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**SENSITIVITY ANALYSES REGARDING NO<sub>2</sub> EXPOSURE ASSESSMENT AND HEALTH  
IMPACTS AT A EUROPEAN SCALE.**

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**Abstract:** Currently, no adequate methodology exists to assess the NO<sub>2</sub> health impacts at an EU-wide level. To a large extent this is attributed to the level of detail required in the NO<sub>2</sub> concentration assessment at EU-level due to the strong spatial gradients for NO<sub>2</sub> around roads. In this contribution we present a sensitivity analysis of the major sources of uncertainty in such an EU-wide health impact assessment for NO<sub>2</sub>. We do this by means of a number of bottom-up NO<sub>2</sub> assessment maps contributed through the FAIRMODE composite mapping platform. We investigate the impact of the spatial resolution of the NO<sub>2</sub> assessment, the available dose response curves and a number of ancillary datasets such as gridded population. We find that the largest source of uncertainty is found in the divergence between the different CRF's available, in particular the choice of a 'cut-off' or 'threshold'. For some cities, such as London, the difference is relatively small. However, the difference for smaller cities, such as Klagenfurt can go up to a factor of 6. Spatial resolution of the air quality maps and population maps is an important factor and depending on the concentration response function, the sensitivity is stronger. This work has been performed in the framework of the DG-ENV service contract 070201/2015/SER/717473/C.3, the conclusions of which contributed to the development of an EU-wide high resolution NO<sub>2</sub> exposure assessment methodology.

**Key words:** *NO<sub>2</sub> exposure, health effects, sensitivity study.*

## **INTRODUCTION**

Elevated concentrations of NO<sub>2</sub> in the ambient air and the health impact attributable to NO<sub>2</sub> exposure are of increasing societal concern: the European Environment Agency (EEA) estimates this to be in the order of more than 70.000 premature deaths across the EU-28 in the year 2012 alone. Given the high spatial variability of NO<sub>2</sub>, especially in hot-spot urban environments, a sufficiently detailed assessment of NO<sub>2</sub> at EU-wide scale remains a challenge. The question however is, "what is sufficient?". In this study we explore a number sensitivity studies targeted at defining the requirements for an improved EU-wide NO<sub>2</sub> exposure assessment methodology. These studies aim to address the uncertainties in deriving population health impacts on an EU scale when considering spatial resolution, population datasets, the concentration response function (CRF), mortality data, population age distribution as well as the effects of dynamic vs. address-based exposure.

## **ANALYSIS**

In order to study these sensitivities, we made use of high resolution NO<sub>2</sub> assessment maps generated by local air quality experts using bottom up emission data. These maps were contributed to the FAIRMODE composite map exercise<sup>1</sup>. The maps for Flanders (VITO, IFDM Gaussian model at 25 m), London (CERC, ADMS Urban at 20 m), Stockholm (Environment and Health Administration, City of Stockholm, Airviro Gaussian model at 30 m), Styria (Umwelt Steiermark, GRAL 25 m), Vienna/Salzburg/Klagenfurt (TU Graz, GRAL at 10 m) and Barcelona (Departament d'Intervenico Ambiental, ADMS-Urban, 5 m) were used in our studies.

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<sup>1</sup> <http://fairmode.jrc.ec.europa.eu/tools.composite.map.html>

### **Spatial scale**

Ideally, the same spatial scale that was used in the original NO<sub>2</sub> data in the epidemiological studies should be employed for the NO<sub>2</sub> assessment scenario calculations. The NO<sub>2</sub> exposure of the participants in epidemiological studies and the health effects, encoded in the RR factors, are statistically linked to that original data. This link should be respected when applying the CRF elsewhere. A key problem is that the spatial scale of the epidemiological studies is not always clear. The question however is how sensitive the results are to the spatial scale in practice.

The sensitivity w.r.t. the spatial scale was assessed by gradually decreasing the resolution via spatial averaging of the contributed high-resolution maps. In this process, we aggregated the maps from their native resolution, as given above, to a 20km<sup>2</sup> resolution. Though this approach cannot entirely be considered representative for running an air quality model at different scales, we can consider it to be a good first approximation. The results of this dependency for the number of attributable deaths are summarized in **Figure 1** below.

