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Estimating concentrations of fine particulate matter in urban background air of European cities

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Abstract

This report presents a generic methodology for estimating, for the purposes of a Europe-wide integrated assessment of the cost-effectiveness of emission control strategies, concentrations of fine particulate matter (PM2.5) in the urban areas of Europe. The report outlines the conceptual approach, discusses input data and presents results from a first implementation for 473 European cities based on input data that are readily available at the European level.

The methodology hypothesizes a functional relationship that connects the most critical city-specific factors with concentration increases in PM2.5 that result from the local low-level emissions in a city. The diameter of a city, annual mean wind speeds, the number of winter days with low wind speeds and emission densities have been identified as the most important local factors.

Parameters of these functional relationships have been determined through a regression analysis of a sample of model responses derived from an ensemble of three state-of-the-art atmospheric dispersion models for seven cities.

To extrapolate the found relationships to all European cities, a set with local input data for the 473 cities with more than 100,000 inhabitants has been compiled from available European data sources. Most strikingly, significant differences in the emission densities across countries are detected, which have a dominating impact on the computed urban increments. A solid validation of the computed urban PM2.5 increments is hampered by the lack of reliable monitoring data.

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Work for this analysis relied on data made available by the Topic Centre on Air and Climate Change (ETC-ACC) of the European Environment Agency, the Joint Research Centre of the European Union (JRC) in Ispra, the Synthesizing Centre West of the European Monitoring and Evaluation Programme (MSC-W of EMEP) and the Meteorological Institute of the Free University Berlin.

About the authors

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1 Introduction

The GAINS integrated assessment model addresses European-scale air pollution with a spatial resolution of 50*50 kilometres, essentially dictated by the spatial resolution of the atmospheric dispersion model (i.e., the EMEP Eulerian model) whose results are incorporated into GAINS. For European-scale analysis, such a resolution is considered adequate for capturing the features of long-range transported pollutants.

However, it is clear that ambient concentrations of some air pollutants show strong variability at a much finer scale (e.g., in urban areas, in street canyons, at hot-spots close to industrial point sources of emission, etc.), and that at least some of these differences result in small-scale variations of pollution impacts on humans and the environment. Thus, for an accurate assessment of the environmental and health impacts of air pollution, there is a need to address air quality problems that occur on a finer scale than the 50*50 km grid mesh that is considered adequate for regional scale pollution.

This report describes the development of functional relationships for use in the GAINS integrated assessment model to quantify urban pollution levels in Europe for the purposes of a health impact assessment. The methodology has been developed within the third phase of the City-delta project (Cuvelier *et al.*, 2006). City-delta has conducted a systematic comparison of regional-scale and local-scale dispersion models, to identify and quantify the factors that lead to systematic differences between air pollution in urban background air and rural background concentrations. City-Delta explored

- systematic differences (deltas) between rural and urban background air quality,
- how these deltas depend on urban emissions and other factors,
- how these deltas vary across cities, and
- how these deltas vary across models.

The analysis addresses the response of health-relevant metrics of pollution exposure (i.e., long-term concentrations with or without thresholds) towards changes in local and regional precursor emissions, including the formation of secondary inorganic aerosols. This enables the generic analysis of urban air quality for a large number of European cities based on information available in the GAINS model framework.

2 Approach

For the purposes of a health impact assessment for fine particulate matter of an urban population that relies on available epidemiological evidence (e.g., Pope *et al.*, 2002), exposure data on PM2.5 concentrations that are characteristic for urban background concentrations are required (see, e.g., WHO, 2001). Furthermore, annual mean concentrations of PM2.5 have been identified as the most powerful predictor.

Therefore, an integrated assessment model requires functional relationships that connect, for a given city, urban and regional emissions with urban background concentrations of PM2.5. Since there is clear evidence for the long-range transport of fine particulates and their precursor emissions, an approach has been selected that computes urban background concentrations of PM2.5 as a function of rural background concentrations as computed by a regional-scale dispersion model, emission densities in a city, and some meteorological and topographic parameters that reflect city-specific dispersion characteristics.

While this approach seems adequate to conduct a health impact assessment based on the epidemiological evidence derived from cohort studies, it is certainly not suited to assessments of compliance with short term air quality limit values that are imposed for hot-spot locations.

2.1 Formation and transport of fine particulate matter at the regional scale

An integrated assessment needs to link changes in the precursor emissions at the various sources to responses in impact-relevant air quality indicators *q* at a receptor grid cell *j*. Traditionally, this task is accomplished by comprehensive atmospheric chemistry and transport models, which simulate a complex range of chemical and physical reactions. The GAINS integrated assessment analysis relies on the Unified EMEP Eulerian model, which describes the fate of emissions in the atmosphere considering more than a hundred chemical reactions involving 70 chemical species with time steps down to 20 seconds including numerous non-linear mechanisms (Simpson *et al.*, 2003). This model was updated in August 2006.

However, the joint analysis with economic and ecological aspects in the GAINS model, and especially the optimization task, calls for computationally efficient source-receptor relationships. For this purpose, an attempt has been made to describe the response surface of the impact-relevant air quality indicators through mathematically simple, preferably linear, formulations. Functional relationships have been developed for changes in annual mean PM2.5 concentrations, deposition of sulfur and nitrogen compounds as well as in long-term levels of ground-level ozone. The (grid- or country-specific) parameters of these relationships have been derived from a sample of several hundred runs of the full EMEP Eulerian model with systematically perturbed emissions of the individual sources. This “calibration sample” spans the policy-relevant range of emissions, i.e., taking the “current legislation” (CLE) emission projection as the upper limit and its “maximum technically feasible reduction” (MTFR) case as the lower end. While the optimization task in GAINS employs these fitted source-receptor relationships, policy-relevant scenario results are validated ex-post through runs of the full EMEP Eulerian model.

Source-receptor relationships have been developed for changes in emissions of SO_2, NO_x, NH_3, VOC and PM2.5 of 39 European countries and five sea areas, describing their impacts for the EU territory with the 50 km × 50 km grid resolution of the geographical projection of the EMEP model (see www.emep.int/grid/index.html).

The health impact assessment in GAINS relies on epidemiological studies that associate premature mortality with annual mean concentrations of PM2.5 monitored at urban background stations. Thus, the source-receptor relationships developed for GAINS describe, for a limited range around a reference emission level, the response in annual mean PM2.5 levels to changes in the precursor emissions SO_2, NO_x, NH_3 and primary PM2.5. The formulation reflects the interplay between SO_2, NO_x and NH_3 emissions in the formation of secondary sulfate and nitrate aerosols in winter. The almost linear response in annual mean PM2.5 produced by the EMEP Eulerian model towards changes in annual emissions of fine primary particulate matter (PM2.5) and of SO_2, as well as for changes in NO_x emissions during the summer, is represented as:

$$\begin{aligned} PM_j &= k_{0,j} + \sum_i pm_i PP_{ij}^A + \sum_i s_i S_{ij}^A + c_0 \left(\sum_i a_i A_{ij}^S + \sum_i n_i N_{ij}^S \right) + \\ &+ (1-c_0) \min \left\{ \max \left\{ 0, k_{1,j} + c_1 \sum_i a_i A_{ij}^W - c_2 \sum_i s_i S_{ij}^W \right\}, k_{2,j} + c_3 \sum_i n_i N_{ij}^W \right\} \end{aligned} \tag{1}$$

with

PM_j	Annual mean concentration of PM2.5 at receptor point j
s_i, n_i, a_i, pm_i	Emissions of SO_2, NO_x, NH_3 and primary PM2.5 in country i
A^X_{ij}, N^X_{ij}, S^X_{ij}, PP^X_{ij}	Matrices with coefficients for reduced (A) and oxidized (N) nitrogen, sulfur (S) and primary PM2.5 (PP), for season X, where X=W (winter), S (summer) and A (annual)
c_0, c_1, c_2, c_3, $k_{0,j}$, $k_{1,j}$, $k_{2,j}$	Model parameters.

While the above formulation with a computationally complex min-max formulation is required to capture changes in chemical regimes when ratios between the abundances of sulfur, nitrogen and ammonia in the atmosphere are changing due to different emission reduction rates of the pollutants involved, a simpler formulation appears to be sufficient when only limited changes in emissions around a reference point are considered. For such optimization problems, Equation 1 can be turned into a linear form:

$$PM_j = \sum_i pm_i \cdot PP_{ij}^A + \sum_i s_i \cdot S_{ij}^A + \sum_i a_i \cdot A_{ij}^A + \sum_i n_i \cdot N_{ij}^A + k_{0,j} \tag{2}$$

For the CAFE programme, where the European Commission explored a wide range of alternative environmental targets implying large differences in emission reductions, the RAINS optimization applied the formulation of Equation 1. For the NEC analysis, however, where the general ambition level has been settled in the Thematic Strategy, the GAINS optimization problem uses Equation 2 with transfer coefficients which have been derived from permutations of emissions around the indicative target emissions levels outlined in the Thematic Strategy. Taking these target levels as the reference point, the GAINS optimization using local derivatives at this point results in a significantly more accurate representation of the underlying EMEP Eulerian model despite the simpler mathematical formulation.

This formulation only describes the formation of PM from anthropogenic primary PM emissions and secondary inorganic aerosols. It excludes PM from natural sources and primary and secondary organic aerosols due to insufficient confidence in the current modeling ability. Thus, it does not reproduce the full mass of PM2.5 that is observed in ambient air. Consequently, results of this approach need to be compared against observations of the individual species that are modeled. The health impact assessment in GAINS is consequently only conducted for *changes* in the specified anthropogenic precursor emissions, and excludes the (largely) unknown role of secondary organic aerosols and natural sources.

