Downscaling tool to construct city emission inventories

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1 Introduction

This report describes the downscaling approach as was developed within the EU PAUL project (Pilot Applications in Urban Landscapes - Towards integrated city observatories for greenhouse gases (ICOS Cities)) (ICOS Cities | ICOS). It is intended as an illustration and support for the city emission inventory guidelines, as well as documentation for atmospheric composition modellers working with the output of the downscaling tool. This report allows users of the data to get a better understanding of how the product was developed and supports in the quality assessment.

Cities are major hotspots of human activities and, consequently, of emissions of greenhouse gases, making cities key contributors to climate change (IPCC, 2022). At the same time, climate change severely impacts urban life, for example, through increased heat stress and flood risk (UN Human Settlements Programme, 2024). In addition, those same human activities cause emissions of air pollutants. In urban areas, high concentrations of air pollutants meet large population numbers, causing a significant negative health impact (Health Effects Institute, 2022). Hence, cities provide great opportunities for combatting climate change, while at the same time creating a healthy, inclusive, and resilient living environment for over half of the world's population.

Detailed knowledge on the local conditions is crucial for city representatives to make informed decisions. City emission inventories provide an overview of how much greenhouse gases and air pollutants are emitted, where, when, and from which type of activities. An emission inventory provides immediate insights in the major sources of emissions, allowing policymakers to target specific types of activities or companies where the largest emission reductions can be expected. Moreover, an emission inventory can be used in atmospheric models to calculate/predict air pollution levels and their health impacts throughout the city, being complementary to the point-wise concentration measurements in local air quality monitoring networks.

Building a city emission inventory can be a demanding task, especially given the large amounts of data that often need to be gathered and processed. Moreover, expert knowledge on emission processes is crucial for a correct interpretation and usage of the data. To support city stakeholders in the process of designing and building an emission inventory, a step-by-step guide was developed. This guideline lists a downscaling approach as an easy way to make a first estimate of city-wide emissions, including the spatial distribution. A downscaling tool was developed that uses open-access, European and global data, allowing city representatives throughout Europe to make an easy assessment of the city-wide emissions. Further improvements can be made by including local knowledge and datasets, but in this report, we only describe the generic European approach.

2 Methodology

Regional to national gridded emission inventories are available, but these are too coarse to support informed decisions at city level. Figure 2.1 shows (part of) a European inventory for PM2.5 at approximately 1 km resolution and a zoom over the city of Brno, Czech Republic. Not enough distinction can be made within the city to be useful for policy support. Hence, the need to increase spatial resolution and level of detail.

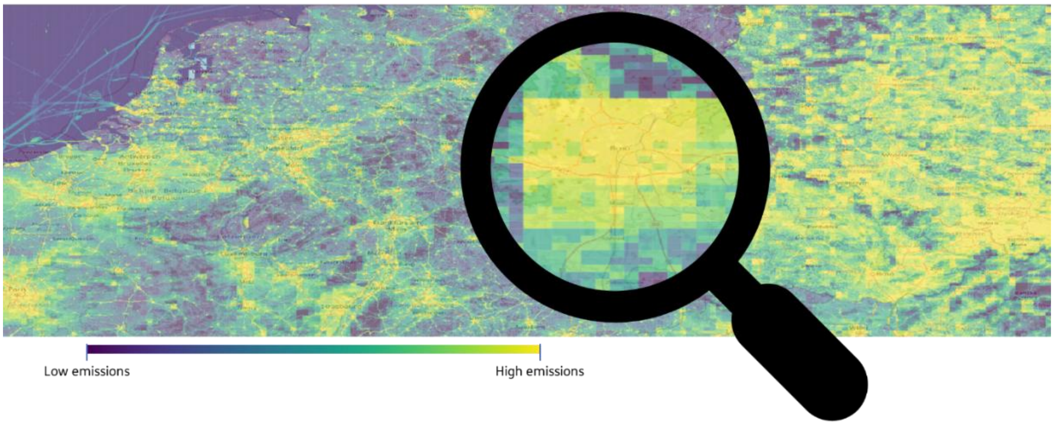

Figure 2.1: Part of the CAMS-REG European emission inventory for PM2.5 at 1/60 x 1/120° resolution (Kuenen et al., 2022). Within the magnifying glass a zoom over the city of Brno, Czech Republic, is shown.