### **Population dataset**

Different EU-wide population datasets exist from which exposure can be derived. In this study, we considered the JRC population grid (*popu01clcv5*) (Gallego, 2010), the GEOSTAT population dataset, the Global Human Settlement Layer dataset for 2015 (*ghs2015*), and the INTARESE / HEIMTSA Age/Sex disaggregated population grid (*iehias*). It must be noted that even though the *popu01clcv5* and derived datasets are presented at a 100m grid, their intrinsic resolution is probably closer to 1 km except for locations where detailed local data was integrated in the EU-wide grid. Regarding the analysed cities, a difference of up to ~7 % was observed between different population datasets in the population weighted mean concentrations.

### **Concentration response function**

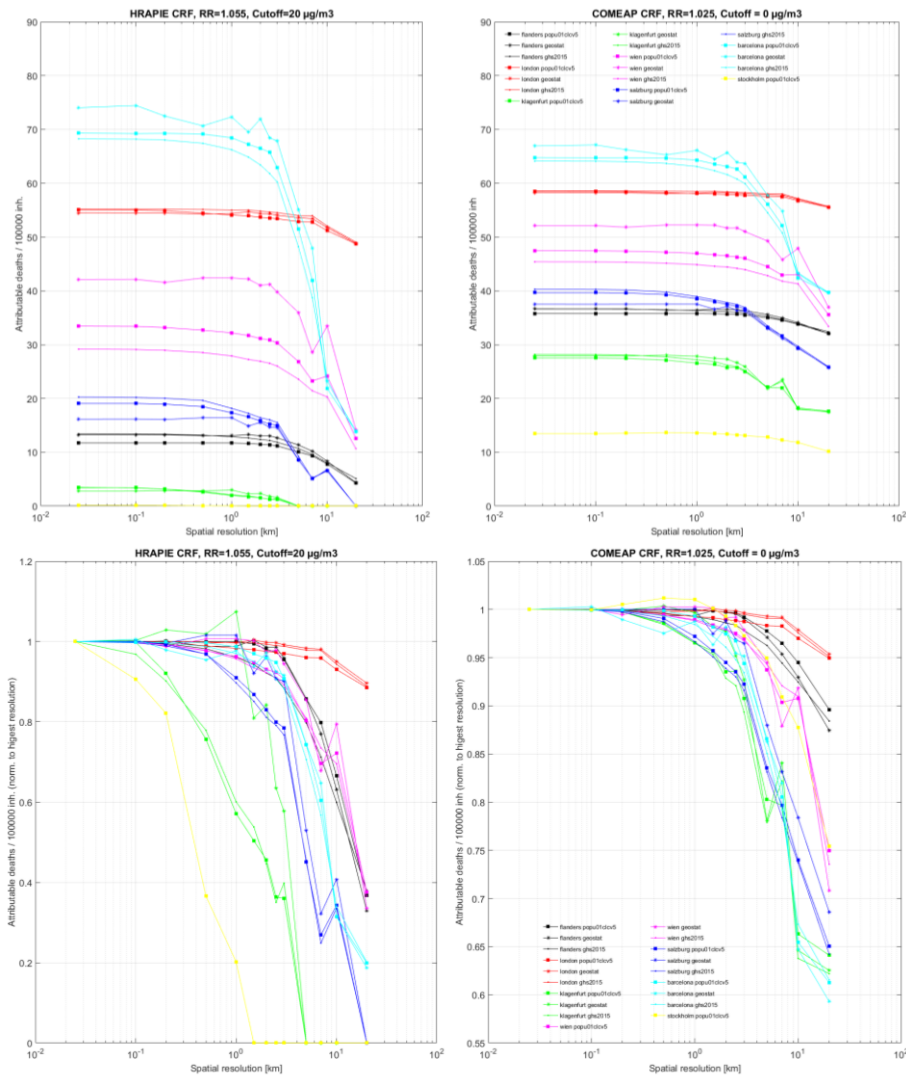
At the time of writing different recommended CRFs were available for assessing NO<sub>2</sub> health impacts. The ones considered were the WHO HRAPIE CRF with a higher relative risk of 1.055 and a cut-off at 20 µg/m<sup>3</sup>, and the preliminary CRF recommendation from the UK Committee of the Medical Effects of Air Pollutants (COMEAP) group, released in 2015, in which a lower RR of 1.025 per 10 µg/m<sup>3</sup> was proposed without a cut-off<sup>2</sup>. Both RR values are to be reduced by 33 % to account for possible overlaps with PM<sub>2.5</sub>. In this study, we compared the amounts of attributable premature deaths for the different contributed domains calculated with the different CRFs.