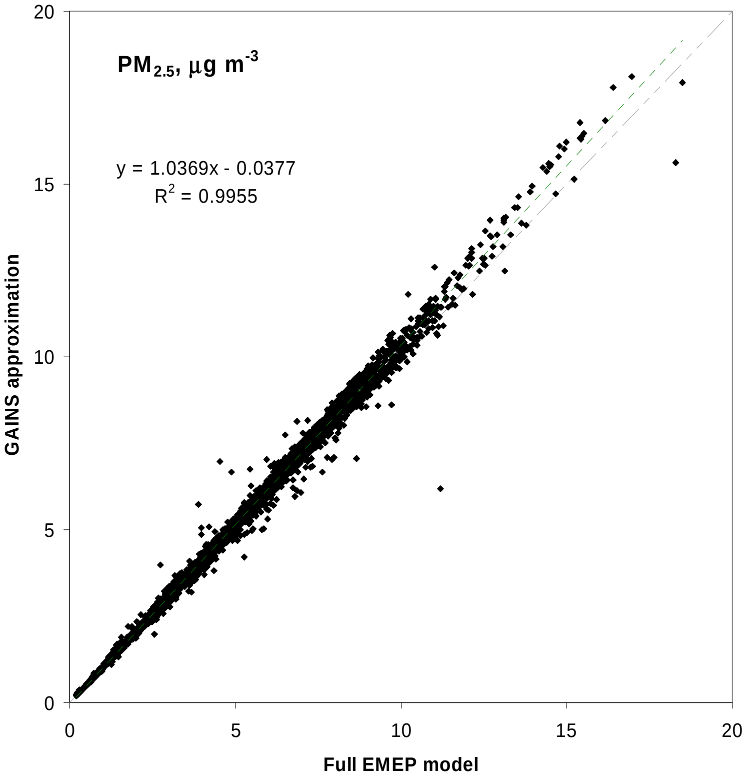


Figure 2.1: Validation of the GAINS approximations of the functional relationships against computations of the full EMEP model around the emission levels outlined in the Thematic Strategy for Air Pollution.

3 PM concentrations at the urban scale

In GAINS the regional-scale assessment is performed for all of Europe with a spatial resolution of 50 km × 50 km. Health impacts are, however, most pertinent to urban areas where a major share of the European population lives. Any assessment with a 50*50 km resolution will systematically miss out higher pollution levels in European cities. Based on the results of the City-delta model intercomparison, which brought together the 17 major European urban and regional scale atmospheric dispersion models (Thunis *et al.*, 2006), a generalized methodology was developed to describe the increments in PM2.5 concentrations in urban background air that originate – on top of the long-range transport component – from local emission sources.

These relationships associate urban increments in PM levels, i.e., incremental (PM2.5) concentrations in a city originating from emissions of the same city with the spatial variations in emission densities of low-level sources in that city and city-specific meteorological and topographic factors. In a second step, urban background PM2.5 concentrations within cities are then computed by correcting the PM concentration value computed by a 50*50 km regional dispersion model with a "city-delta", i.e., the local increase in concentration in the city due to emissions in the city itself. In the regional-scale calculations this contribution is smeared out over the whole 50*50 km grid element. In the City-delta approach the mass of PM within the 50*50 km grid element is redistributed in such a way that the concentration in the city is increased by the "city-delta" increment, whereas the concentration in the country-side consequently is decreased. In this way mass is being conserved.

The GAINS/City-delta methodology starts from the hypothesis that urban increments in PM2.5 concentrations originate predominantly from primary PM emissions from low-level sources within the city. The formation of secondary inorganic aerosols, as well as the dispersion of primary PM2.5 emissions from high stacks, is reflected in the background computed by the regional-scale dispersion model.

Based on this hypothesis, urban increments have been derived with the following approach:

Step 1: Preparation of a data sample of responses of state-of-the-art atmospheric dispersion models to switching off urban low level emissions in seven selected cities

Step 2: Hypothesis of local determinants and the functional forms for computing the urban increments

Step 3: Regression analysis for the seven cities

Step 4: Extrapolation to all European cities

Step 5: Calculations of the "city-deltas"

Step 6: Validation with monitoring data

The following sections describe this process in more detail.

3.1 Step 1: Preparation of a data sample of model responses

Three urban dispersion models (Chimere, CAMx, REM3) have been used to generate a data sample with computed impacts of local emission control measures on urban PM2.5 concentrations for seven European cities with different characteristics (Berlin, Krakow, Lisbon, London, Milan, Paris, Prague). Scenarios have been computed for emissions in 2020 with and without urban emissions from low level sources, using the meteorological conditions of the year 2004.

Due to differences in methodologies and input data, different models do not always produce the same results. Figure 3.1 illustrates the range of PM2.5 concentrations computed with the three participating models for the seven cities for the year 2004 and compares them with available monitoring data. The graph clearly indicates that models and measurements exhibit within each city domain significant spatial variations in PM2.5 concentrations. Models covering the full city domain show larger variations than monitoring data that are usually available only for a few specific sites within a city. In general, there is reasonable agreement among the three models on the variations within each individual city. However, some of the available monitoring data fall outside the concentration range that is computed by the models, especially for Prague, Milan and London.

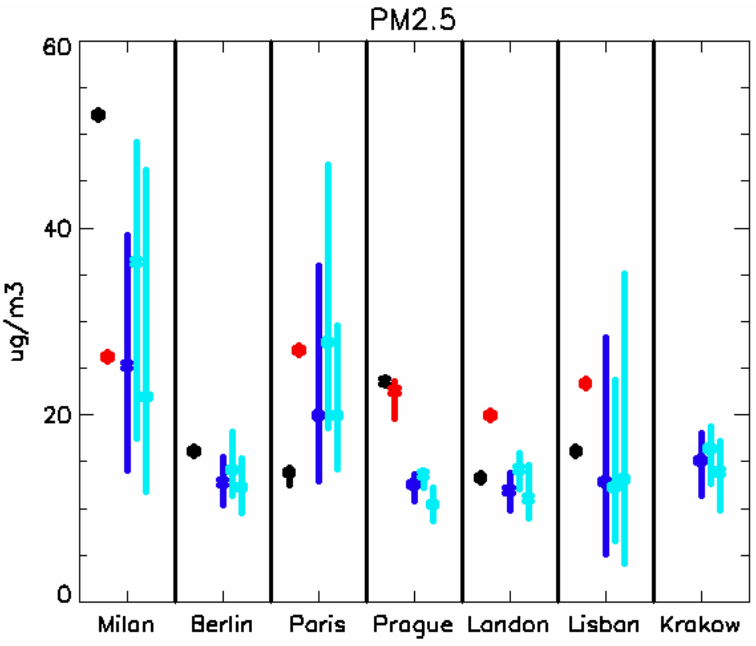


Figure 3.1: Comparison of observed and computed PM2.5 annual mean concentrations in the seven City-delta cities. The red dots indicated measurements at traffic stations; black dots measurements at urban background stations. The blue ranges indicate, for the three models participating in the exercise, the spatial spread of computed PM2.5 concentrations within the 300*300 km model domains.

Accepting the current performance of the three models against the available monitoring data, they have been used in a further step to compute the responses in urban PM2.5 concentrations towards a complete elimination of the low-level emissions in each of the cities. Figure 3.2

compares these model responses for the seven cities, for the emission levels of the year 2020. Model responses show significant variations, although no clear bias of any single model can be detected.

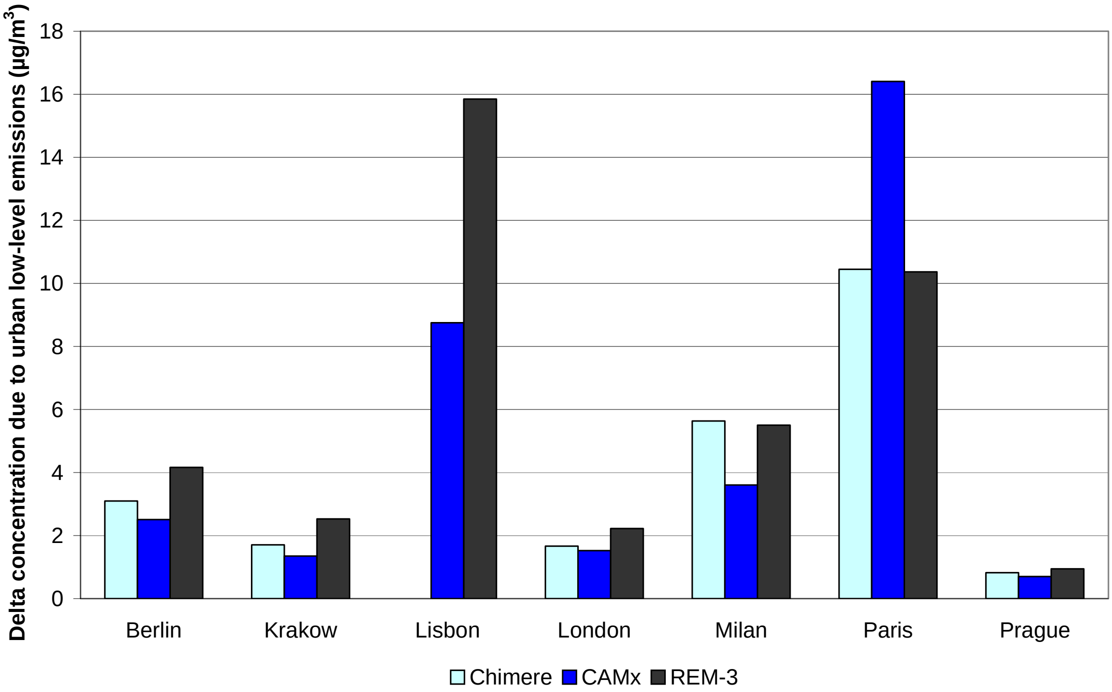


Figure 3.2: Summary of model responses in PM2.5 concentrations in urban background air towards switching off urban low-level emissions in 2020 when PM2.5 emissions will be 40-60 percent lower than in 2000.

