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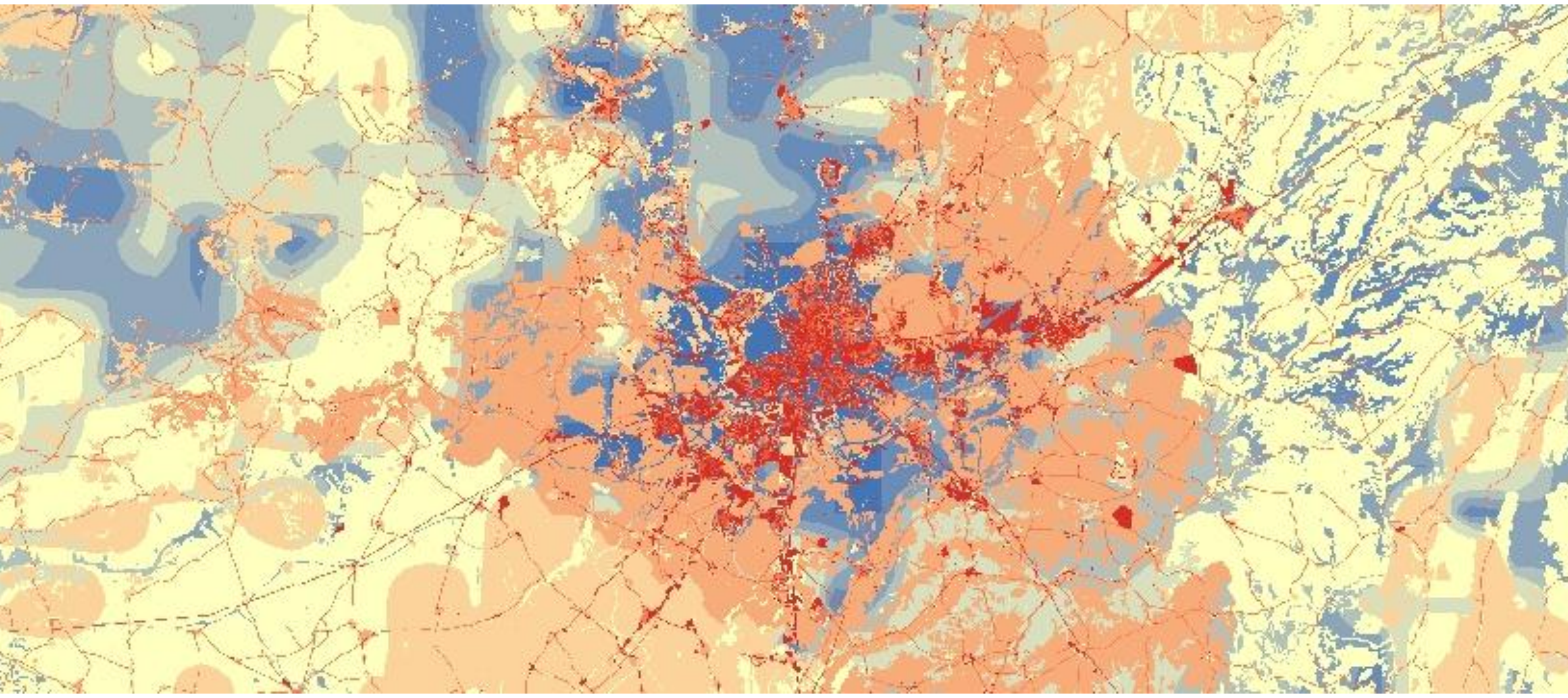

# Methods for Regional Integrated Assessment: High resolution gridded emission distribution in the LUISA Platform

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2014

Report EUR 27005 EN

Joint Research Centre

**European Commission**
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JRC93813

EUR 27005 EN

ISBN 978-92-79-44672-6 (PDF)

ISSN 1831-9424 (online)

doi:10.2788/46604

Luxembourg: Publications Office of the European Union, 2014



**Abstract**
This report illustrates the progresses made towards the inclusion of air quality related issues in the Land Use-based Integrated Sustainability Assessment (LUISA) platform. It focuses on the description of the methodology to derive high-resolution gridded-emission spatially geo-referenced layers from outputs and datasets integrated in LUISA.
In the framework of the integration of the Regional Integrated Assessment Tool (RIAT model) and the Land Use Modelling Integrated Sustainability Assessment (LUISA) platform, we implemented the downscaling of atmospheric emission data from national level to very high spatial resolution (100m). The GAINS model (IIASA) provides the input emission data for different scenarios, up to year 2030, which are disaggregated based on 34 different surrogates. Each surrogate is calculated by means of the integration of several proxies derived by statistical datasets, ancillary models and GIS layers in the framework of the LUISA platform. The preliminary results for NOx, PM10 and NH3 (year 2010) are presented in this report together with their first assessment, based on existing emission maps at 7 and 10 Km resolution. Future steps for further refinements are also discussed.

## Contents

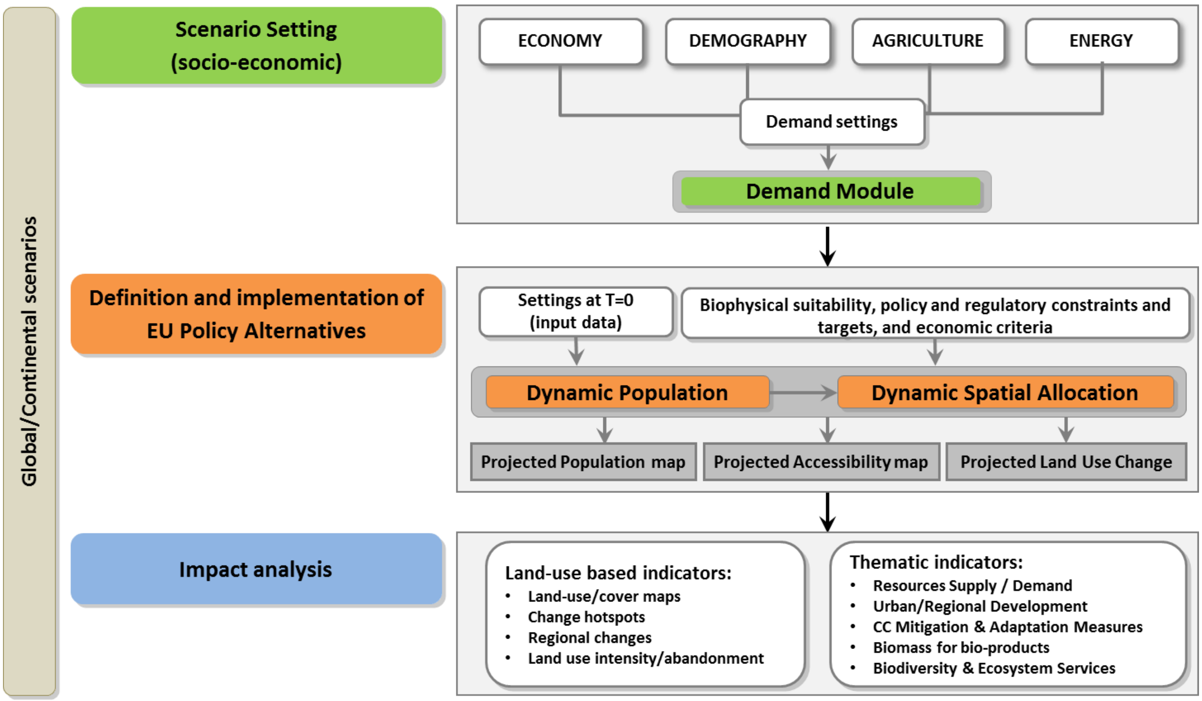
# 1. Introduction

This report illustrates the progresses made towards the inclusion of air quality related issues in the Land Use-based Integrated Sustainability Assessment (LUISA) platform. It focuses on the description of the methodology to derive high-resolution (100x100 mt) gridded-emission spatially geo-referenced layers from outputs and datasets integrated in LUISA.

