

Comparison and assessment of two emission inventories for the Madrid region

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Abstract

Emission inventories are databases that aim to describe the polluting activities that occur across a certain geographic domain. According to the spatial scale, the availability of information will vary as well as the applied assumptions, which will strongly influence its quality, accuracy and representativeness. This study compared and contrasted two emission inventories describing the Greater Madrid Region (GMR) under an air quality simulation approach. The chosen inventories were the National Emissions Inventory (NEI) and the Regional Emissions Inventory of the Greater Madrid Region (REI). Both of them were used to feed air quality simulations with the CMAQ modelling system, and the results were compared with observations from the air quality monitoring network in the modelled domain. Through the application of statistical tools, the analysis of emissions at cell level and cell – expansion procedures, it was observed that the National Inventory showed better results for describing on – road traffic activities and agriculture, SNAP07 and SNAP10. The accurate description of activities, the good characterization of the vehicle fleet and the correct use of traffic emission factors were the main causes of such a good correlation. On the other hand, the Regional Inventory showed better descriptions for non – industrial combustion (SNAP02) and industrial activities (SNAP03). It incorporated realistic emission factors, a reasonable fuel mix and it drew upon local information sources to describe these activities, while NEI relied on surrogation and national datasets which led to a poorer representation. Off – road transportation (SNAP08) was similarly described by both inventories, while the rest of the SNAP activities showed a marginal contribution to the overall emissions.

Keywords: air quality modelling, emission inventory, scale interaction.

1 Introduction

Emission inventories describe the only direct link that exists between the atmosphere and human activities and are thus useful to guide on possible actions to be as to mitigate high concentrations [1]. Because emission inventories are geographically specific, the scale upon which each is compiled is an important issue to study. This premise highlights the fact that the analysed region might be described by several inventories differently, usually depending on the scale upon which each one has been built.

Emission inventories may be used for different objectives, namely policy purposes or scientific activity. To this respect, a policy maker might be interested in the fact that a given inventory is recognised as valid by the institutions involved the policy making process. When inventories are studied under a scientific scope, inventory data must be evaluated as whether they are true or not as well as if they describe reality accurately [2]. Under both perspectives, the scale factor is a very challenging issue. The difference in the development of scaled inventories lies in the level of detail of the input data, hypotheses, and analysed parameters. National inventories require a broader approach for emissions estimation, as they encompass sources with larger geographic scales, including air and maritime transport as well as the national energy grid. An emission inventory at national level also depends on many factors such as vehicle technology, socio – economic characteristics, transport policies, etc. This information is intrinsically included in each respective local inventory [3].

In order to evaluate the scale issue, the use of an air quality simulation approach seems reasonable since air quality models are a valuable information link between emission inventories and measurements at monitoring stations [4]. The robustness of the inventory is strictly related with the consistency, within an acceptable uncertainty margin, between the inventory modelled data and real observations [5]. If this does not occur, it is necessary to identify the causes of the departures between data pairs. This evaluation process may include tracing the original sources of the emission factors used to construct the inventory through testing the sample set for appropriateness, reproducibility, statistical variance, etc.; the assessment of the robustness of the survey and compilation techniques might give strong hints about systematic differences [6].

2 Materials and methods

This study relies on the baseline hypothesis that the accuracy of an emission estimate is related to the degree of correspondence of ambient observations and the results of an air quality model (AQM) fed with a given emission inventory. The analysis of the differential response of the AQM at representative points (monitoring stations) along with the analysis of the difference on alternative emission estimates is used to find out which of the underlying methods and information sets used in any of the inventories corresponds better with reality.