The downscaling procedure starts with the definition of the output domain. For the selected domain, both the emissions input and the proxy data are prepared. In our emissions input, point sources are given at their exact location and do not need to be processed. The area sources are downscaled using the proxy data, after which some post-processing steps are needed to create the final output. The steps are summarized in Figure 2.2 and explained in more detail in the remainder of this section.

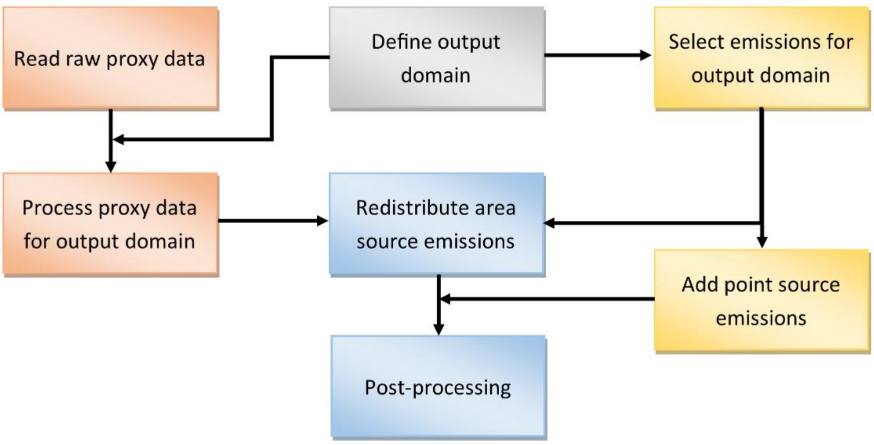

Figure 2.2: Flow chart depicting the downscaling tool. Red boxes are related to the proxy data, yellow boxes to the original emissions data, and blue boxes to the high-resolution city emissions.

2.1 The output domain

The required output domain depends partly on the purpose of the city's emission inventory. For emission accounting and decision-making purposes, the domain should match the official political boundaries. However, when the inventory is used as input for atmospheric models to calculate air pollution levels, a larger domain needs to be covered.

In the downscaling tool, the boundaries can be defined by manual specification of the coordinates of the lower left corner of the domain and the number of grid cells in both directions, resulting in a rectangular domain. Another option is to provide a GIS file containing the boundaries as polygon (for example, red outline in left panel of Figure 2.3). By default, we use GIS files with official city boundaries from local authorities, or, if these are not available to us, the city boundaries defined by OpenStreetMap (Ground Zero Communications AB, 2025). The city boundary is translated into a rectangle (‘envelop’, blue dashed outline in left panel of Figure 2.3), like the manual entry. In both cases, the required grid cell size in both directions needs to be specified to make an output grid. The default step size is 1/600 x 1/1200 ° (~100 m resolution at mid-latitudes).

The final output will be cut off at the domain boundaries, but the intermediate processing is done for a larger domain. This is determined by the emissions input (yellow grid in left panel of Figure 2.1 because we need to ensure that all emission grid cells that fall (partly) within the city boundaries are included for full conservation of the emissions input. The proxy data is also prepared for this domain, but at the resolution of the output grid.