The research work is part of a joint effort between the Sustainability Assessment Unit (H08) and the Air and Climate Unit (H02) of the Institute for Environment and Sustainability, towards the integration of the RIAT (the Regional Integrated Assessment Tool) model and the LUISA platform.

## Background

The Land Use Integrated System Platform (LUISA) is an integrated framework in "support to the conception, development, implementation and monitoring of EU policies". Such a framework is based upon the integration of spatially explicit land use models with other modelling activities in thematic fields such as hydrology, agriculture, economy, forestry, etc.




In this context, a planned development of the platform is the integration with the modeling efforts on-going in the HO2 unit, in the field of air-quality (ref.: submitted paper with the title: "A new approach to design source-receptor relationships for air quality modeling", by Clappier A., E. Pisoni and P. Thunis). The air-quality model to be integrated in the LUISA platform is the Regional Integrated Assessment Tool (RIAT) model. RIAT (Carnevale et al., 2012) implements an integrated assessment modeling approach for air quality, with a focus on the regional/local scale. More in details, RIAT is based on the following components:

- Source-receptor models, to simulate the link between emissions and concentration levels at a high spatial resolution. These source-receptor models provide a quick evaluation of the effect of regional/local scale policies on air quality;

- Abatement measures, to evaluate costs and benefit of air quality policies. Based on an optimization approach, RIAT is in fact able to deliver an optimal set of emission reduction measures to be implemented at the local scale, to improve air quality given a cost constraint. The RIAT framework allows i.e. to use a GAINS projection as starting point scenario, to analyze which policies can be further applied at the regional/local level "on top" of EU-wide policies.

Currently, one of the main limitations to apply RIAT is related to the difficulties in producing the needed input data. LUISA contains data and methods that can help in this direction, as explained in the following sections.

## Integration of RIAT and LUISA

The integration between RIAT and LUISA can be implemented in various directions. The next Figure shows the foreseen interactions between the two models.

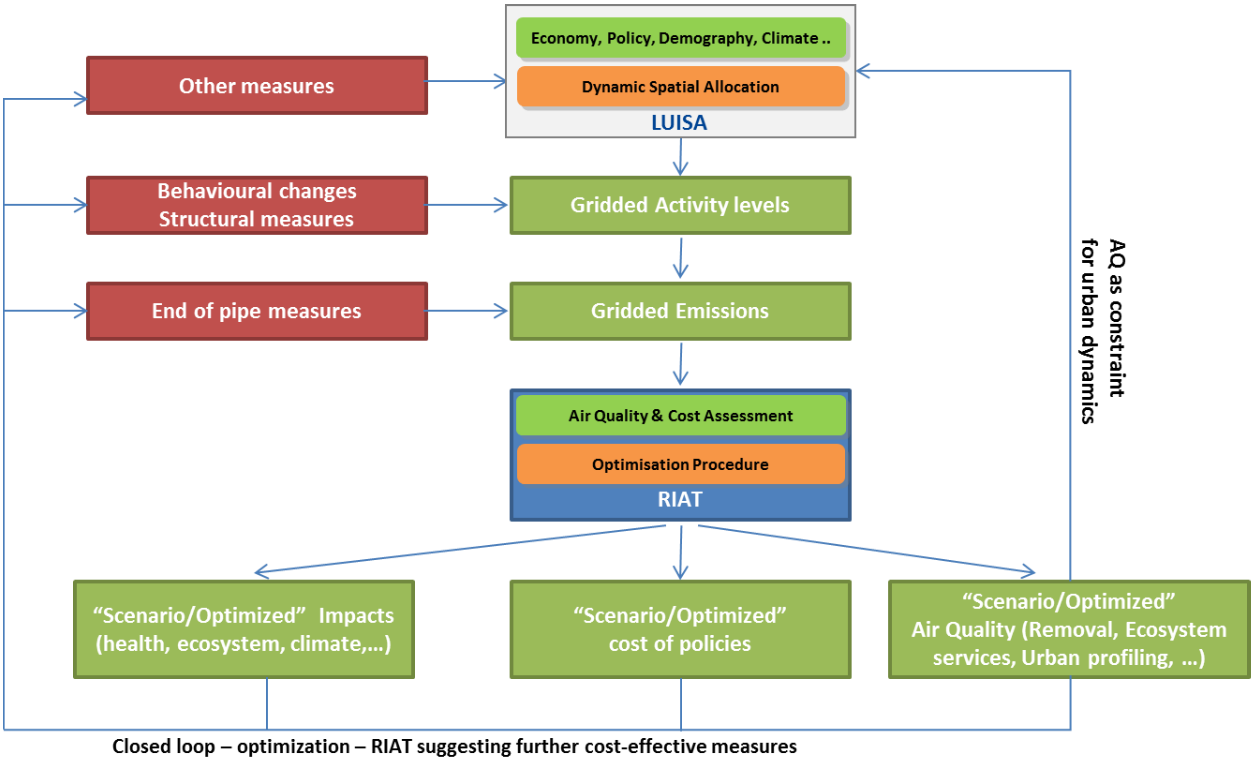



*Figure 1: Foreseen interactions between LUISA and RIAT, in the context of policy conception, development and evaluation*

More in details, in the context of policy conception, development, and evaluation, the LUISA-RIAT interaction will work through these strands:

1. LUISA simulates a possible policy scenario, starting from projections of economy, demography, climate, etc…
2. Starting from aggregated values, LUISA downscales/grids (i.e. at 100m spatial resolution) activity levels and emissions. This task is really important for the interaction between LUISA and the air quality part, as it produces input data for RIAT applications in any possible European region/local domain.
3. Activity levels and emissions are then used by RIAT, for the simulation of air quality and for the computation of optimal abatement measures.

4. The RIAT simulated air quality can be used as a constraint in the dynamic spatial allocation performed by LUISA.
5. The RIAT suggested optimal policies can provide a feedback (closed loop optimization) to LUISA, in terms of end-of-pipe measures, structural measures and other (i.e. land-use) additional measures.

This deliverable focuses mainly on the point 2 of the previous list, that is to say the steps/procedure applied to downscale aggregated (country-level) emissions on a 100x100 m grid. Even if in this deliverable all the steps are related to emissions, the same approach can be replicated for activity level downscaling.

## Scope and Objectives

The aim of this work is to formalize and apply a downscaling methodology to disaggregate atmospheric emissions from the national scale to grid level (100 m). This refined product represents an essential input for detailed air-quality models which simulate source-receptor dynamics and consequent pollutants concentrations.

In Europe, regional and local emission inventories are managed and compiled by several different agencies which, relying on different standards, methods and categories. In some cases, this can yield a heterogeneous and inconsistent picture when collating these data for usage in continental scale approaches. There have been several implementations of this kind of top-down approach, downscaling national emissions estimates at a finer resolution (Beelen et al., 2009; Thelokeet al., 2009, Thelokeet al., 2012; Kuenen et al., 2014). Most of these studies reach a resolution of 7 or 10 km and are applied to estimates from current of previous years. Furthermore, only a limited number of broad source categories are usually considered.

The top-down approach presented in this report has the aim to overcome the limitations normally linked to standard bottom-up approaches. The novelty of our approach relies on the very high spatial resolution of the LUISA platform (100m) and its ability to model scenarios up to 2050. Furthermore, the modelled emission data used as input for our model come from the **G**reenhouse Gas and **A**ir Pollution **In**teractions and **S**ynergies Model (**GAINS**), which provides emission estimates at high thematic resolution, explaining very fine sector-activity combinations.

# 2. Material and Methods

The methodology implemented for the generation of the surrogates and the consequent downscaling process is better detailed in Trombetti et al., 2014.

## Input emission data

The GAINS model has been developed by the International Institute for Applied Systems Analysis (IIASA) and it "provides a consistent framework for the analysis of co-benefits reduction strategies from air pollution and greenhouse gas sources" (Amann et al., 2011). The model considers emissions of different compounds (Carbon dioxide, Methane, Nitrogen oxides, Nitrous oxide, Particulate matter, Sulfur dioxide, Volatile organic compounds). Emissions of pollutants are estimated for each country based on information collected by available international emission inventories country-provided information. The GAINS Model specifies emission projections in five year intervals up to 2030.