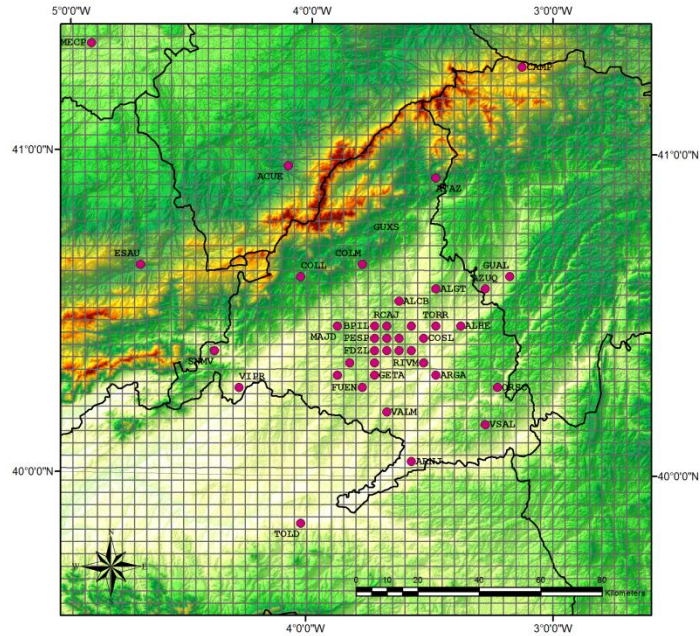


Figure 1: Modelled domain and monitoring network over the GMR.

2.1 Modelled domain

The GMR was modelled as a grid of $48 \times 48 \text{ km}^2$, with 2304 grid cells of a 4 km size each. This grid was centred approximately between the $5,0^\circ \text{ W} - 2,5^\circ \text{ W}$ longitudes and the $39,5^\circ \text{ N} - 41,5^\circ \text{ N}$ latitudes. The studied region included the entire Autonomous Community of Madrid (CAM) as well as some portions of the provinces of Avila, Segovia, Valladolid, Guadalajara, Cuenca and Toledo, fig. 1. The before mentioned geographic domain was studied from January 1st to December 31st, 2007 with an hourly resolution for the 365 days of the year.

2.2 Emission inventories

The National Emission Inventory is compiled by the Spanish Ministry for the Environment, and will be referred with the acronym NEI (National Emission Inventory) throughout this work. The Regional Emission Inventory has been produced by the Environment, Housing and Territory Council of the Autonomous Community of Madrid. References to this work will be made through the acronym REI (Regional Emission Inventory).

2.3 Air quality modelling

Two annual runs were carried out over the GMR domain to uncover any differences in using alternative inventories when estimating air quality. The implemented AQM system is the Community Multiscale Air Quality Model (CMAQ) [7]. Emissions were processed by the Sparse Matrix Operator Kernel Emissions (SMOKE) modelling system as described in Borge *et al* [8]. The meteorological fields needed to simulate the air pollution processes have been generated through the Weather Research and Forecasting (WRF) modelling system. Both emission datasets and meteorology corresponded to the year 2007.

Four pollutants were followed throughout the domain: nitrogen oxides (NO_x), sulphur dioxide (SO₂), and two fractions of particulate matter, PM₁₀ and PM_{2.5}. Although the reported pollutants for the emission inventories are total nitrogen oxides (NO_x), basically a sum of NO and NO₂, the assumption that mostly all the NO has been transformed into NO₂ will be considered as valid in order to make comparisons easier. Such an assumption seems reasonable since nitrogen dioxide is a regulated pollutant, as well as the more concerning than NO. It also happens that at urban surroundings NO rapidly oxidises to NO₂.

2.4 Statistical analysis

Using statistic indicators is useful to analyse the general performance of the inventories due to the great number of data to be processed. The selected statistic indicators for this work seek to characterise the performance of the modelling system under different perspectives (table 1). First, its ability to reproduce the temporal and geographical evolution of the prediction was evaluated by the Pearson's correlation coefficient (*r*). Second, the characterisation of the average behaviour through the mean bias (MB). Finally, the diagnosis of the general tendency for over or underprediction was examined from the mean fractional bias (MFB) values.

Table 1: Statistics used for model evaluation and experiment comparison.