We observed that for all cities except Barcelona, the COMEAP number of attributable premature deaths is significantly higher than in the HRAPIE case. For Barcelona, we noticed that the number of attributable premature deaths according to COMEAP is systematically lower than when calculated with the HRAPIE CRF. Furthermore, it was noted that the sensitivity to spatial resolution is much less pronounced when using the CRF without a cut-off. Especially in the case of Barcelona, we clearly see a much steeper drop-off starting at ~1 km spatial resolution when using the HRAPIE CRF. This is consistently so for all the cities considered.

The difference in estimated health effect between the two CRFs also depends strongly on the concentration levels. For regions with lower NO<sub>2</sub> concentrations (Klagenfurt, Salzburg), the difference is easily a factor of 2 or more, for regions with higher concentrations (London, Barcelona), the difference is smaller. The difference between the CRFs for Flanders is also relatively large as we have considered the whole region, not only the hotspots in the city (as is also the case with Stockholm). Finally, the COMEAP CRF also accumulates mortality outside hotspot regions, whereas the 20µg/m<sup>3</sup> cut-off in HRAPIE limits the mortality to areas with higher concentrations.

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<sup>2</sup> COMEAP has not yet completed its report, but a preview of the COMEAP conclusions was included in the 'Technical Report in the Defra Plans for tackling NO<sub>2</sub> concentrations in the UK' from July 2017. It can be found in Annex A of [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/632916/air-quality-plan-technical-report.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/632916/air-quality-plan-technical-report.pdf). A RR of 1.023 is recommended for use to assess the traffic mixture, and a smaller one for the analysis of policies that reduce NO<sub>x</sub> emissions alone. Earlier discussions suggested calculations should be done with and without a cut-off of 5 µg/m<sup>3</sup>.



**Figure 1.** Top: Comparison between the number of attributable deaths for the different areas using different population datasets as a function of spatial resolution (x-axis) expressed as the number of attributable premature deaths per 100,000 inhabitants (y-axis). The left panel shows the result using the HRAPIE CRF, the right side the COMEAP Interim result. Bottom : normalised to the results of the assessment with the highest spatial resolution.

**Baseline mortality rates**

HRAPIE (WHO, 2013) recommends the use of the WHO mortality database which contains all-cause mortality rates by country. Ideally, the health impact assessment method would take the spatial variation in mortality rates into account. We carried out some initial exploration of the data comparing concentrations and mortality at ward level, and mortality rates for all ages obtained from the UK Office for National Statistics. There was a 6 – 12 % underestimate when using country wide mortality rates compared to using local ones when comparing life-years lost. This issue becomes more important when using cut-offs in the CRF as the parts of the country with lower NO<sub>2</sub> concentrations do not necessarily have the same distribution of mortality rates as the country as a whole.

**Population age distribution**

In this study, a very brief analysis was performed of the difference in exposure for the entire population and the population above 30. This preliminary investigation does not take the full age distribution or different mortality rates in different age groups into account. The differences in exposure appeared to be only minor, for example in the order of 1% in the population weighted averaged concentrations at the

scale of London. These results confirm to some extent the rather small impact of gender and age on the exposure which were found in (Gariazzo et al., 2016). Note that (Cesaroni et al., 2013) mentions evidence of differences in health effects dependent on age and sex, with stronger effects for males (though controversial) and in the younger age group (< 60 years).