The emissions data are provided for hundreds of combinations of GAINS sectors (category of emission) and activities (usually fuels). At this stage of the work (to start with a limited number of categories, being still in a pilot phase of the work) a selection of these sector-activity combinations explaining 90% of the total national emissions has been selected for each chemical. Hence, the resulting maps of disaggregated emissions at 100m resolution are for now maps of the 90% of emissions. The next refinement of the methodology will allow for the inclusion of the total amount of emissions. The list of the sector-activities combinations considered so far is shown in Appendix I.

## Proxies and Surrogates

The disaggregation of national data is based on the usage of spatial surrogates as explained in Maes et al., 2009. A spatial surrogate is a value between zero and one which represents the fraction over the national total to be assigned to the considered pixel (Eyth and Habisak, 2003).

As mentioned earlier, at this stage we considered only the 145 combinations of sector and activities explaining the 90% of the total emitted amounts. These 145 combinations are then further grouped in 34 macro-categories, according to the spatial proxies able to spatially explain them. A surrogate is then produced for each of the considered macro-categories and applied to the corresponding amount of emissions for each country.

The generation of this wide number of surrogates involves the combined usage of different proxies acquired from several statistical databases, spatial datasets and linked external models.

In case the data for our model comes from simulations done with connected models, we are able to generate 'dynamic' proxies matching the year of the simulation performed by GAINS (e.g.: CAPRI for the agricultural sector, LUISA for population density and land use).

In the other cases, although varying the year of analysis, we have to rely on 'static' proxies, which have to be assumed to be constant through the years (e.g.: livestock densities (FAO), road networks (OSM), employment and airport traffic statistics (EUROSTAT)).

## 3. Preliminary Results

The methodology described above was implemented using the GAINS national emission inventories relative to year 2010. The chemicals considered at this stage are NOx, PM10 and NH3. The output dataset consist of a set of raster grids at 100m resolution for all the EU28 member states. Beside the total disaggregated emissions, we produce a raster file for each of the component macro-categories, which allow us understanding the impact and behavior of component sectors.

In the figures below, we show some examples of the total output and the most important component categories for some hot-spot areas around Europe. Emissions are reported in quintals/year, where 1 quintal = 100 kg.

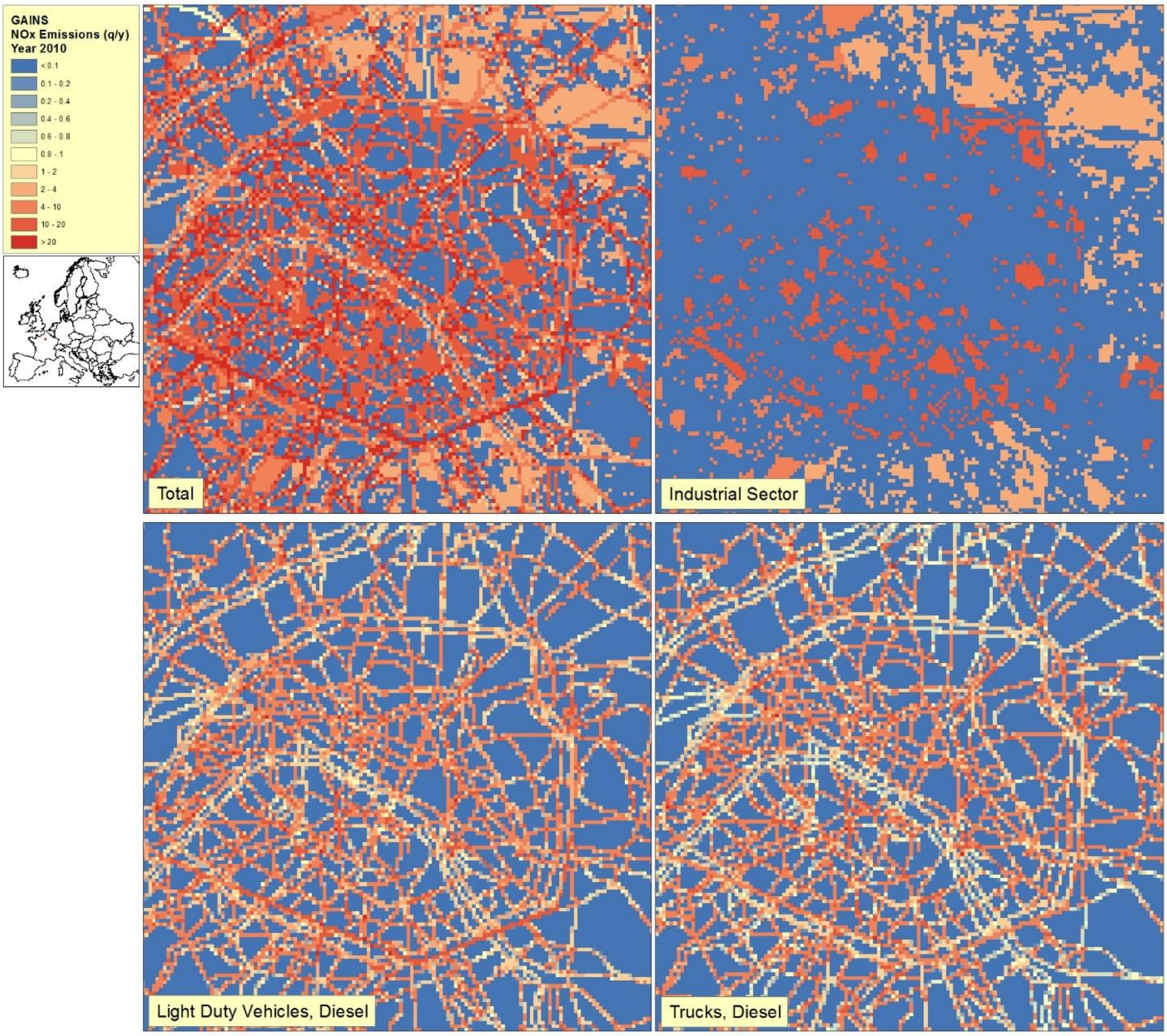



*Figure 2: Disaggregated NOx emissions from GAINS model over the Paris metropolitan area; Year 2010.*