Statistic	Units	Definition
Mean Bias (MB)	(ppm / $\mu\text{g}\cdot\text{m}^{-3}$)	$MB = \frac{1}{N} \cdot \sum_{i=1}^N (M_i - O_i)$
Mean Fractional Bias (MFB)	%	$MFB = \frac{2}{N} \cdot \sum_{i=1}^N \frac{M_i - O_i}{M_i + O_i}$
Pearson's correlation coefficient (<i>r</i>)	–	$r = \frac{\sum_{i=1}^N (M_i - \bar{M})}{\left[\sqrt{\sum_{i=1}^N (M_i - \bar{M})^2} \right] \cdot \left[\sqrt{\sum_{i=1}^N (O_i - \bar{O})^2} \right]}$

Additionally, Taylor diagrams were drawn as to have a better overview of the general behavior of the simulation looking to find a compromise between the

complexity of the evaluation and the need of having simple and straightforward diagnosis tools. These diagrams were drawn according to Thunis *et al* [9].

Comparisons were carried out with observations coming from a 55 – monitoring – station network conveniently placed over the GMR (Figure 1) and measuring the before mentioned pollutants on an hourly resolution.

2.5 Emission analysis at cell – level

For a certain number of stations, a detailed analysis of the emissions at cell – level was carried out, segregating such emissions according to the SNAP nomenclature. This analysis was conducted in two main aspects, namely (i) absolute emissions (E_{SNAPi}) for each pollutant and SNAP group, in daily emitted metric tons (ton/day) and (ii) the relative emissions of every SNAP group ($P_{SNAPi,j}$) over the gross totals computed for every pollutant, expressed as a percentage according to eqn (1):

$$P_{SNAPi,j} = \frac{\sum_{k=1}^N E_{SNAPi,j,k}}{E_j} \times 100 \quad (1)$$

Where $E_{SNAPi,j}$ are the emissions for pollutant j originated by activity k contained in $SNAP_i$, and E_j are the total emissions produced at the given cell for pollutant j .

3 Results

In general, it was shown that there are sound differences between both inventories describing the very same geographic domain. The basic criterion used to define well or badly correlated stations was the degree of departure between inventories at the summary diagrams for a given location. Although the fact of having high correlation coefficients was positively considered, it was not a core – concept for discriminating between stations. Additionally, stations located away from the city centre of Madrid were preferred above those emplaced at the urban nucleus.

For well correlated stations, the points for both inventories lie closely while bad correlated stations exhibit sizeable distances in between. Figure 2 shows the well correlated stations chosen for the description of the GMR, where it is also evident that the points for both inventories, NEI and REI lie close to each other. For nitrogen dioxide, most of these well – correlated stations showed high correlation coefficients (r). As for particulate matter (PM_{10} , $PM_{2.5}$), stations classified as well – correlated according to the before mentioned criterion, exhibited poor correlation coefficients in every case below $r = 0.4$. Furthermore, these stations presented systematic errors ($\sigma_M < \sigma_O$) and negative mean bias values (MB), as Figure 2 suggests. However, they were selected for presenting the best available performance for particles.

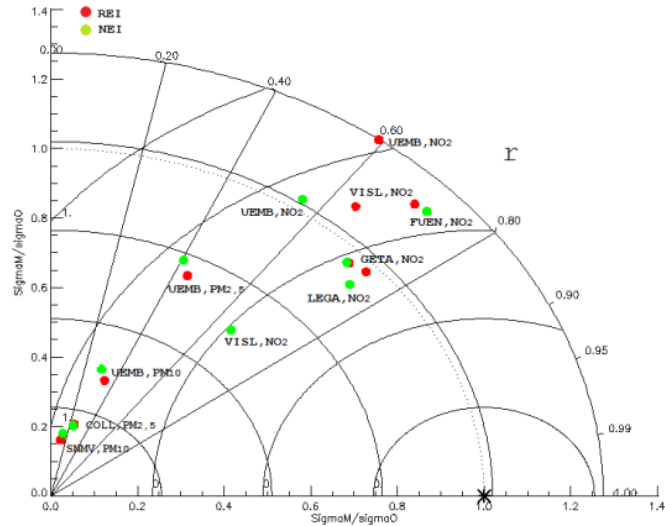


Figure 2: Taylor diagram for the analysed stations.

Badly correlated stations in most cases exhibit both, high departures between points and low correlation coefficients. In the case of particles, the presence of highly negative mean bias values (MB) was an additional feature that was regarded to classify stations as such.