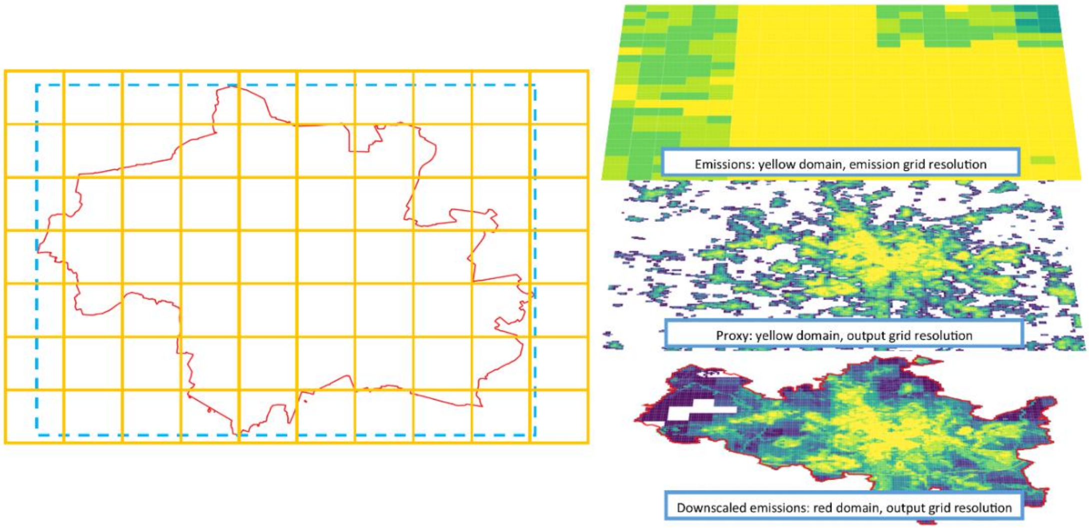

Figure 2.3: Left panel: The city boundary of Munich is shown in red; the blue dashed line indicates the ‘envelop’ around the city boundary; in yellow, the emissions input grid is shown (not necessarily at the actual scale), which is the domain used in the processing steps. Right panel: Example of how the different domain definitions are used in the processing for Brno.

2.2 Emissions input

The default emissions input is the CAMS-REG v8.2 European emission inventory for greenhouse gases and air pollutants for 2022 (Kuenen et al., 2022). Whereas the original inventory is at 0.05 x 0.1° resolution, we use another, high-resolution version at 1/60 x

1/120° for the downscaling, which is completely consistent with the official CAMS-REG version. Therefore, the documentation for the official CAMS-REG dataset also applies to the higher resolution dataset, except the proxy data are processed at a higher resolution. An important update is made to the distribution of road transport emissions (Hohenberger et al., 2025) compared to the version documented by Kuenen et al. (2022).

The inventory contains emissions for greenhouse gases (CO2, CH4) and air pollutants (CO, NOx, PM2.5, PM10, NMVOC, NH3, SOx) and covers 12 GNFR (Gridded Nomenclature For Reporting) sectors (Table 1). Specifically for the application in cities, an additional sector has been added to cover emissions from human respiration (GNFR R). This is especially relevant if the city inventory is to be used in combination with observation-based monitoring of CO2 emissions. To support the downscaling, the off-road sector is split into four sub-sectors, which each have a very distinct spatial pattern.

In the inventory, area sources are specified per grid cell, and the downscaling is applied to these area sources only. The point sources are placed at their exact known location. They are cropped using the domain boundaries (red outline in left panel of Figure 2.3) and added to the area sources after the downscaling step.

2.3 Proxy data

Proxy data are selected for each GNFR (sub-)sector based on how representative the proxy is for the spatial patterns in the emissions from that sector. Additionally, important criteria are that the data is open-access and covers at least the European continent, and that the data are available at a resolution of 100m or higher. An overview of the data used is given in Table 2.1. Note that for some sectors (fugitives, solvents, and waste) no detailed proxy data are available and therefore the original spatial distribution at 1/60 x 1/120° is maintained.