3.2 Step 2: Hypothesis of local determinants and the functional forms for computing the urban increments

Based on atmospheric diffusion theory, potential determinants of urban increments and functional forms of their relationships have been hypothesized. Under neutral atmospheric conditions, the vertical diffusion of a non-reactive pollutant from a continuous point source can be described in general form through the following relationship (e.g., Seinfeld and Pandis, 1998):

$$\sigma_z^2 = \frac{2K_{zz}x}{U} \tag{3}$$

with σ_z^2 [m^2] indicating the variance of the vertical diffusion after a distance x [m] from the source, K as the Eddy diffusivity [m^2 s^{-1}] and U [m s^{-1}] as the wind speed. For a homogenously distributed area source with source strength (emission rate) Q, the resulting concentration Δc of a pollutant due to emissions in the city can be derived from a spatial integration over the diameter of the city D [m] (Anton Eliassen, personal communication)

$$\Delta c = \frac{1}{2\sqrt{2}} \frac{1}{\sqrt{K_{zz}}} \left(\frac{D}{U} \right)^{1/2} Q \quad . \tag{4}$$

The diffusivity K_{zz} as well as wind speeds and city diameters along the wind directions show variations over the year. In Equation 3 K_{zz} and U are constant with height. In reality and under neutral atmospheric conditions, K_{zz} increases approximately linearly with height, whereas U increases with the logarithm of the height. Moreover, at a relative short distance from the low source the plume is reflected at the earth's surface. Therefore only the general relation between Δc and $(D/U)^{0.5}$ is used in Equation 4, whereas all other effects are described by the diffusion characteristics of the city given by the constant α. Equation 5 shows that the urban concentration increments Δc can be described as a function of city diameter D, wind speed U, emission rates Q:

$$\Delta c = \frac{1}{2\sqrt{2}} \frac{1}{\sqrt{K}} \left(\frac{D}{U} \right)^{1/2} Q = \alpha \cdot \left(\frac{D}{U} \right)^{1/2} Q \tag{5}$$

In principle, the same type of model could also describe the relation under stable atmospheric conditions. However, it will be difficult to describe the situation for wind speeds below 0.5 – 1.0 m s^{-1}, as the flow will no longer be determined by the external wind speed, but by other effects such as differences in heating of the earth's surface and differences in terrain height.

Low wind situations in summer are different from low wind situations in winter. In summertime in a high pressure area during day time there are unstable conditions leading to a well-mixed atmosphere. In such situations the increase in concentration due to the low wind speed (causing less dilution) is partly compensated by a decrease in concentration due to better vertical mixing.

In winter, low wind speed conditions are mostly related to shallow boundary layers, in which emissions from local sources accumulate over time. Since process modelling of such conditions would require detailed meteorological information on the situation within cities that is usually unavailable for most European cities, a statistical approach has been adopted that builds upon model computations carried out by the City-delta models for the seven cities. Figure 3.3 indicates that winter days with wind speeds below 1.5 m/s make a stronger contribution to annual mean PM2.5 concentrations than days with higher wind speeds.

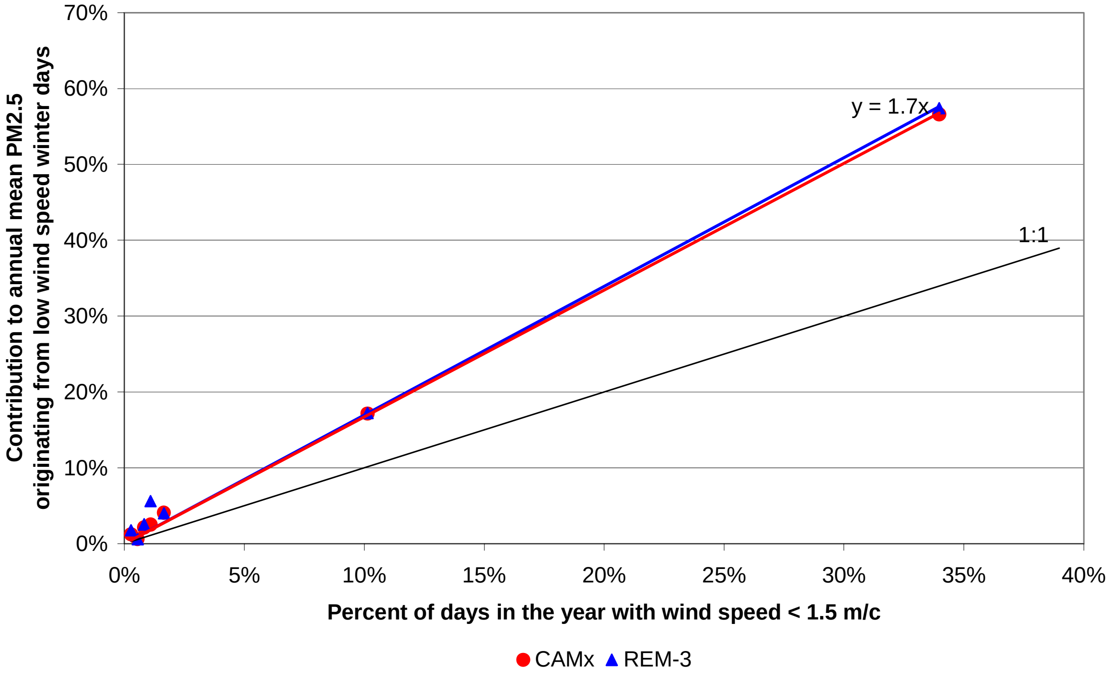


Figure 3.3: Contribution to annual mean PM2.5 concentrations originating from low wind speed days in winter, as computed by the CAMx and REM-3 models for the seven City-delta cities

As a pragmatic approach for determining the urban increments, the City-delta approach considers a second term that is related to the number of low wind speed days in winter (*d*):

$$\Delta c = \alpha \cdot \left(\frac{D}{U}\right)^{1/2} Q + \beta \cdot \left(\frac{D}{U}\right)^{1/2} Q \cdot \frac{d}{365} \tag{6}$$

3.3 Step 3: Regression analysis for the seven cities

In a further step, a regression analysis estimated the regression coefficients α and β in Equation 6 from the data sample on Δc computed by the three urban dispersion models for the seven City-delta cities, with city-specific data on diameters D, wind speeds U, low wind speed days d, and changes in emission fluxes ΔQ. Results of the computations of the three urban dispersion models indicate a strong influence of the chosen of the size target domain for which the average change in PM2.5 concentrations is computed. As shown in Table 3.1, concentration changes associated with urban low-level emissions vary by more than a factor of two, depending on the city.

Table 3.1: Computed changes in mean concentrations (in µg/m^3) for target domains of different sizes (domains located around the grid cell with the largest change in concentrations

	*15*15 km*	*10*10 km*	*5*5 km*
Berlin	1.6	2.5	3.4
Krakow	4.4	6.6	8.4
Lisbon	5.8	9.1	12.4
London	2.4	3.8	5.2
Milan	10.8	15.3	17.7
Paris	5.3	8.3	11.2
Prague	4.0	6.3	8.5

As a consequence, a choice needs to be made for which target domain the urban increments should apply. For concentration changes averaged over 10*10 km domains in the city centers, the regression analysis renders statistically significant values for α of 0.22 and for β of 0.48 with an R^2 of 0.89. With these coefficients, the functional relationships according to Equation 11 deliver for the seven sample cities urban increments that lie within the range produced by the three detailed urban dispersion models (Figure 3.4).

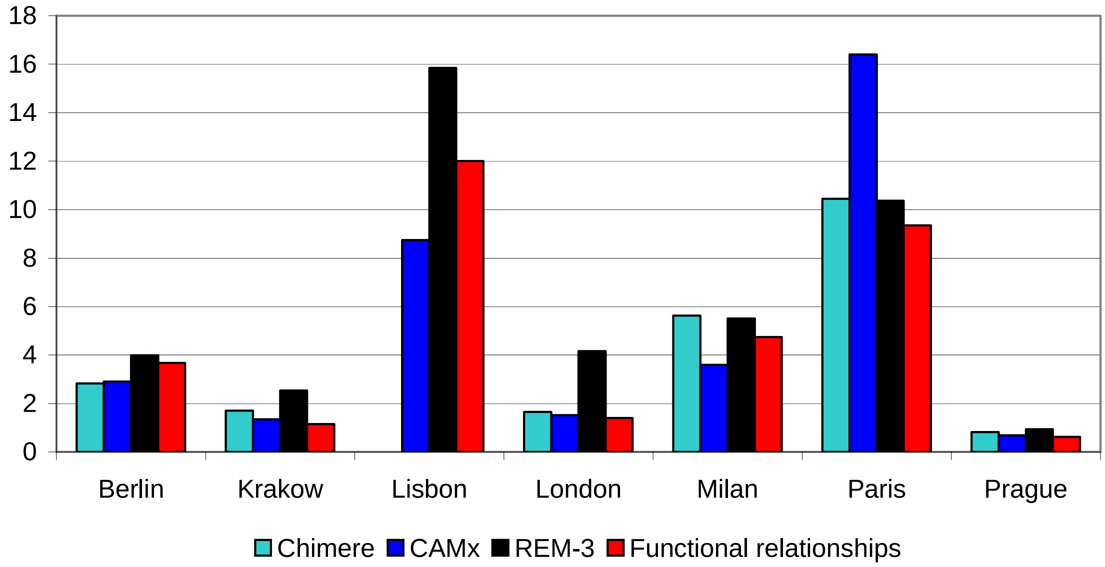


Figure 3.4: Urban increments of PM2.5 (in µg/m^3) computed by the three detailed urban dispersion models and the City-delta functional relationships for the seven City-delta cities, for the CAFE baseline emissions for 2020

3.4 Step 4: Extrapolation to all European cities

To estimate urban increments for all European cities based on the functional relationship identified in Equation 6, a database has been prepared with city-specific information on population densities, city area, city diameters, wind speeds, number of low wind days in winter for the 473 cities with more than 100,000 inhabitants.

3.4.1 Input data: Population data and shapes of cities

Urban areas and diameters were derived from the JRC European population density data set and the *www.citypopulation.de* database using a special algorithm that associates populated areas with the individual urban agglomerations under consideration.