The chosen stations for sulphur dioxide have not been presented in Figure 2 because of their high mean bias values, which would affect the scale of the diagrams. For example, Arganda del Rey (ARGA) shows a mean bias value of 13.43 ppb for the REI, with a very low correlation coefficient ($r = 0.02$). On the contrary, Leganés (LEGA) presents a high correlation coefficient for both inventories ($r = 0.60$).

4 Discussion

4.1 Non – industrial combustion plants (SNAP02)

This group includes combustion devices with low thermal capacities, namely those used for heat generation at residential and service buildings. Through inspection, it seems that the uses of boilers at commercial and institutional sectors (020103) as well as in residences (020302) are the cause of the observed distortions. The analyses for this activity group have been carried out over the Urbanización Embajada (UEMB) station. Nitrogen dioxide emissions produced by the problematic activities have been differently accounted by both inventories. While the REI computed a total emission of 0.011 ton/day, the NEI quantified a threefold emission, namely 0.033 ton/day.

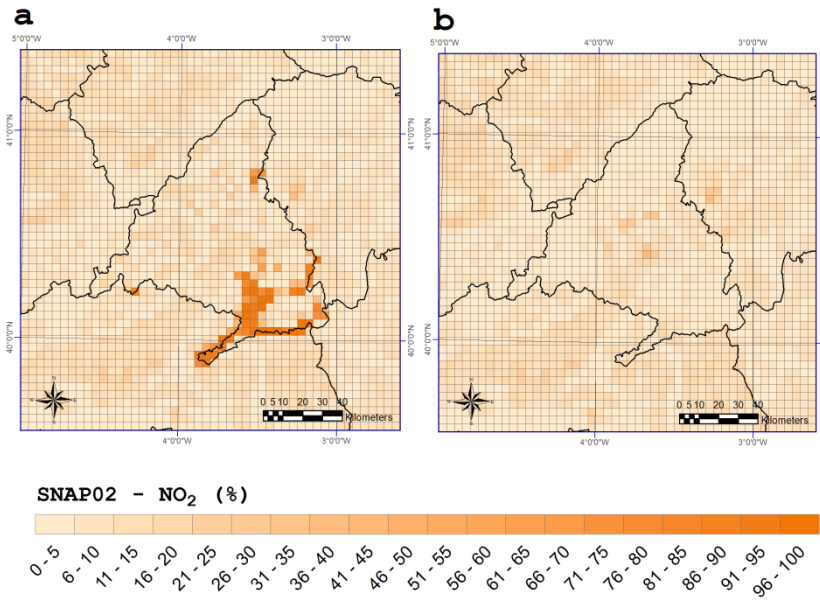


Figure 3: SNAP02 percentage (P_{SNAP02}) at cell level for NO₂ over the GMR according to a) REI and b) NEI.

The REI apportioned 5% of such emissions to the commercial and institutional sectors while the rest, a 95% was assigned to the residences. On the other hand, the NEI assigned a 15% to the first activity and an 85% to the latter. A similar behaviour is observed with PM₁₀ and PM_{2.5} emissions at this precise location. The NEI estimated PM₁₀ emissions to be 0.036 ton/day and the REI a total of 0.011 ton/day, while for PM_{2.5} the emissions were 0.033 ton/day and 0.017 ton/day respectively. The share of each respective sector is exactly the same as the one for NO₂.

Slightly differences were observed for SO₂, for which the NEI distributed 52% of the emissions for the commercial and institutional sectors and 48% to residential heating for a total emission rate of 0.156 ton/day. Conversely, the REI maintained the same proportions between sectors even for this pollutant, of which 0.168 ton/day are produced.

Figure 3 shows the spatial distribution of P_{SNAP02} at cell level for NO₂, for the entire GMR. As it is evident, the REI is able to differentiate between cells that are highly influenced by SNAP02, basically suburban and rural locations where road – traffic tends to contribute less; the NEI on the other hand, shows a uniform contribution degree of SNAP02 throughout the studied domain. The fact that this inventory is not able to differentiate between zones is an indicator of its poor resolution degree for the chosen scale.

The differences observed in this category are a consequence of the fact that the NEI considers consumptions of a representative Spanish fuel mix composed of coal, petroleum coke, natural gas, LPG, among others. On its behalf, the REI has made a series of assumptions which distributed certain fuel types exclusively to certain sectors; in this case for the residential and commercial sectors LPG and natural gas were assigned as the only fuels being consumed.