For land use we combine three datasets, namely the CLCplus Backbone land cover data (European Union's Copernicus Land Monitoring Service information, 2024), the Impervious Built-up data (European Union's Copernicus Land Monitoring Service information, 2020a), and the CORINE Land Cover data (European Union's Copernicus Land Monitoring Service information, 2020b). The first two datasets have a spatial resolution of 10 m, whereas the CORINE Land Cover data has a minimum mapping unit of 25 ha/100 m, which doesn't give a lot of detail in built-up areas. However, the CORINE Land Cover data contains 44 land use classes, whereas the CLCplus Backbone land cover data only separates 11 basic land use classes. Therefore, we use the CLCplus Backbone land cover data to increase the spatial resolution of the CORINE Land Cover data. Additionally, the Impervious Built-up data helps us to separate pixels with buildings from other types of sealed surfaces (e.g., parking areas). We make an overlay of the three datasets and assign a land use category to each 10 x 10 m pixel based on each unique combination. With this approach we can separate, for example, grasslands within the city from grasslands in agricultural areas.

The basis for our road transport proxy is OpenTransportMap (Jedlička et al., 2016), a vector dataset with line segments, updated and gap filled as described by Hohenberger et al. (2025). From this, we take the total vehicle kilometres per road segment, excluding tracks and service roads, which are gridded to the output domain. We use these data for additional filtering of the road-rail land use category for railroads as well, by excluding pixels containing roads. Additionally, we make a gridded dataset of the total track length to improve the proxy for off-road transport from agriculture and forestry by including only pixels that have tracks.

The other proxy data are The Copernicus Global Human Settlement Layer GHS-BUILT-V - R2023A built-up volume dataset (Pesaresi and Politis, 2023) and the Copernicus Global Human Settlement Layer GHS-POP - R2023A population volume dataset (Schiavina et al., 2023), both with a resolution of 100 m. For the built-up volume we only select those pixels for which the land use category is set to 'residential/commercial'.

Each dataset has certain characteristics, which determine what the processing looks like to get the proxy data on the output grid. For example, land use data is categorical and the proxy is based on the total area of a land use category within each grid cell; in contrast, the built-up volume dataset is numeric and the proxy is based on the density to ensure the conservation of the total built-up volume when grid cells are split up.

Table 2.1: Overview of all sectors in the emissions input and the proxy data used for downscaling those emissions.

GNFR sector	Proxy
A – Public power	Point sources + land use (industry)
B – Industry	Point sources + land use (industry)
C – Residential/commercial combustion	Built-up volume + land use (res-comm)
D – Fugitives	NA*
E – Solvents	NA*
F – Road transport	Vehicle kilometres
G – Shipping	Land use (shipping)
H – Aviation	Land use (airport)
I – Off-road transport	
1. Industry	Land use (industry)
2. Agriculture/forestry	Land use (cropland + forest) + tracks
3. Railroads	Land use (road-rail) + vehicle kilometres
4. Other	Population volume
J – Waste	NA*
K – Agriculture livestock	Land use (livestock)
L – Agriculture other	Land use (cropland)
R – Human respiration	Population volume

* NA = Not available

2.4 Redistributing emissions and post-processing

For the downscaling, we do not maintain the spatial patterns in the original emission data. Instead, we take the sum of the emissions over the selected domain (section 2.1). The final proxy maps are translated into fraction maps (the proxy per grid cell / sum of the proxy over all grid cells), indicating the fraction of the total emission that occurs in each grid cell. These fractions are multiplied by the emission sum to get the emission per grid cell in the output grid. Finally, we crop the gridded emissions using the domain boundaries (final step in right panel of Figure 2.3), so we only keep grid cells within the city domain.

The post-processing consists of several steps, such as adding the point sources and grouping the sub-sectors of GNFR I into one GNFR category.

3 Output

The default output is a GeoPackage (GPKG) file, containing spatially explicit emissions per pollutant and GNFR sector. The GeoPackage files contain both polygons (area sources) and points. All this information is presented in the same layer. Additionally, plots of the emissions per pollutant (per GNFR sector and all sectors combined) are stored. As an example, we present here the PM2.5 emissions for Brno (Figure 3.1). The point sources are also visible as circles with the same colour coding as the area source emissions.