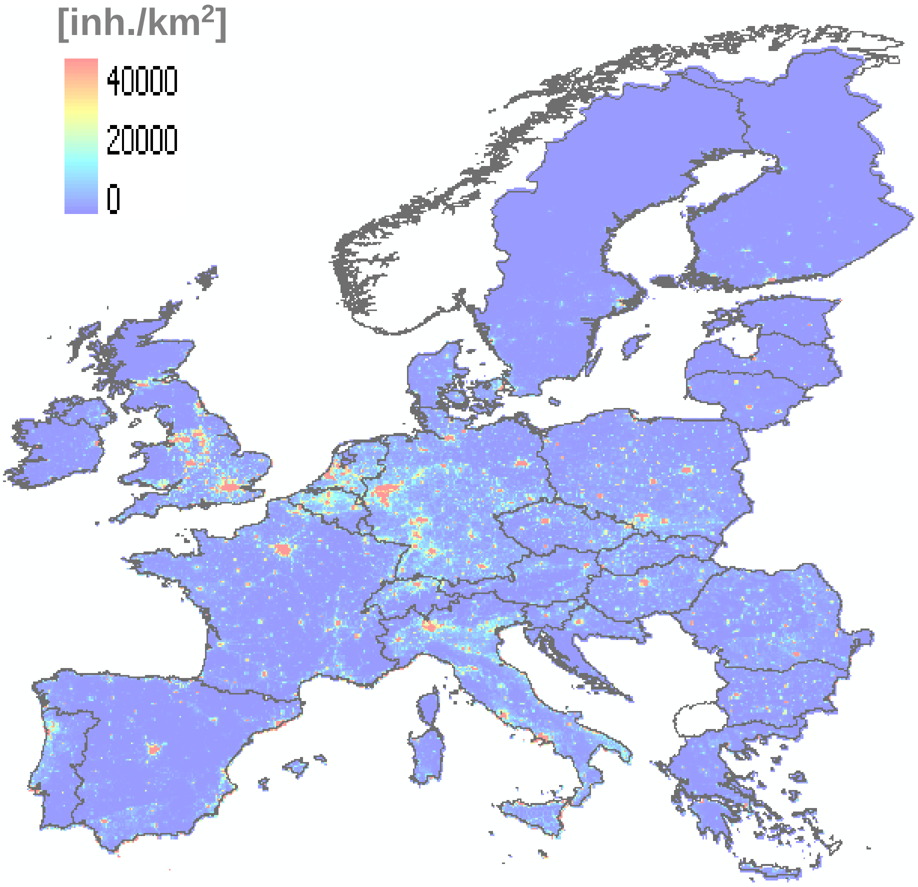
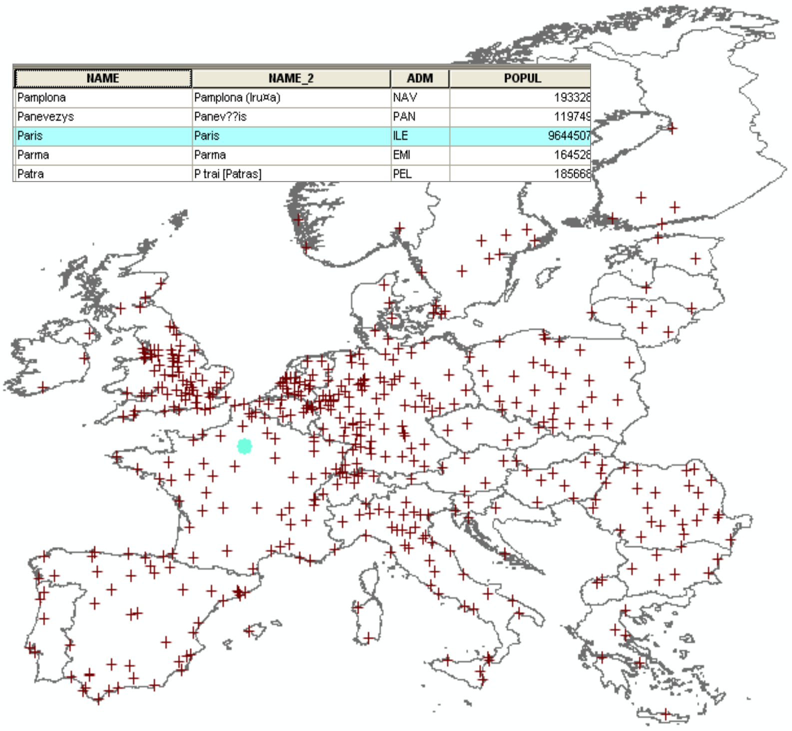


Figure 3.5: Population densities in Europe. Source: JRC



NAME	NAME_2	ADM	POPUL
Pamplona	Pamplona (Iru¤a)	NAV	193328
Panevezys	Panev??is	PAN	119749
Paris	Paris	ILE	9644507
Parma	Parma	EMI	164528
Patra	P trai [Patras]	PEL	185668

Figure 3.6: Location of the centre points of cities with more than 100,000 inhabitants. Source: www.citypopulation.de and ArcEurope base map

Figure 3.7: Populated area that has been allocated to the 473 cities in Europe with more than 100,000 inhabitants based on the information presented in the preceding graphs

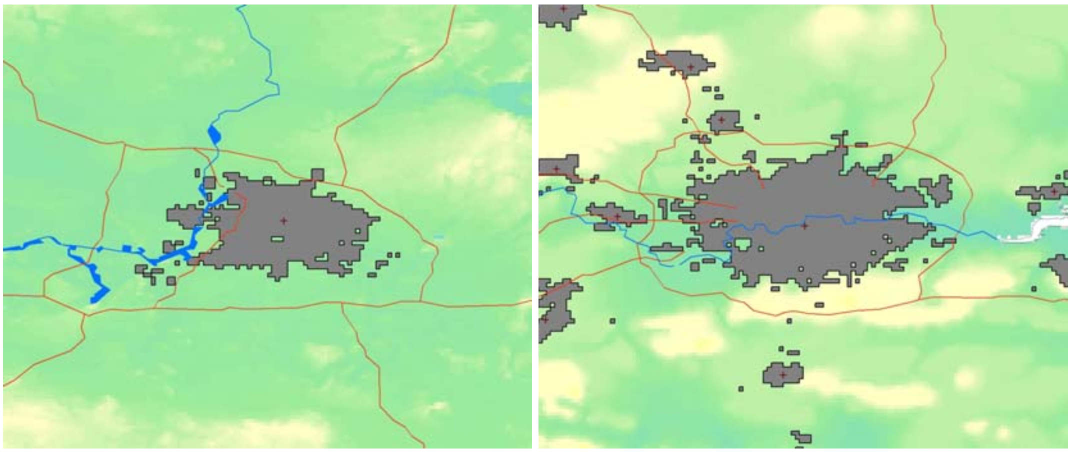


Figure 3.8: Area in which 80 percent of the population of the urban agglomeration lives for Berlin (left panel) and London (right panel)

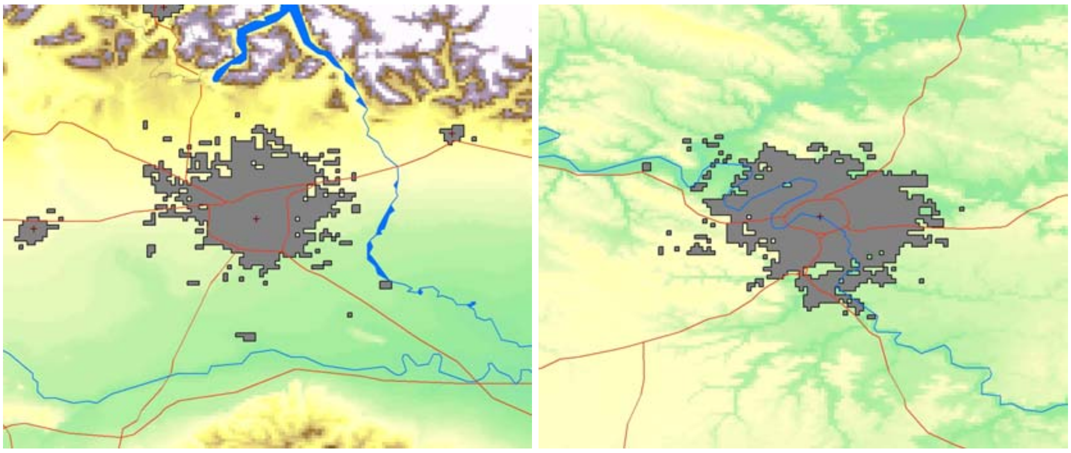


Figure 3.9: Area in which 80 percent of the population of the urban agglomeration lives for Milan (left panel) and Paris (right panel)

3.4.2 Input data: Wind speed data

Wind speed data have been extracted from the MARS meteorological database of JRC, which provides interpolated meteorological information derived from 2000 weather stations in Europe. Furthermore, local observations on wind speeds from a European database provided by the Free University Berlin have been used for German cities and other countries, when these data are more representative for city-centers than the interpolated MARS data (Figure 3.10, Figure 3.11).

A comparison of the data provided by Germany with the European wide dataset exhibits some relevant differences, most likely related to different met stations that are contained in the different data sets for the various cities. Since, within the time given for this work, it was impossible to validate the Europe-wide data for other countries, further analysis and refinements of the data set by national experts could significantly improve the accuracy of the GAINS estimates.