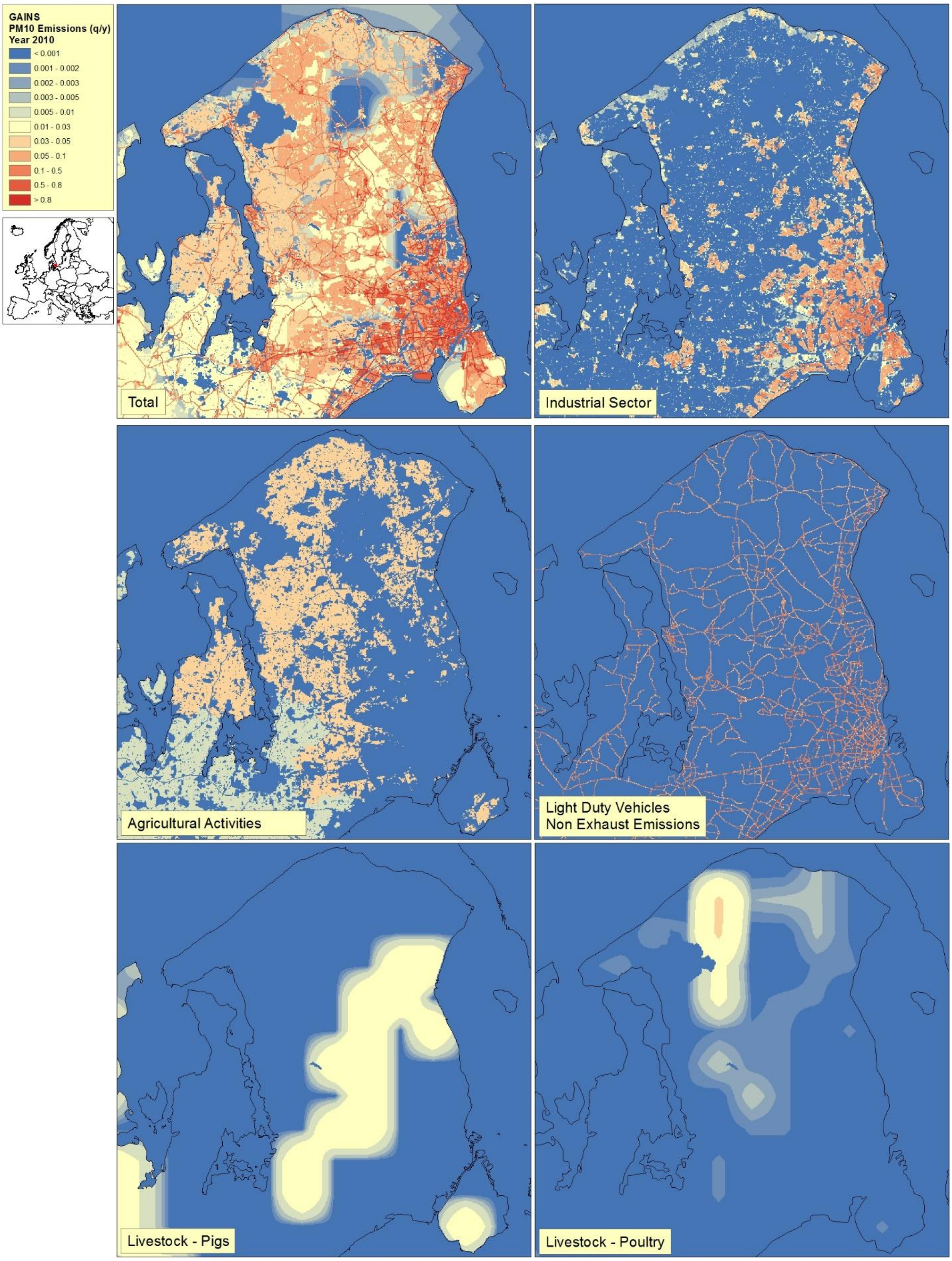



*Figure 3: Disaggregated PM10 emissions from GAINS model over southern Denmark; Year 2010.*

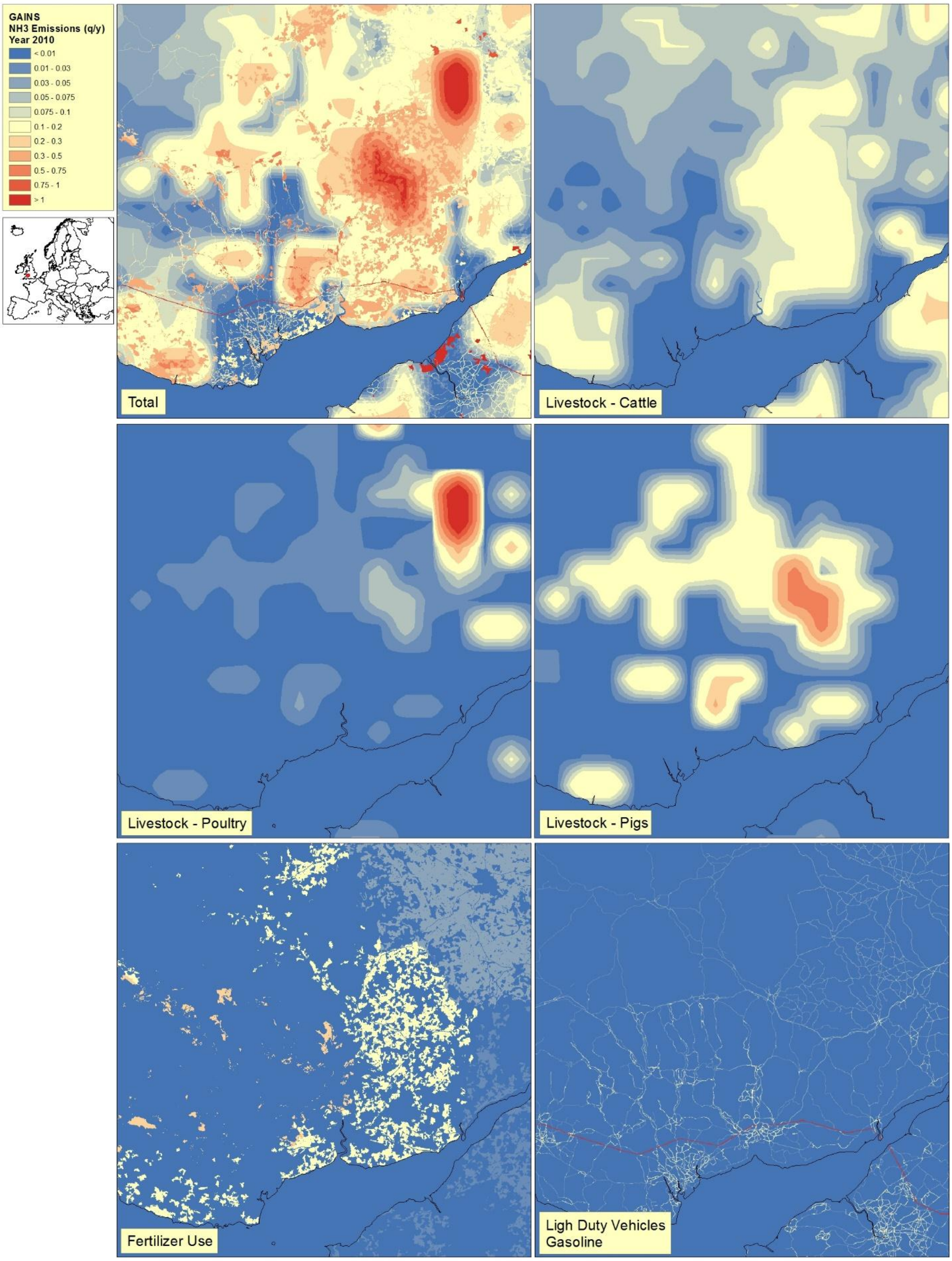



*Figure 4: Disaggregated $NH_3$ emissions from GAINS model over southern Wales; Year 2010.*

# 4. Preliminary comparison with other available emission inventories

Thus no atmospheric emission information spatially distributed at a comparable spatial resolution (100m) exist, a wide number of options are available to compare this new emission inventory with other available “lower resolution” state-of-the-art dataset.

At this stage, a preliminary assessment of the results was realized basing on two available dataset, JRC-EDGAR and TNO-MACC, as described in the following sections.

## EDGAR dataset

The first considered dataset comes from the EDGAR database (Emission database for global atmospheric research; http://edgar.jrc.ec.europa.eu). EDGAR is a global emission inventory which, based on consistent and homogeneous information coming from international bodies, calculates for each country on the globe the atmospheric emissions at 0.1 degrees resolution, yielding a 38 years historical trend.

For our purposes, we considered the last available year (2008, EDGAR v4.2, as downloaded from the EDGAR website) and compared to our results aggregated to the common 10km grid resolution.

Although the thematic and spatial resolution of the 2 compared datasets is very different (EDGAR considers 7 main sources categories, compared to the 34 macro-categories of our approach), a general agreement in the distribution patterns can be noticed in Figure 5 and Figure 6 (NOx) and Figure 7 and Figure 8 (PM10). In the Figures, GAINS (left subfigure) refers to the emission as derived from the LUISA platform starting from the GAINS totals.