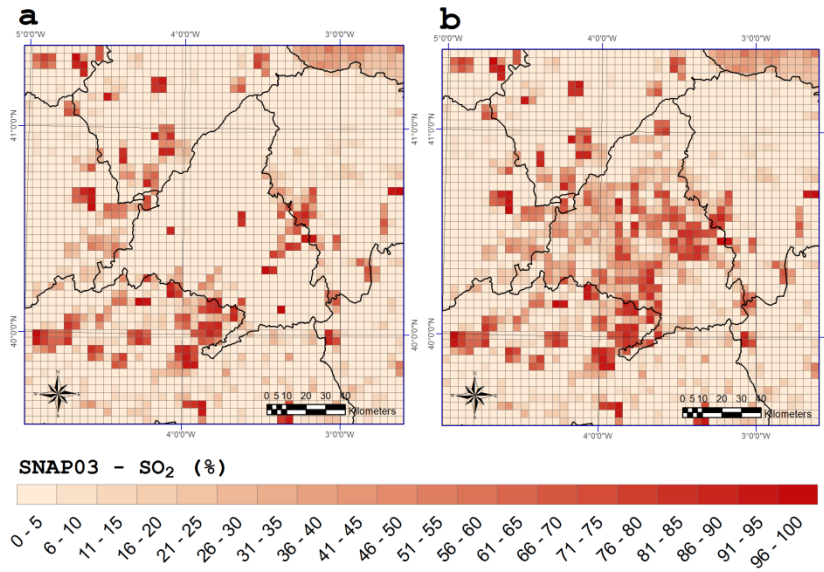


Figure 4: SNAP03 percentage (P_{SNAP03}) at cell level for SO₂ over the GMR according to a) REI and b) NEI.

4.2 Industrial combustion plants (SNAP03)

The analysis for this SNAP group was best described by the behaviour of SO₂ emissions. The observed differences between inventories are dramatic, depicted by the spatial distribution of E_{SNAP03} at cell level in Figure 4. While the REI inventory identifies SNAP03 contribution at much localised points, the NEI inventory considers a heavy contribution of SNAP03 on SO₂ emissions over a wide area of the domain. This very first assessment might not be completely right, since the Madrid region is not reputed for hosting extensive industrial zones. The analysis was carried out over Arganda del Rey (ARGA), which is of industrial type. The NEI accounted for this location a total of 0.26 ton/day, of which combustion plants (030103) had a 41%, gas turbines (030104) an 11%, stationary engines (030105) and plaster furnaces (030204) a 6% each and lime processes (030312) a 34%. On the contrary, the REI computed a total emission of 2.46 ton/day for this location which is 9 times higher than the NEI value and is caused in a 99% by lime processes.

It seems that the NEI has the provincial level as the maximum data resolution. To this respect, emission processing has been carried out through a surrogation, as described in Borge *et al* [8] applied over industrial and commercial land uses specified by the CORINE land cover database. The REI relied on a direct on-site activity variable collecting campaign, accomplished through the use of the questionnaires and surveys such as PRTR and the request of private information.

This surrogation process is deemed to be the cause of the large discrepancies observed between inventories, experienced by the high overestimations produced by the MB values for the NEI against the REI. Hence, the use of surrogate disaggregation is not recommendable for finer resolutions, encouraging the use of local or regional emission inventories instead, when available. Typically, SO₂

is not a good pollutant to be surrogated since it is known that few large point sources dominate the spatial emission pattern for such pollutant.