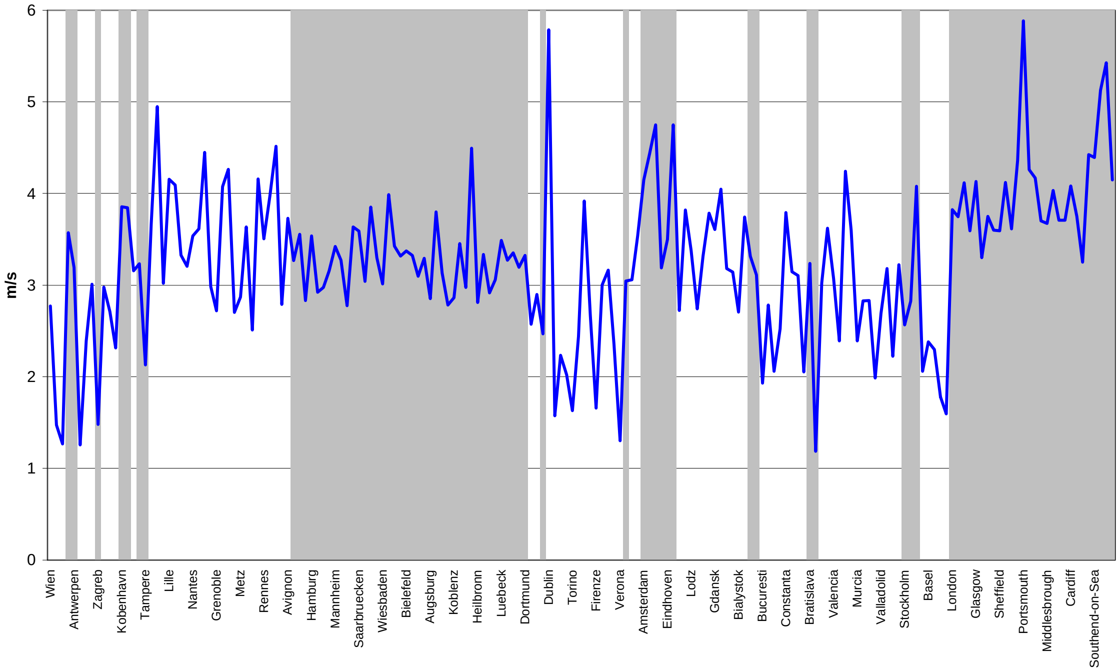


Figure 3.10: Mean annual wind speeds for the European cities with more than 250.000 inhabitants

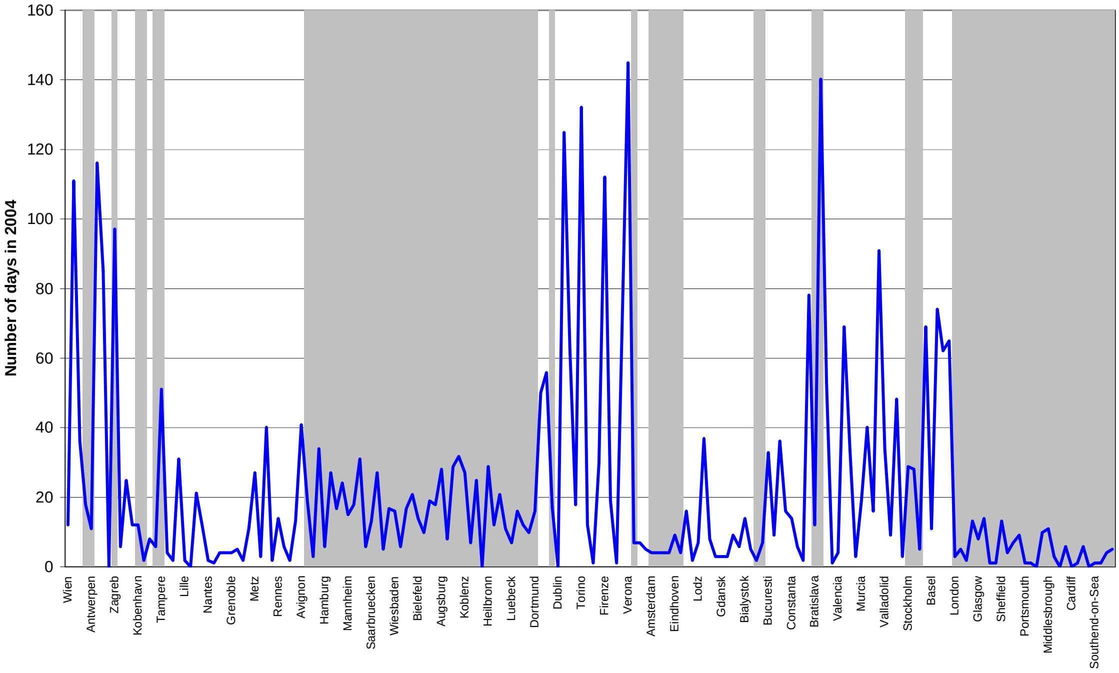


Figure 3.11: Number of days in winter with wind speeds below 1.5 m/s for cities with more than 250.000 inhabitants

With these data, the term $(D/U)^{1/2}$ in Equation 11 that reflects the influence of topography and meteorological conditions of a specific city on the dispersion characteristics of local emissions can be derived (Figure 3.12). This indicator displays a strong influence of the city size (shown by declining factors for the cities in each country, which are ranked by population) with the modifications of meteorological conditions.

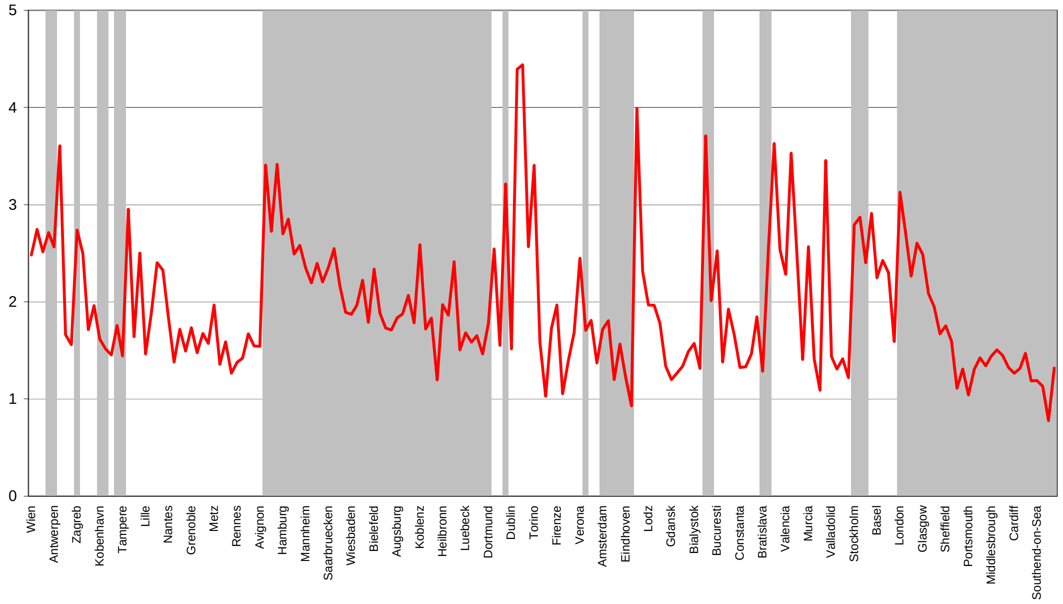


Figure 3.12: Topographic factors $(D/U)^{1/2}$ in Equation 11 that are proportional to the concentration increment (in $\mu g/m^3$) per ton PM2.5 emissions under neutral atmospheric conditions for the cities with more than 250.000 inhabitants

3.4.3 *Input data: Urban emissions*

Special emphasis has been devoted to estimating urban emissions of low level sources. In the absence of city-specific emission inventories available at the European scale, urban emissions have been estimated on a sectoral basis (distinguishing the SNAP sectors) from the gridded emission inventory compiled for the calculations of the EMEP model. First, for each country, national emissions reported in the EMEP database for each of the SNAP sectors have been scaled to the sectoral estimates of the GAINS model, which have been recently agreed upon with national experts in the bilateral consultations with IIASA. In a second step, for each city, the sectoral emissions reported in the EMEP inventory for the specific grid cell (adjusted for the GAINS estimates) have been allocated to cities based on the distribution of urban and rural population within the grid cell. For splitting total emissions into low and high-level sources, the assumptions listed in Table 3.2 have been made. Essentially, it is assumed that all emissions of SNAP sector 2 (domestic and service sector), SNAP sector 4 (non-combustion related emissions from industrial processes, usually cold processes), SNAP sector 7 (traffic) and SNAP sector 8 (off-road sources, such as construction machinery, etc.) are emitted at low heights. Emissions from power stations (SNAP 1) and waste incineration plants (SNAP 9) are assumed to be high level, while in the absence of more city-specific information 50 percent of the PM2.5 emissions reported under SNAP 3 (industrial combustion and manufacturing) are assumed to be released into the surface layer.

It has to be mentioned that in the course of the bilateral consultations with national experts the RAINS estimates of sectoral PM2.5 emissions have been adjusted to match as far as possible the national inventories with plausible data on emission factors, removal efficiencies, activity rates and application rates of control measures.

As for meteorological information, more accurate information on city-specific emissions would greatly improve the estimates of urban PM2.5 concentrations.

Table 3.2: Assumptions about emission height for the SNAP sectors

SNAP sector		*Assumption about emission height*
1	Combustion in energy and transformation industries	0 % of emissions low level
2	Non-industrial combustion plants (domestic and service sector)	100 % of emissions low level
3	Combustion in the manufacturing industry	50 % of emissions low level
4	Production processes (e.g., diffusive emissions in industry, etc.)	100 % of emissions low level
5	Extraction and distribution of fossil fuels and geothermal energy	0 % of emissions low level
6	Solvent and other product use	Not relevant for PM2.5
7	Road transport	100 % of emissions low level
8	Other mobile sources and machinery	100 % of emissions low level
9	Waste treatment and disposal	0 % of emissions low level
10	Agriculture	Not relevant for urban PM2.5
11	Other sources and sinks including nature	Not relevant for urban PM2.5

However, it has to be mentioned that the information contained in the gridded EMEP emission inventory is burdened with uncertainties, since only few countries (Austria, Denmark, Spain, Finland, France and Lithuania) have provided information for PM2.5 and UK for PM10. For all other countries the spatial allocation of national PM2.5 emissions has been performed by EMEP based on surrogate indicators such as population densities.

A particularly relevant source of uncertainties is related to emissions from wood burning. While a number of countries report rather high emissions from these activities, it is not always clear to what extent wood burning occurs within cities. There are indications that practices are different between countries, and gridded inventories that are not built upon bottom-up estimates but employ generic assumptions (like population-weighted spatial distributions) might result in serious over- or underestimates of urban PM2.5 emissions. However, there is little solid information on this subject available at this time at the European level that could allow further refinement of the current GAINS estimates.

The data set exhibits striking differences in per-capita emissions and emission densities from urban low-level sources across the European cities. Differences in industrial emissions could possibly be explained by the existence of specific plants in a given city. However, their exact locations (i.e., within or outside the city boundaries) would need to be validated on a case-by-case basis (

Figure 3.14). Certain differences in the per-capita emissions from the domestic and service sector could potentially be related to different levels of wood burning, although the question to what extent wood burning takes place within a specific city needs further attention (Figure 3.13).