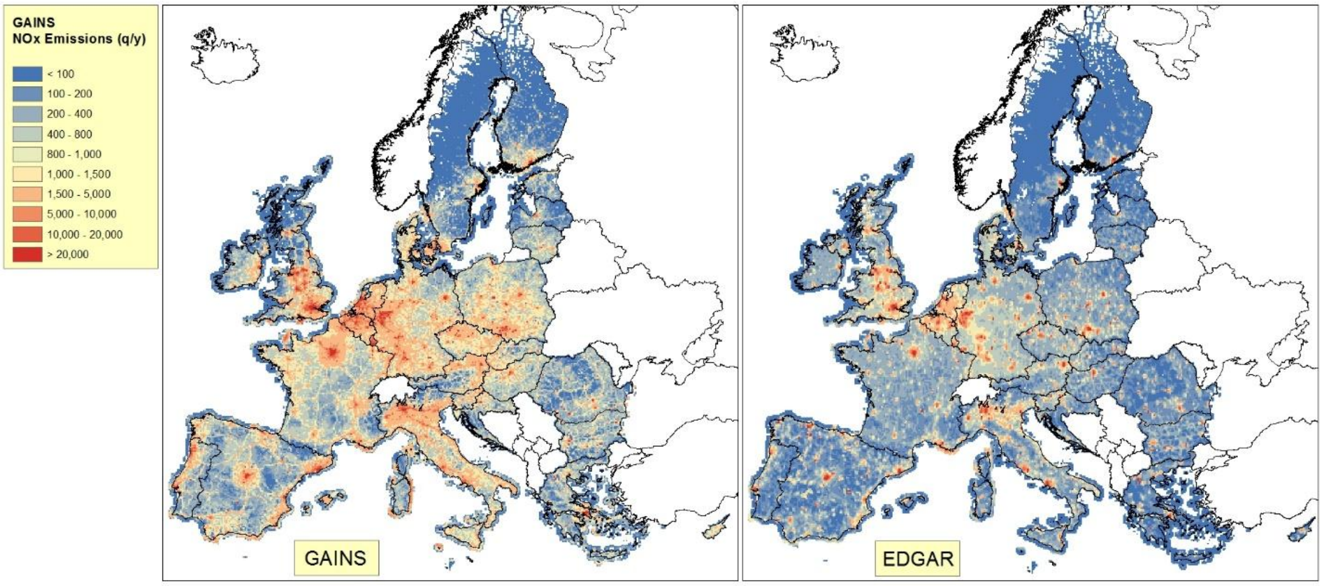



*Figure 5: Comparison at the European level between GAINS-derived NOx atmospheric emissions (year 2010) and the EDGAR database (year 2008).*

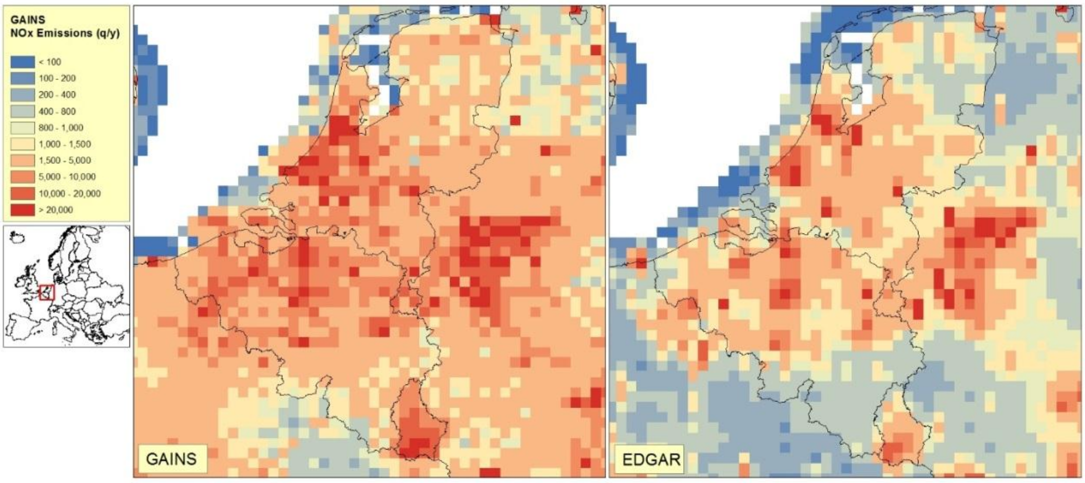



*Figure 6: Comparison between GAINS-derived NOx atmospheric emissions (year 2010) and the EDGAR database (year 2008): BENELUX*

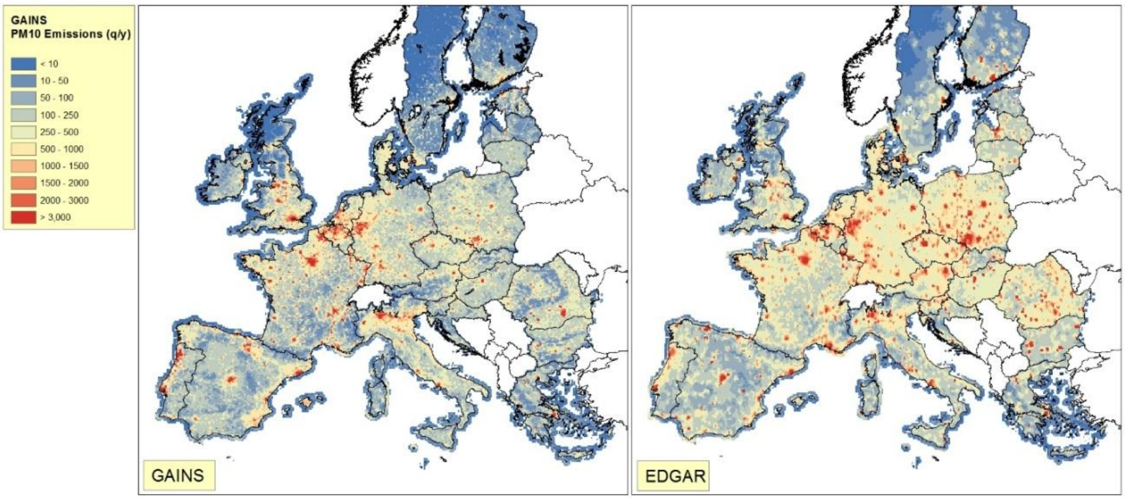



*Figure 7: Comparison at the European level between GAINS-derived PM10 atmospheric emissions (year 2010) and the EDGAR database (year 2008).*

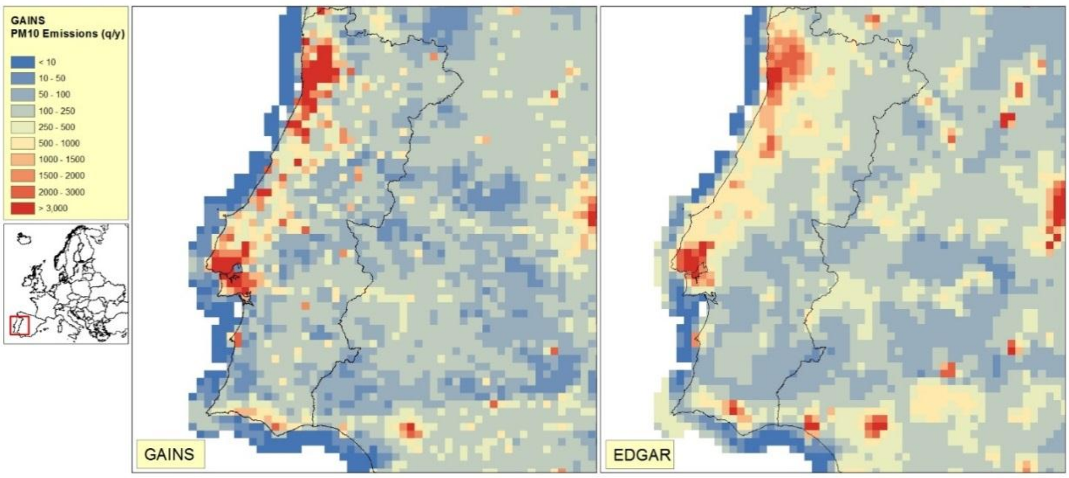



*Figure 8: Comparison between GAINS-derived NOx atmospheric emissions (year 2010) and the EDGAR database (year 2008): Southern Portugal*

## TNO-MACC

The second dataset used for the assessment of our preliminary results comes from the TNO-MACC inventory, commonly used by the air quality modelling community. The data we used are for the year 2009 and are provided with a corresponding resolution of approximately 7 km. The measuring unit is in $\frac{\frac{\mathrm{Kg}}{\mathrm{m2}}}{s}$ and it is converted to $\frac{\mathrm{q}}{\mathrm{y}}$ to allow for comparison with the GAINS-derived emissions.