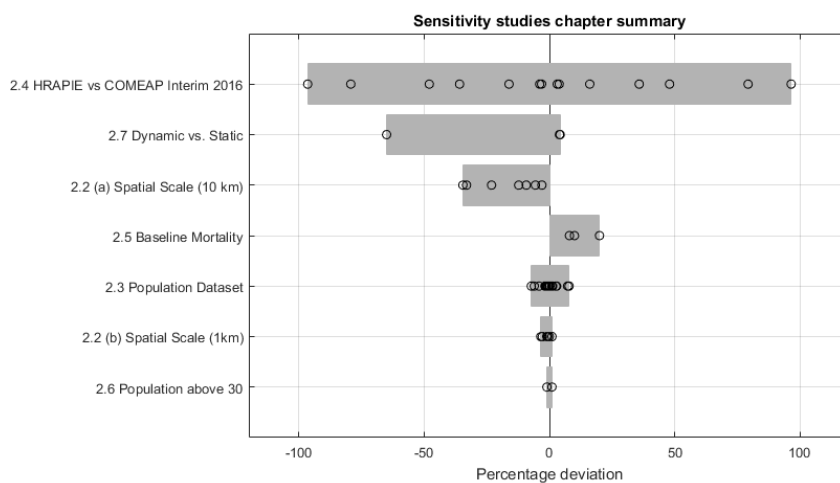
### Dynamic vs. Static exposure

Finally, we comment on the sensitivity of the estimated number of premature deaths with respect to the exposure assessment methodology. As mentioned above, we focused here on a static exposure assessment methodology, because using a dynamic or a personal approach is currently not feasible at an EU-scale. However, the question arose whether there is a significant difference between both approaches. A number of studies have already demonstrated significant differences between observed personal exposure and estimated exposure outdoors at the residential address (Adgate et al., 2007; Brauer et al., 2002; Cyrys et al., 2008; J.D Smith et al, 2016). There are arguments however that indicate that a static exposure estimate can be considered to be a reasonable approximation at population level.

When taking mobile phone data-based travel patterns into account, (Dewulf et al., 2016) found a 4.3 % increase in total (Belgian) population exposure during the week and 0.4 % during the weekend compared to a static assessment. This is in line with the findings of the TECNAIRE-CM project<sup>3</sup>. In contrast, (Smith et al., 2017) found annual mean exposure to be 63% lower when using a dynamic approach in London. This study was based on a travel-demand survey and micro-environment concentrations, including lower ambient pollution-derived concentrations indoors.

## CONCLUSIONS

The plot below summarizes the sensitivity studies performed in this study. We can formulate the following conclusions:



**Figure 2.** Plot summarizing the sensitivity studies conducted in this chapter. The plot shows the range (minimum – maximum) of percentage deviations over the different cities considered (or values obtained from literature). The individual markers show the values for the individual cities/literature results.

- The exposure assessment and the health impacts are most sensitive to the CRF used and the uncertainty associated with it. Between the two different CRFs considered in this study, the health impacts differ by a factor of 2 to 3 in regions with moderate concentrations. This is mainly because with a hard cut-off, the NO<sub>2</sub> concentrations below the threshold are not taken into account. In urban hotspot areas, with NO<sub>2</sub> levels well above 20 µg/m<sup>3</sup>, the difference is smaller, but still the most dominant source of uncertainty.
- We found that the population dataset and its disaggregation is the second largest dominant source of uncertainty (when neglecting effects of dynamic exposure). This was clearly illustrated by the large

<sup>3</sup> [http://tecaire-cm.org/wp-content/uploads/2016/08/ICCS\\_2016-RBorge.pdf](http://tecaire-cm.org/wp-content/uploads/2016/08/ICCS_2016-RBorge.pdf)

differences in particular for the city of Vienna which showed significantly different population averaged NO<sub>2</sub> concentrations when using different population disaggregation methods. Note that this issue is relevant to any pollutant, not just NO<sub>2</sub> and is an issue for improving health impact calculations across the board.

- The sensitivity with regard to spatial scale is a less dominant source of uncertainty when the spatial scale of the NO<sub>2</sub> assessment is finer than 1 km. We cannot conclude however that this is sufficiently high resolution, instead it is recommended to attain a resolution in the order of 100m, EU-wide. For assessments with a spatial resolution coarser than ~5-10 km, the spatial resolution becomes a dominant source of uncertainty. The sensitivity to spatial scale is diminished when using a CRF without a hard cut-off.
- On a population scale, static exposure can probably be used as an adequate approximation at EU level, if it is assumed that the relationship between the static exposure and the population distribution of dynamic personal exposures is similar to that in the original studies used to derive the health impacts.

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