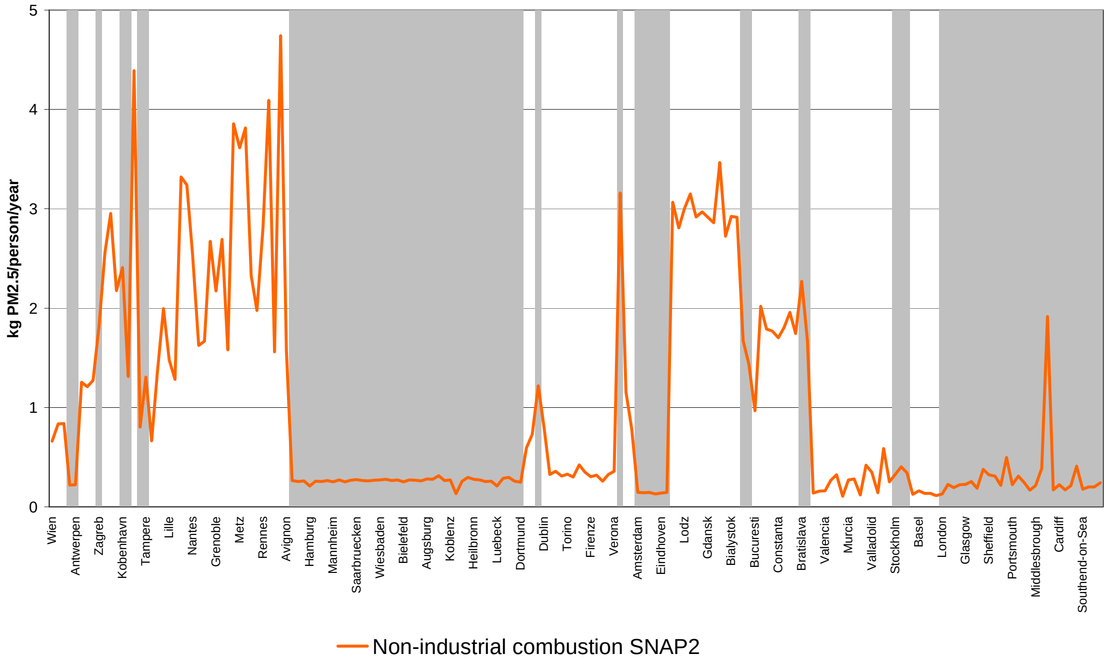


Figure 3.13: Urban per-capita emissions from non-industrial combustion (domestic and service sectors) – SNAP2 from the RAINS database for the year 2000, for the European cities with more than 250.000 inhabitants

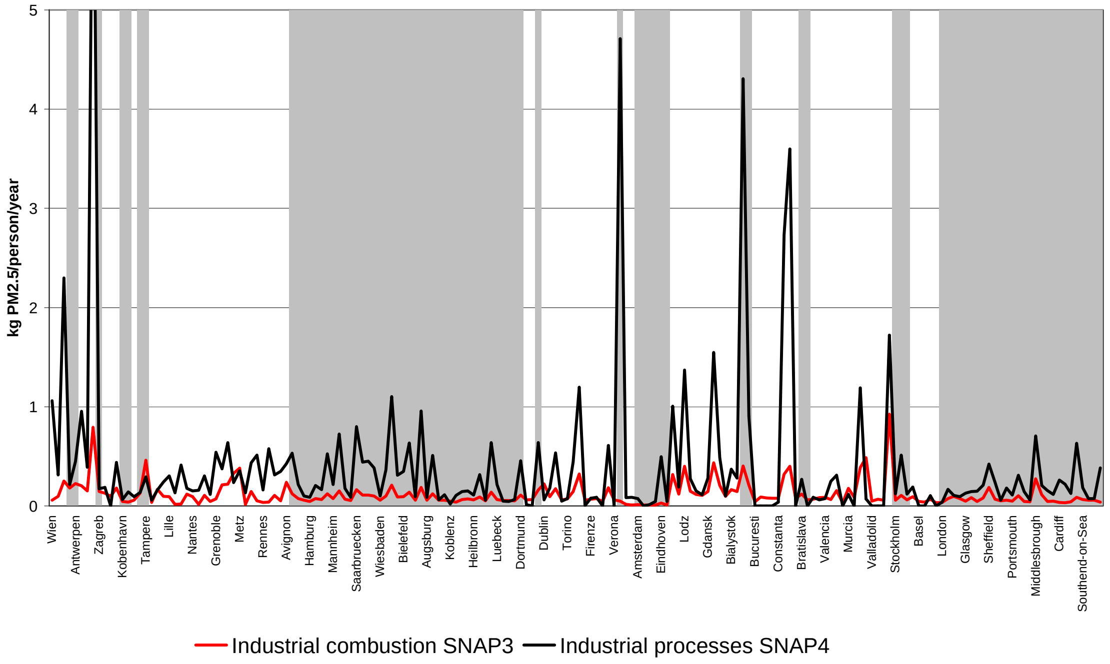


Figure 3.14: Urban per-capita emissions from industrial combustion (SNAP 3) and industrial processes (SNAP4) from the RAINS database for the year 2000, for the European cities with more than 250.000 inhabitants

Most striking, however, are variations in per-capita emissions from the transport sector across European countries. As shown in Figure 3.15, national inventories imply significant differences in per-capita emissions, with relatively high emissions for Belgium, the Czech Republic, France, Italy, Portugal and Slovakia, and low levels in German, Poland, Romania and Switzerland.

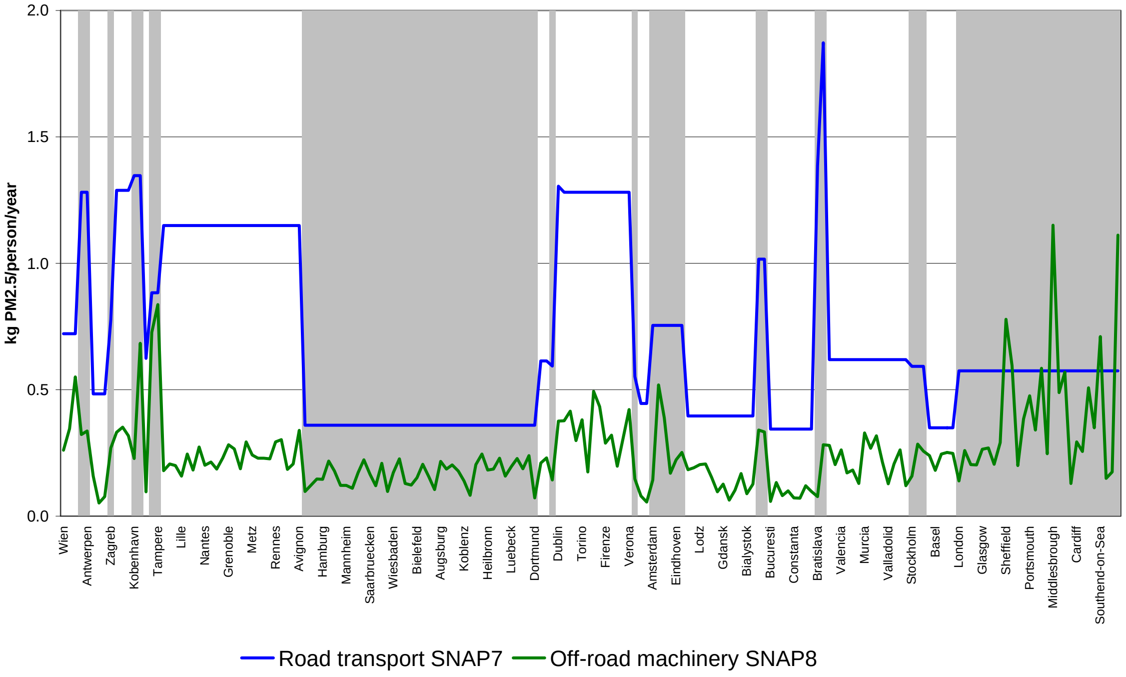


Figure 3.15: Urban per-capita emissions from road transport (SNAP 7) and off-road machinery (SNAP 8) from the RAINS database for the year 2000, for the European cities with more than 250.000 inhabitants

While some of the differences can be explained by, e.g., different shares of diesel vehicles, different implementation schedules of emission control legislation and some other factors, a more detailed analysis reveals surprising differences in emission factors used by countries in their national inventories for the same source categories. As an illustration, Figure 3.16 presents emission factors that are implied in the national emission inventories for the year 2000 for diesel passenger cars with Euro-2 emission standards. To what extent these different emission factors represent reality needs further exploration.

These discrepancies in per-capita emissions and emission factors have a direct impact on the spatial emission densities (Figure 3.17, Figure 3.18), and subsequently on the computed urban increments of PM2.5 concentrations (Figure 3.19).

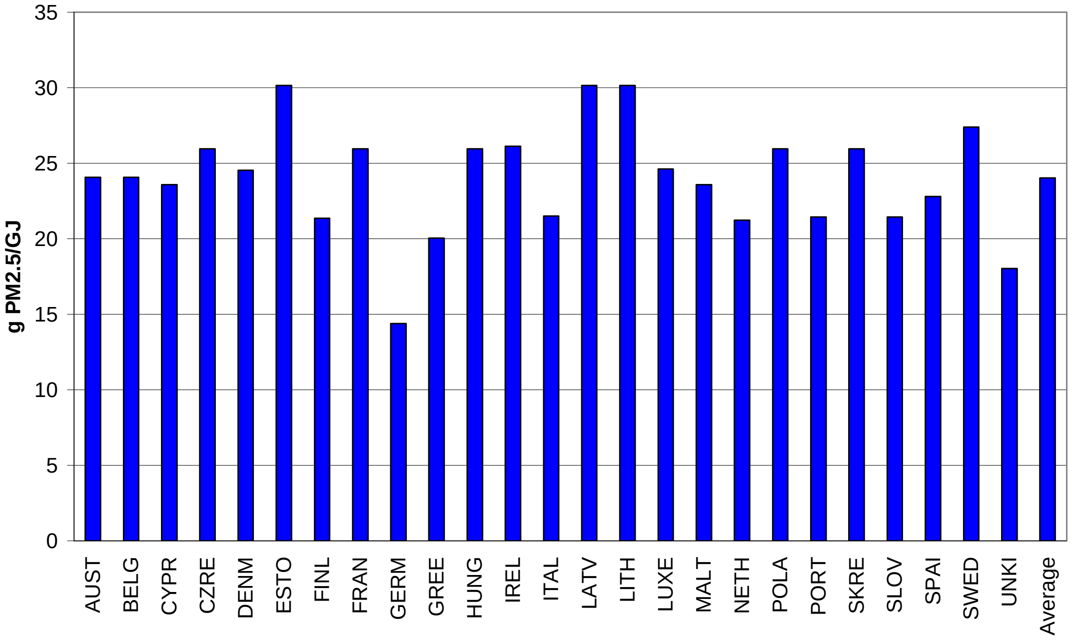


Figure 3.16: PM2.5 emission factors implied in the national inventories for diesel passenger cars with Euro-2 emission control techniques