Despite of the fact that we compare different spatial resolutions and different years of analysis, the results shown in the following figures show a reasonable agreement between the two datasets.

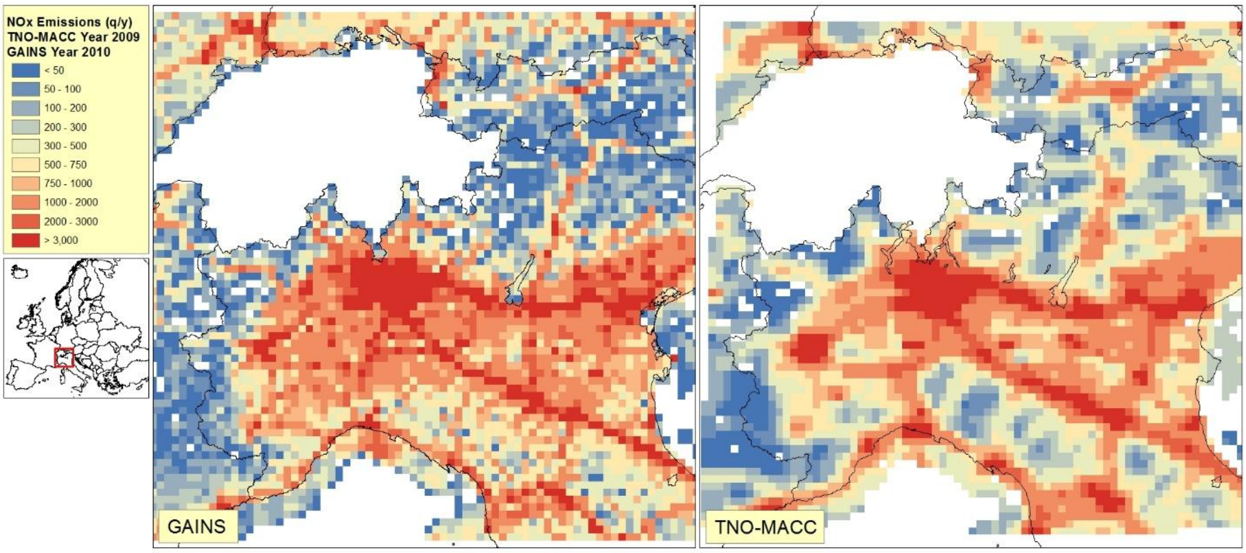



*Figure 9: Comparison between GAINS-derived NOx atmospheric emissions (year 2010) and the TNO-MACC database (year 2009)*

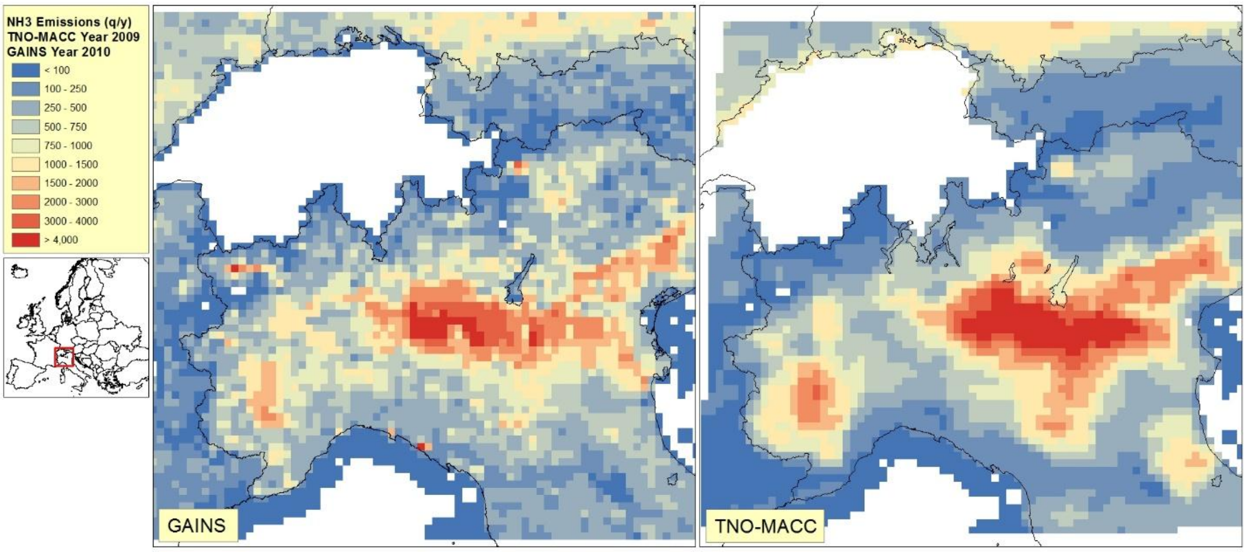



*Figure 10: Comparison between GAINS-derived $NH_3$ atmospheric emissions (year 2010) and the TNO-MACC database (year 2009)*

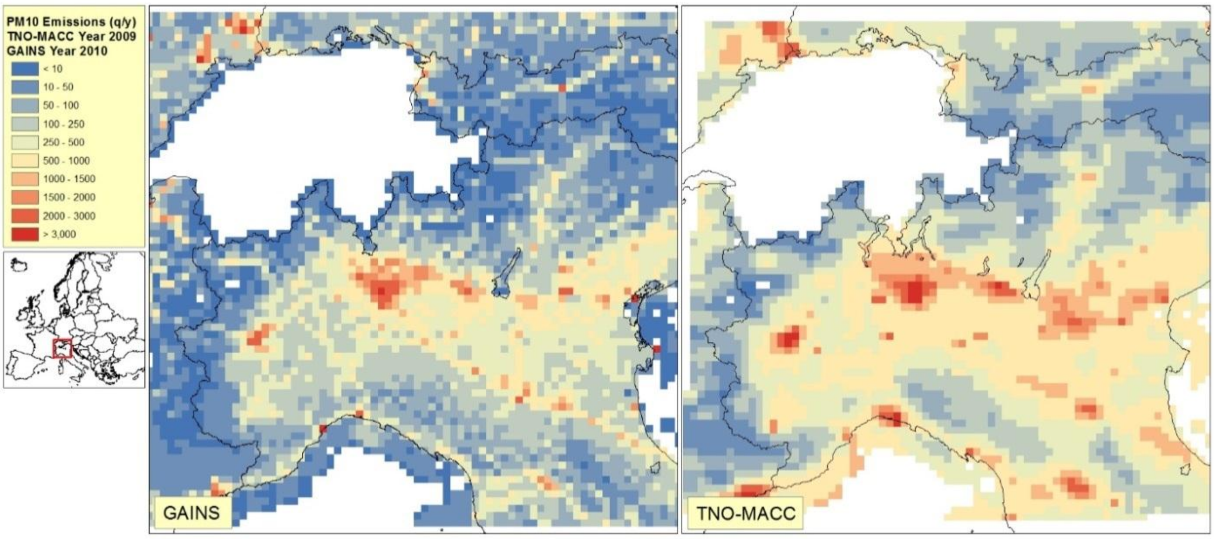



*Figure 11: Comparison between GAINS-derived PM10 atmospheric emissions (year 2010) and the EDGAR database (year 2009)*

This general agreement is confirmed when looking at the correlation between the values of the single grid cells (Number of cells for the considered domain = 4342). For all the considered chemical, the resulting $R^2$ shows high correlation and it varies from 0.43 for NOx to 0.70 for $NH_3$

Figure 12).