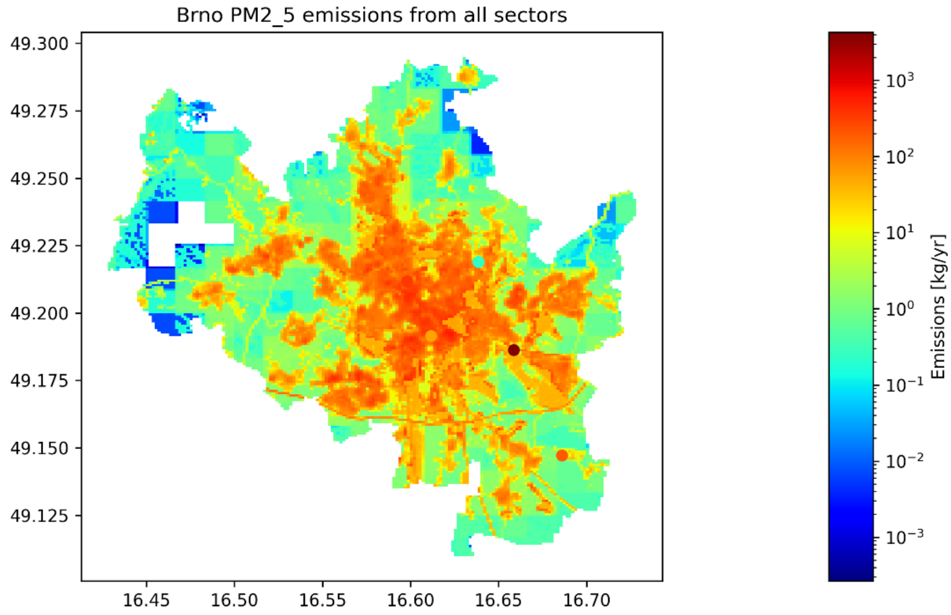

Figure 3.1: Total PM2.5 emissions in Brno at 100x100m resolution, as a result of the downscaling.

Finally, the emission sum per pollutant and GNFR sector is written in a CSV file for a quick overview. This table shows that the residential/commercial combustion sector strongly dominates emissions from PM2.5 and CO, whereas NOx emissions are dominated by road transport.

Table 3.1. Overview of PM2.5, CO and NOx emissions [ton/y] per GNFR sector for Brno, including the relative contribution to the total emission sum.

	PM2.5		CO		NOx	
Public power	22	3%	279	2%	118	8%
Industry	39	5%	1337	10%	145	10%
Residential/commercial	651	82%	10854	81%	452	31%
Road transport	35	4%	711	5%	663	46%
Off-road transport	2	0%	223	2%	63	4%
Other	42	5%	67	0%	6	0%
Total emission sum	792		13470		1448	

4 Guidance for users

As discussed before, the data presented here are the result of a downscaling tool using open-access, large-scale data. It provides a first indication of emissions in a city and should be treated as such. With bottom-up approaches – based on local data and considering city-specific conditions – improvements can be made to this product, although even in bottom-up inventories large uncertainties exist despite the large effort needed to create such a product. Therefore, the value of our product is its simplicity and accessibility for city representatives that want to act. Note that for 15 cities results are already summarized in the guidelines.

A validation against bottom-up inventories across several cities shows that the downscaling approach works reasonably well for road transport and residential/commercial combustion. Often, these are the largest sectors in the city. Improvements to the road transport proxy at the European scale were made to reduce the underestimation of road transport emissions in cities and the spatial patterns in the road network are represented well.

Major discrepancies are mostly found for small point sources in the public power and industry sectors. Large facilities are included as point sources, but locations of smaller facilities are often unknown. Therefore, emission estimates are rough indications and placed at ‘industrial/commercial’ land use sites as area sources. Additionally, localized activities, such as major construction works, are unknown to us and therefore not well represented in the emission inventory.

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