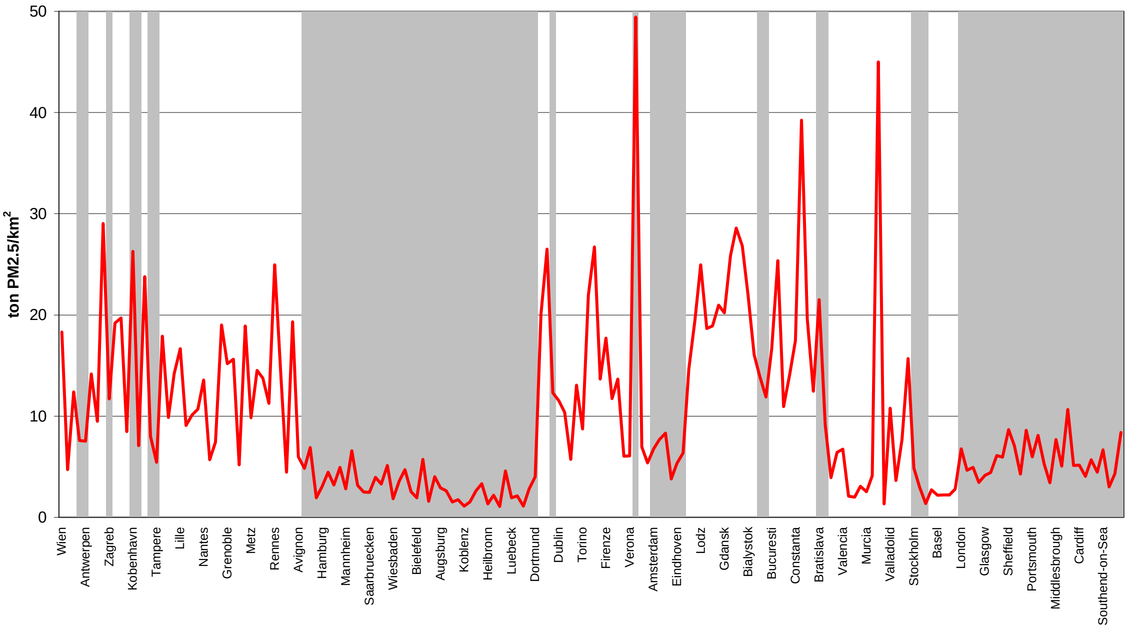


Figure 3.17: Spatial emission densities of PM2.5 from urban low level sources (all sectors) for the European cities with more than 250.000 inhabitants

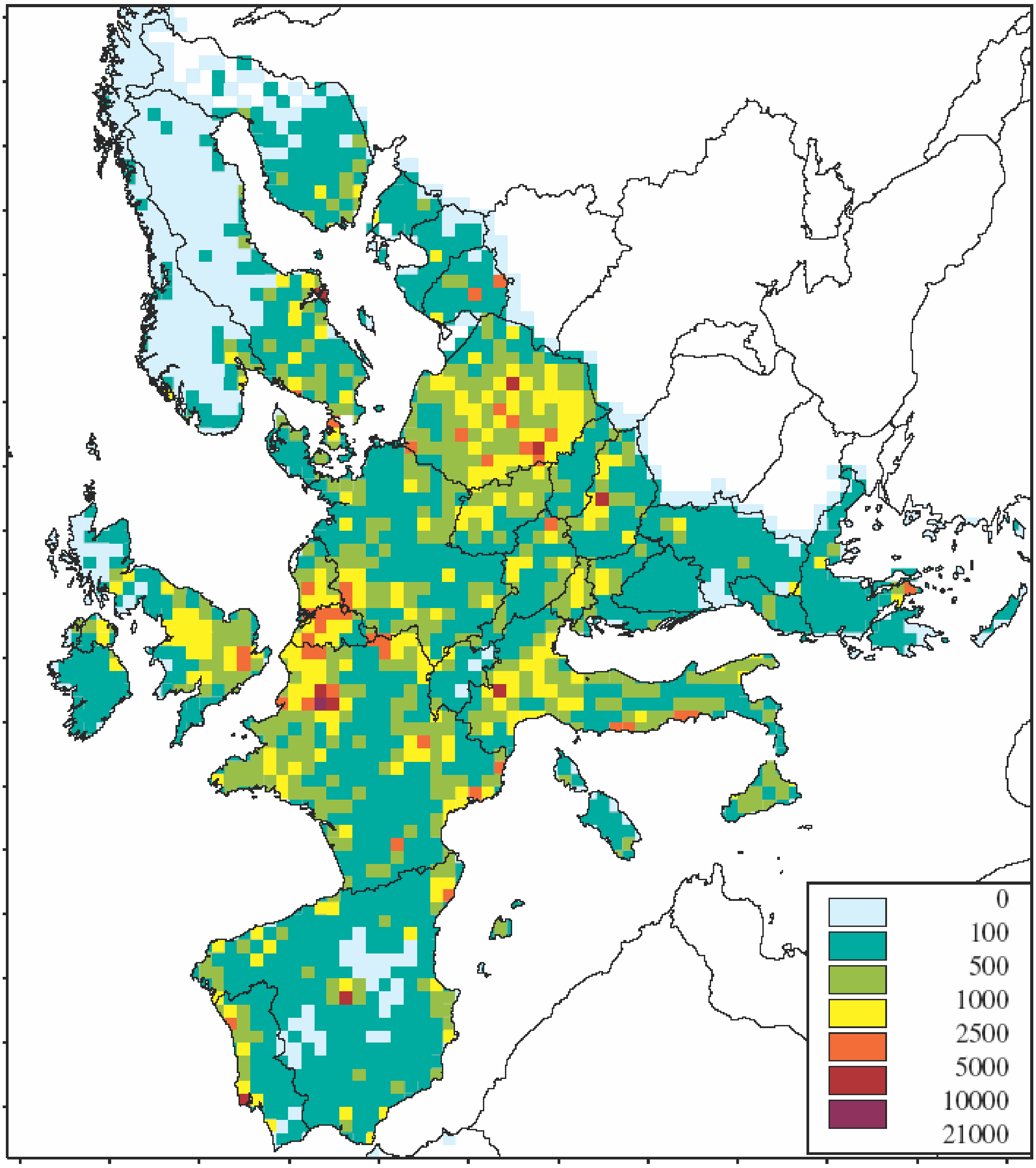


Figure 3.18: Density of primary PM2.5 emissions from low-level sources for the year 2000 (in tons/km^2) as used as input to the EMEP model calculations

3.4.4 Estimates of the urban increments for the European cities

With all this information, urban increments have been estimated according to Equation 6 for the 473 European cities that have more than 100,000 inhabitants. Calculations show a wide spread across Europe, with peaks reaching between 15 and 19 µg/m^3 (Riga, Sofia, Milan, Athens, Katowice). Low emission densities in the UK and Germany (see Figure 3.17) result in comparably lower increments (e.g., London 4.8 µg/m^3, Sheffield 3.6 µg/m^3; Berlin 4.2 µg/m^3, Essen 4.1µg/m^3). Detailed input data and results are presented in the table in the Annex.

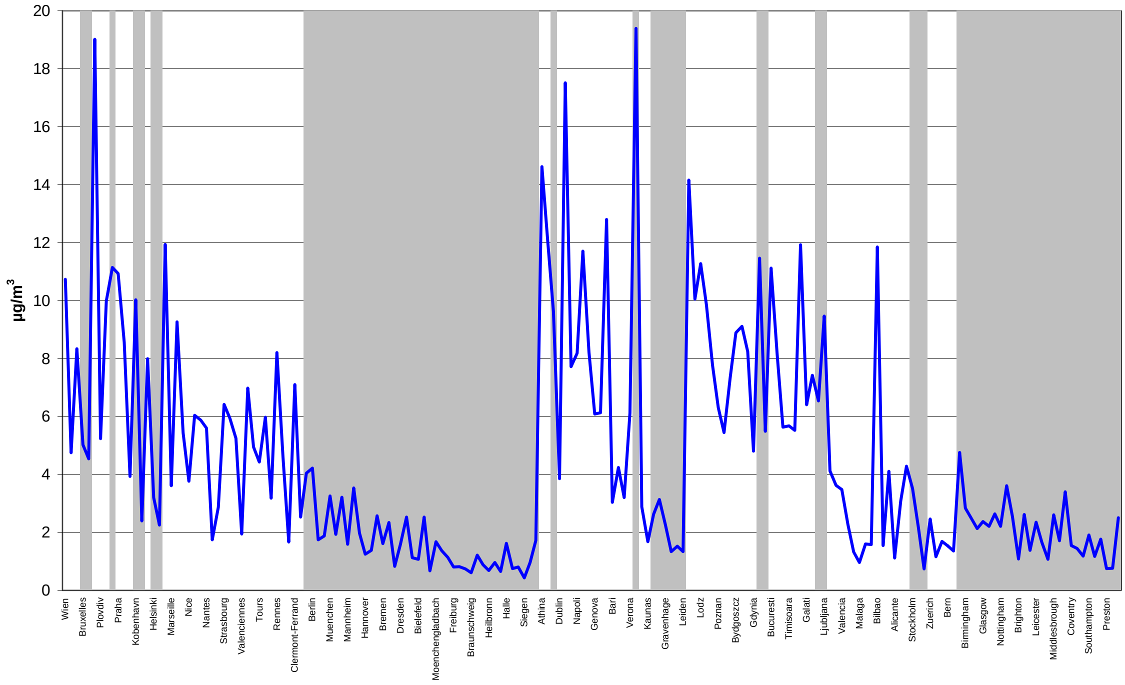


Figure 3.19: Computed urban increments for the year 2000 for the European cities with more than 250.000 inhabitants

3.5 Step 5: Calculations of the "city-deltas"

In a final step, the "city-deltas", i.e., the correction factors that have to be applied to the results of the EMEP regional scale model calculations in order to derive estimates of urban air quality, have been developed. As a pragmatic solution double-counting of the urban emissions (i.e., in the regional scale EMEP calculations and the urban increments) has been avoided by estimating the PM increase from the urban emissions that is applied in the EMEP model. With some simplifying assumptions, the city-deltas *CD* compute as:

$$CD = \alpha \cdot \Delta Q . \frac{1}{\sqrt{U}} \cdot \left((1+\beta \frac{d}{365}) \cdot \frac{\sqrt{D}}{A_C} - \frac{\sqrt[4]{A_E}}{A_E} \right) \tag{7}$$

with the index *C* indicating city-related data and the index *E* values for the entire 50*50 km EMEP grid cell, and *A* relating to the respective areas .