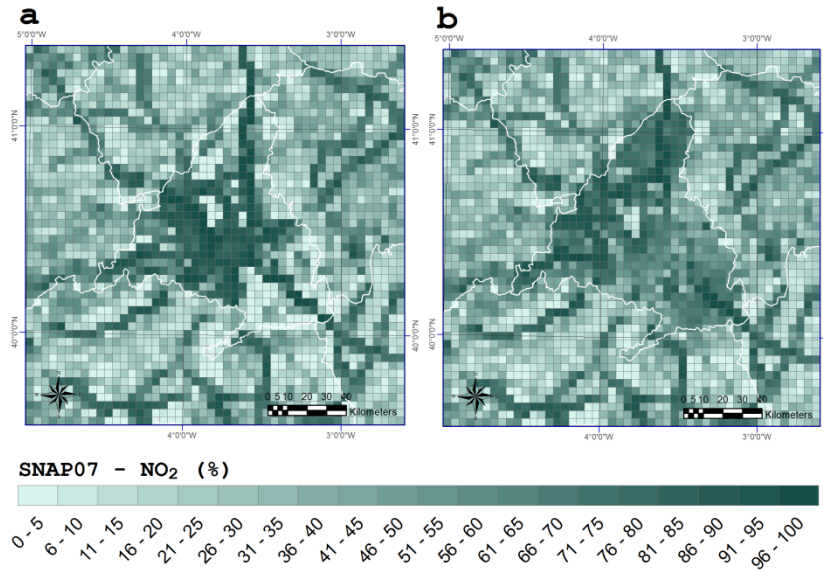


Figure 5: SNAP07 percentage (P_{SNAP07}) at cell level for NO₂ over the GMR according to a) REI and b) NEI.

4.3 Road traffic (SNAP07)

Emissions coming from road traffic are the most relevant throughout the entire GMR. Figure 5 shows the spatial distribution of the SNAP07 contribution (P_{SNAP07}) at cell level for NO₂, for the studied domain. The NEI shows lower SNAP07 percentages for the city centre and cells where highways are located show moderate values; the REI on the contrary shows heavy SNAP07 contributions along highways and the city centre, while no continuity with the neighbouring provinces is evident.

The Getafe (GETA) station is clearly classified as a well – correlated location. Passenger cars under highway driving (070101) have a 12% share at the NEI and 13% at the REI, accounting both a 0.33 ton/day emission. Passenger cars under urban driving (070103) are heavily considered by the NEI (0.90 ton/day – 33%) while the REI made an analogous consideration with heavy duty vehicles under highway driving (0.98 ton/day – 38%). Although these categories were accounted differently, the total emissions were computed similarly: the NEI reporting a 2.67 ton/day rate and the REI 2.53 ton/day. A similar behaviour was observed for Fuenlabrada (FUEN) and Leganés (LEGA). For the first station, the

NEI quantified 1.64 ton/day and the REI 1.82 ton/day and for the latter, 2.89 ton/day and 3.21 ton/day respectively.

On the contrary, for Villarejo de Salvanés (VISL), the source of differences is basically the overwhelming consideration of HDV under highway driving by the REI. For this category, this inventory quantified 1.06 ton/day (69%) against 0.15 ton/day (20%) reported by the NEI, computing a total 1.52 ton/day for the first inventory and 0.74 ton/day for the second. This situation is also evident if analysing the emissions at Arganda del Rey (ARGA), with 0.91 ton/day from the REI against 0.22 ton/day from the NEI and Rivas Vaciamadrid (RIVM) with 1.22 ton/day and 0.07 ton/day respectively.

The main source of discrepancies between both inventories for this activity seems to be an excessive contribution of heavy duty vehicles in highway driving situation. Normally, activity ratios (traffic intensity) should be more accurately depicted by the REI, since it is based on link – specific traffic intensities. However, it appears as if COPERT has not been run at road – level, being secondary emission factors used instead. This fact points out the need of a purely bottom – up computation approach, whenever detailed traffic data are available.

One problem that needs to be urgently solved is the omission of some important PM10 emission activities in the REI, such as the wear of brakes and clutches which are usually within the coarse particle fraction [10]. About 40% of total particle emissions coming from traffic are brake wear related emissions [1]. Thus, the need to importantly consider such emission sources at every inventory is paramount.