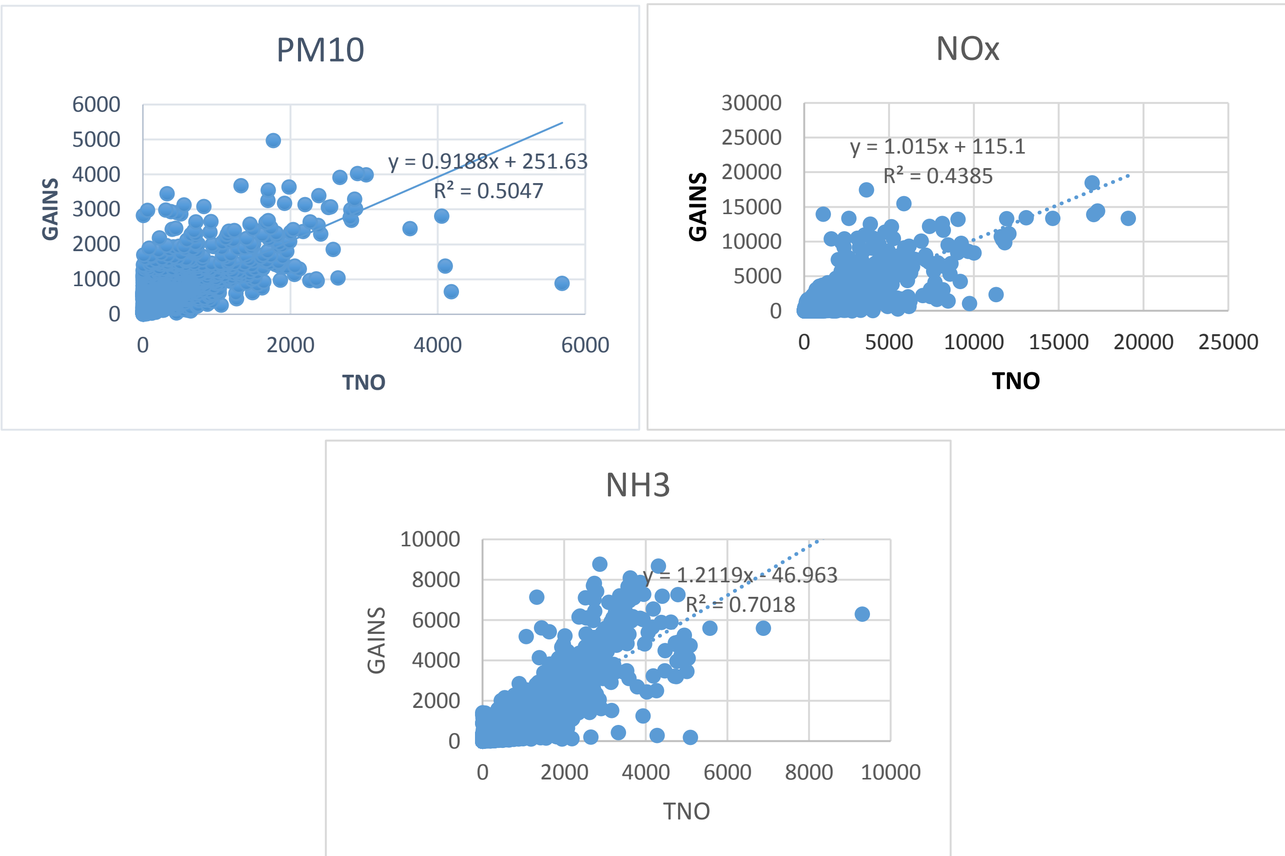



*Figure 12: Correlation between GAINS and TNO-MACC datasets for PM10, NOx and NH3*

## Conclusions and future refinements

The first results of the developed methodology are promising when compared to other existing state-of-the-art dataset. The inclusion of the whole set of the GAINS categories will allow for a more complete and exhaustive analysis, which will constitute the first product of this kind at a very high spatial resolution.

Another foreseen step to be implemented is the inclusion of other chemicals in the dataset ($SO_2$, CO, NMVOC) together with the modelling of scenarios for years 2020 and 2030.

The refined version of the model will be then implemented in order to validate the final product against a wider set of local and regional inventories, together with continental datasets already introduced in this report.

# 5. Appendix 1

List of considered GAINS sector-activities combinations

| GAINS Sector | GAINS Activity |
|---|---|
| Other transport: air traffic - civil aviation | Gasoline and other light fractions of oil |
| Industry: chemical industry (other combustion) | Natural gas (incl. other gases) |
| Inorganic chemical industry, fertilizers and other | Emissions of NMVOC |
| Organic chemical industry - downstream units | Emissions of NMVOC |
| Ind. Process: Fertilizer production | No fuel use |
| Ind. Process: Nitric acid | No fuel use |
| Ind. Process: Sulfuric acid | No fuel use |
| Steam cracking (ethylene and propylene production) | Ethylene and Propylene |
| Power & district heat plants, existing; coal/lignite fired, large units ( > 50 MW th ) | Brown coal/lignite grade 1 |
| Power & district heat plants, existing; coal/lignite fired, large units ( > 50 MW th ) | Brown coal/lignite grade 2 (also peat) |
| Power & district heat plants, existing; coal/lignite fired, large units ( > 50 MW th ) | Hard coal, grade 1 |
| Power & district heat plants, existing; coal/lignite fired, large units ( > 50 MW th ) | Hard coal, grade 2 |
| Power & district heat plants, existing; coal/lignite fired, large units ( > 50 MW th ) | Hard coal, grade 3 |
| Power & district heat plants, existing; coal/lignite fired, small units ( < 50 MW th ) | Hard coal, grade 1 |
| Power & district heat plants, new; coal/lignite fired, large units ( > 50 MW th ) | Brown coal/lignite grade 1 |
| Power & district heat plants, new; coal/lignite fired, large units ( > 50 MW th ) | Hard coal, grade 1 |
| Power & district heat plants, new; coal/lignite fired, large units ( > 50 MW th ) | Hard coal, grade 2 |
| Agriculture: Livestock - other cattle | Other cattle - liquid (slurry) systems |
| Agriculture: Livestock - other cattle | Other cattle - solid systems |
| Agriculture: Livestock - dairy cattle | Dairy cows - liquid (slurry) systems |
| Agriculture: Livestock - dairy cattle | Dairy cows - solid systems |
| Milk yield over 3000 kg/animal treshold | Dairy cows - liquid (slurry) systems |
| Milk yield over 3000 kg/animal treshold | Dairy cows - solid systems |
| Agriculture: Livestock - other animals (sheep, horses) | Sheep and goats |
| Agriculture: Livestock - pigs | No fuel use |
| Agriculture: Livestock - pigs | Pigs - liquid (slurry) systems |
| Agriculture: Livestock - pigs | Pigs - solid systems |
| Agriculture: Livestock - poultry | Laying hens |
| Agriculture: Livestock - poultry | No fuel use |
| Agriculture: Livestock - poultry | Other Poultry |

