in the SI (Table 3) together with the detailed reclassification for a representative SNAP MacroSector (SNAP04, Production Processes, Table 4, SI).
- TNO-MACCII (Denier van der Gon et al., 2010; Kuenen et al., 2011, 2014), hereafter referred to as MACCII. The TNO emission inventory was developed for Europe by TNO for the years 2003–2009. It has a 1/8° longitude x 1/16° latitude resolution and covers NO_x, SO_2, NMVOC, NH_3, CO, PPM_{10}, $PPM_{2.5}$ and CH_4. This dataset is not available for 2010, consequently the 2009 dataset has been used instead.
- TNO-MACCIII (Kuenen et al., 2014, 2015; MACC-III Final Report, 2016), hereafter referred to as MACCIII. It is the updated version of the TNO-MACCII product, which extended the time-series from year 2000 to year 2011. All years were revisited and the spatial distribution proxies updated and improved, often based on user comments.
- INERISinv (hereafter referred to as INERIS): The INERIS inventory is based the work by Bessagnet et al. (2016) with the following changes for the Macro Sectors analysed in this work.
  MS34: The E-PRTR database is used for Large Point Sources of emissions (Mailler et al., 2017)
  MS07: Road transport emissions of all considered countries are distributed using a proxy based on the combination of several databases and the French bottom-up emission inventory (Mailler et al., 2017)

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