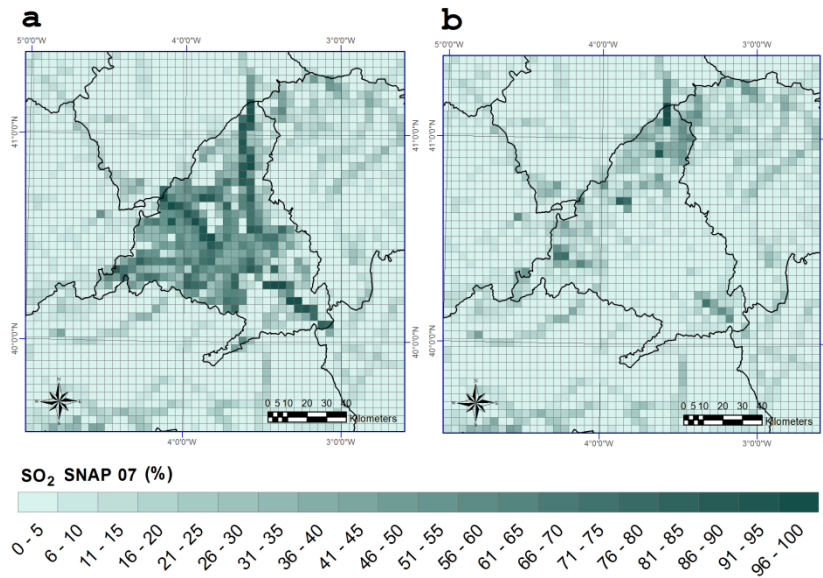


Figure 6: SNAP07 percentage (P_{SNAP07}) at cell level for SO₂ over the GMR according to a) REI and b) NEI.

Finally for SO₂, an analysis carried out over the Fuenlabrada (FUEN) station exhibited sensitive differences between inventories for SNAP07. The total emissions reported by the REI are 0.056 ton/day while the NEI presented a 0.009 ton/day value, approximately sixfold. The NEI yielded a total 271 ton emission for 2007, while the REI gave a 2.876 ton emission. The cause of discrepancies is the fact that the REI incorporated emission factors from the NEI for 2004 whose sulphur content in fuels was higher than for 2007. This is such a situation in which the predicted concentrations are directly proportional to the used emission factors, which led to high on – road SO₂ emissions, as it can be seen in Figure 6. This fact stresses out the need of keeping emission factors up to date with any modifications.

4.4 Agriculture (SNAP10)

Although agricultural activities exhibited low absolute emissions, the considered activities showed sound differences among inventories. Analysis for PM₁₀ at San Martín de Valdeiglesias (SNMV) revealed that the NEI clearly considers more categories than the REI version, of which manure management (100500) has an overwhelming contribution to the total emissions (1.6×10^{-4} ton/day). If comparing the gross totals for both inventories, the emissions compiled by the NEI inventory are 60 times higher than the emissions considered by the REI, namely 1.6×10^{-4} ton/day against 2.6×10^{-6} ton/day. A tendency to underestimation was evidenced by the very low MFB at this location, –139.9 % for the REI and –135.8 % for the NEI. For the whole domain, the causes for differences within this category are basically related with the considered activity variables and emission factors.

5 Conclusions

According to the general issues discussed above, the estimates produced by the REI are better for almost every SNAP category except for road traffic (SNAP07) and agriculture (SNAP10). At these weak points, the NEI behaved more accurately. This study has shown that the sources of disagreement between inventories and actual observations are due to a series of issues. The data and information scale upon which each of the inventories has been based their assumptions is different; the NEI incorporated data from national and supra – national entities (national ministries, international agencies, etc.), the REI used information coming from national and regional sources.

When describing a given domain, available information for the scale of this domain should be chosen over information available for larger or smaller scales. Although surrogation is a smart procedure to transfer these large – scale to smaller scales, a limit scale exists under which the resulting information is no longer adequate.

Given the fact that emission inventory compilations need to be fed with a huge amount of data, the quality of this information is vital to guarantee their quality. It is therefore of paramount importance to assure that the information is

actual, valid and representative. The inventory compiler might come across the dilemma between describing a certain activity using the best methodological resources yet reproducing reality inaccurately or even worse, not reproducing it. In every case, common sense should always prevail.

In general terms, the fact of having a real and accurate emission inventory would result in better, cheaper and more assertive monitoring and control policies whose final aim is assure a good environmental quality for life and health. Therefore, considerable effort should be still put on harmonising and reconciling inventory scales.

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