| GAINS Sector | GAINS Activity |
|---|---|
| Power & district heat plants existing, non-coal; for GAS - boilers | Fuelwood direct |
| Power & district heat plants new, non-coal; for GAS - turbines | Fuelwood direct |
| Power & district heat plants with internal combustion engines | Natural gas (incl. other gases) |
| Power & district heat plants existing, non-coal; for GAS - boilers | Natural gas (incl. other gases) |
| Modern power plants (coal: ultra- and supercritical; gas: CCGT) | Natural gas (incl. other gases) |
| Power & district heat plants new, non-coal; for GAS - turbines | Natural gas (incl. other gases) |
| Gasoline distribution - service stations | Gasoline and other light fractions of oil |
| Extraction, proc. and distribution of gaseous fuels | Emissions of NMVOC |
| Extraction, proc. and distribution of liquid fuels | Emissions of NMVOC |
| Other transport: agriculture and forestry | Medium distillates (diesel, light fuel oil) |
| Manufacture of automobiles | Vehicles |
| Manufacture of automobiles (new installations) | Vehicles |
| Construction activities | No fuel use |
| Degreasing | Solvent use |
| Degreasing (new installations) | Solvent use |
| Commercial | Natural gas (incl. other gases) |
| Commercial | Medium distillates (diesel, light fuel oil) |
| Factor only: Medium boilers (<50MW) - automatic | Hard coal, grade 1 |
| Fat, edible and non-edible oil extraction | Seeds |
| Industrial application of adhesives (use of high performance solvent based adhesives) | Adhesives |
| Industrial application of adhesives (use of traditional solvent based adhesives) | Adhesives |
| Industry, transformation sector, combustion in boilers | Heavy fuel oil |
| Industry: other sectors; combustion of fossil fuels other than brown coal/lignite and hard coal | Fuelwood direct |
| Industry: other sectors; combustion of fossil fuels other than brown coal/lignite and hard coal | Heavy fuel oil |
| Other Industry: Other combustion | Natural gas (incl. other gases) |
| Other Industry: Other combustion | Heavy fuel oil |
| Other industrial use of solvents | Emissions of NMVOC |
| Other industrial sources | Emissions of NMVOC |
| Industrial paint applications - General industry (continuous processes) | Paint use |
| Industrial paint applications - General industry | Paint use |
| Industrial paint applications - General industry (plastic parts) | Paint use |
| Leather coating | Coating |
| Other PM emissions not included separately in GAINS and statistical differences | No fuel use |
| Other SO2 emissions not included separately in GAINS and statistical differences | No fuel use |

| GAINS Sector | GAINS Activity |
|---|---|
| Products incorporating solvents | Paint and glue produced |
| Polystyrene processing | Expandable polystyrene beads consumption |
| Ind. Process: Cement production | No fuel use |
| Ind. Process: Glass production (flat, blown, container glass) | No fuel use |
| Ind. Process: Lime production | No fuel use |
| Ind. Process: Production of glass fiber, gypsum, PVC, other | No fuel use |
| Ind. Process: Paper pulp mills | No fuel use |
| Ind. Process: Crude oil & other products - input to Petroleum refineries | Crude oil |
| Ind. Process: Crude oil & other products - input to Petroleum refineries | No fuel use |
| Ind. Process: Agglomeration plant - sinter | No fuel use |
| Ind. Process: Small industrial and business facilities - fugitive | No fuel use |
| Printing, offset, new installations | Printing inks |
| Flexography and rotogravure in packaging, new installat | Printing inks |
| Manufacturing of shoes | Shoes |
| Other transport: mobile sources in construction and industry | Medium distillates (diesel, light fuel oil) |
| Tyre production | Tyres |
| Vehicle refinishing (new installations) | Paint use |
| Wood preservation (not creosote) | Wood treated |
| Wood coating | Coated surface |
| Decorative paints | Paint use |
| Industry: iron and steel (other combustion) | Derived coal (coke, briquettes) |
| Industry: iron and steel (other combustion) | Natural gas (incl. other gases) |
| Industry: iron and steel (other combustion) | Hard coal, grade 1 |
| Industry: iron and steel (other combustion) | Heavy fuel oil |
| Ind. Process: Basic oxygen furnace | No fuel use |
| Ind. Process: Cast iron (grey iron foundries) | No fuel use |
| Ind. Process: Cast iron (grey iron foundries) (fugitive) | No fuel use |
| Ind. Process: Coke oven | No fuel use |
| Ind. Process: Electric arc furnace | No fuel use |
| Ind. Process: Other non-ferrous metals prod. - primary and secondary | No fuel use |
| Ind. Process: Pig iron, blast furnace | No fuel use |
| Power & district heat plants with internal combustion engines | Heavy fuel oil |
| Domestic use of solvents (other than paint) | Population |
| Factor only: Single house boilers (<50 kW) - manual | Fuelwood direct |
| Factor only: Single house boilers (<50 kW) - manual | Hard coal, grade 1 |
| Factor only: Cooking stoves | Fuelwood direct |
| Residential | Natural gas (incl. other gases) |
| Residential | Medium distillates (diesel, light fuel oil) |
| Factor only: Fireplaces | Fuelwood direct |
| GAINS Sector | GAINS Activity |
| Factor only: Single house boilers (<50 kW) - manual | Fuelwood direct |
| Factor only: Single house boilers (<50 kW) - manual | Hard coal, grade 1 |

| GAINS Sector | GAINS Activity |
|---|---|
| Factor only: Cooking © Heating (H) stoves | Fuelwood direct |
| Factor only: Cooking © Heating (H) stoves | Hard coal, grade 1 |
| Food and drink industry | Population |
| Residential: Meat frying, food preparation, BBQ | No fuel use |
| Residential: Cigarette smoking | No fuel use |
| Residential: Fireworks | No fuel use |
| Other transport: off-road; sources with 2-stroke engines | Gasoline and other light fractions of oil |
| Treatment of vehicles | Population |
| Other transport: maritime, large vessels, >1000 GRT | Heavy fuel oil |
| Other transport: maritime, large vessels, >1000 GRT | Medium distillates (diesel, light fuel oil) |
| Other transport: maritime, medium vessels <1000GRT | Medium distillates (diesel, light fuel oil) |
| Fertilizer use - other N fertilizers | No fuel use |
| Fertilizer use - urea | No fuel use |
| Agriculture: Ploughing, tilling, harvesting, Arable agricultural land in temporal and subboreal climate | No fuel use |
| Waste: Agricultural waste burning | No fuel use |
| Evaporative emissions from gasoline vehicles | Gasoline and other light fractions of oil |
| Light duty vehicles: cars and small buses with 4-stroke engines | Gasoline and other light fractions of oil |
| Evaporative emissions from 4-stroke cars | Gasoline and other light fractions of oil |
| Light duty vehicles: cars and small buses with 4-stroke engines | Medium distillates (diesel, light fuel oil) |
| Light duty vehicles: light commercial trucks with 4-stroke engines | Medium distillates (diesel, light fuel oil) |
| Light duty vehicles: cars and small buses with 4-stroke engines | Non exhaust PM emissions - brake wear |
| Light duty vehicles: cars and small buses with 4-stroke engines | Non exhaust PM emissions - tyre wear |
| Heavy duty vehicles - buses | Medium distillates (diesel, light fuel oil) |
| Heavy duty vehicles - trucks | Non exhaust PM emissions - brake wear |
| Heavy duty vehicles - trucks | Medium distillates (diesel, light fuel oil) |
| Heavy duty vehicles - trucks | Non exhaust PM emissions - tyre wear |
| Motorcycles, mopeds and cars with 2-stroke engines | Gasoline and other light fractions of oil |
| Motorcycles with 4-stroke engines | Gasoline and other light fractions of oil |
| Other transport: rail | Medium distillates (diesel, light fuel oil) |
| Other transport: inland waterways | Gasoline and other light fractions of oil |
| Other transport: inland waterways | Medium distillates (diesel, light fuel oil) |
| Mining: Bauxite, copper, iron ore, zinc ore, manganese ore, other | No fuel use |
| Oth. En. Sect.: combustion | Natural gas (incl. other gases) |
| Oth. En. Sect.: combustion | Heavy fuel oil |
| Oth. En. Sect.: combustion | Liquefied petroleum gas |
| Power & district heat plants existing, non-coal; for GAS - boilers | Waste fuels, non-renewable |
| GAINS Sector | GAINS Activity |
| Waste: Open burning of residential waste | No fuel use |
| Waste treatment and disposal | Emissions of NMVOC |
| Waste treatment and disposal | No fuel use |

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European Commission
**EUR 27005 EN – Joint Research Centre – Institute for Environment and Sustainability**

Title: **Methods for Regional Integrated Assessment: High resolution gridded emission distribution in the LUISA Platform**

Authors: Marco Trombetti, Joachim Maes, Enrico Pisoni, Carlo Lavalle, Philippe Thunis

Luxembourg: Publications Office of the European Union

2014 – 21 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online)

ISBN 978-92-79-44672-6 (PDF)

doi:10.2788/46604

LB-NA-27005-EN-N

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doi:10.2788/46604

ISBN 978-92-79-44672-6