The resulting city-delta CD_C can then be added to the EMEP regional scale results PM_{EMEP} to attain total PM concentrations in urban areas PM_C:

$$PM_c = PM_{EMEP} + CD_c \tag{8}$$

Step 6: Validation

Finally, the total PM2.5 concentrations computed along Equation 8 together with generic assumptions on the PM contribution from mineral dust and sea salt have been compared against available monitoring data. However, such a comparison is inherently difficult for two major reasons:

- First, the computed urban increment that reflects PM concentrations in urban background air is rather sensitive towards the target domain for which it is computed. Sensitivity analyses show that urban increments computed with the detailed urban dispersion models for 5*5 km, 10*10 km and 15*15 km domains differ typically by a factor of two to three. While the impact assessment in GAINS should ideally use a population-weighted change in concentrations to connect to the relative risk functions provided by epidemiological studies, it is not always clear for which domain size a given observation can be considered as representative.
- Second, there are significant uncertainties in the reported monitoring data for PM2.5, both about their representativeness within a given city as well as on monitoring techniques and applied correction factors in an international context. While it seems difficult to quantify the uncertainties around the available monitoring data, they establish a serious obstacle for a solid intercomparison between monitoring data and model results.

Figure 3.20 to Figure 3.24 compare the contributions of mineral dust, the long-range component and the estimated city-delta to urban background PM2.5 with available measurements. For mineral dust, it has been assumed that concentrations range between 1 and 3 µg/m^3 as a function of geographical latitude. The long-range component represents the PM2.5 concentration computed by the EMEP Eulerian model (for primary PM and secondary inorganic aerosols) for the meteorology of the year 2004, while the city-deltas have been calculated according to the methodology outlined above. Furthermore, the graphs provide measurement data extracted from the AIRBASE database and from other sources. Measurement data are displayed as contained in AIRBASE. They include, inter alia, different assumptions on correction factors or are uncorrected values, and the description of the station characteristics (urban background/traffic/etc.) is not always unambiguous.

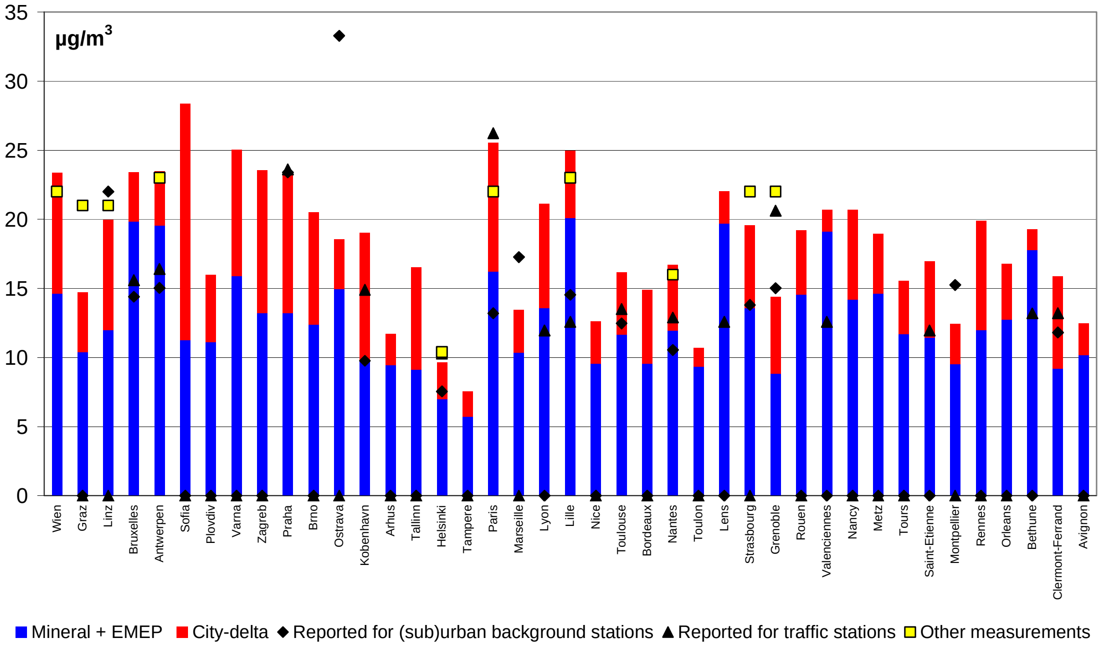


Figure 3.20: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France.

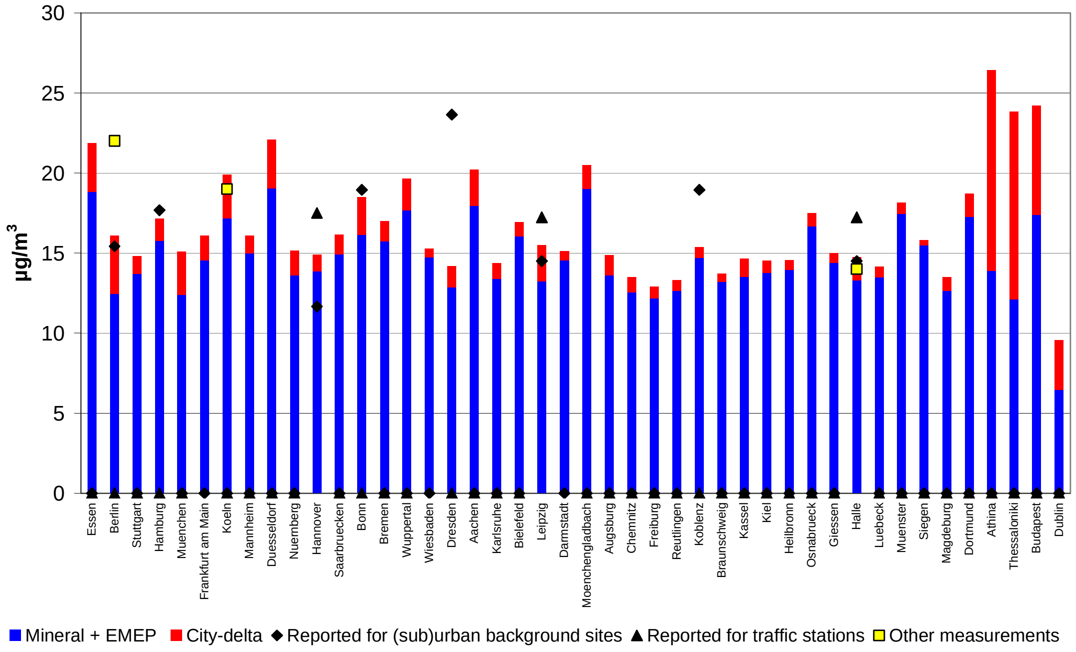


Figure 3.21: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for Germany, Hungary and Ireland.

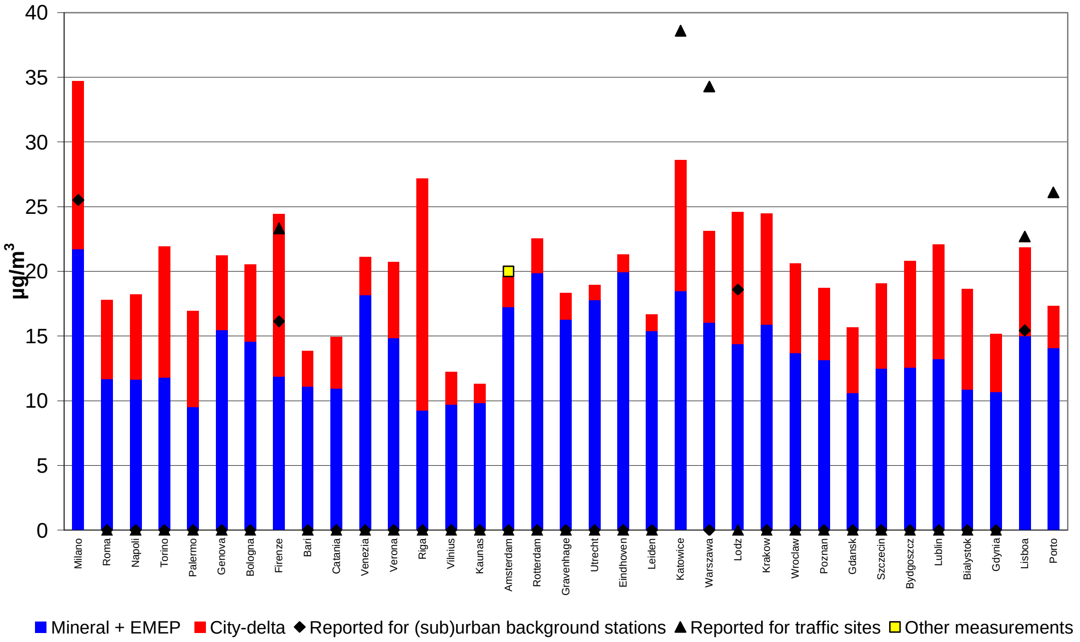


Figure 3.22: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for Italy, Latvia, Lithuania, Netherlands, Poland and Portugal.

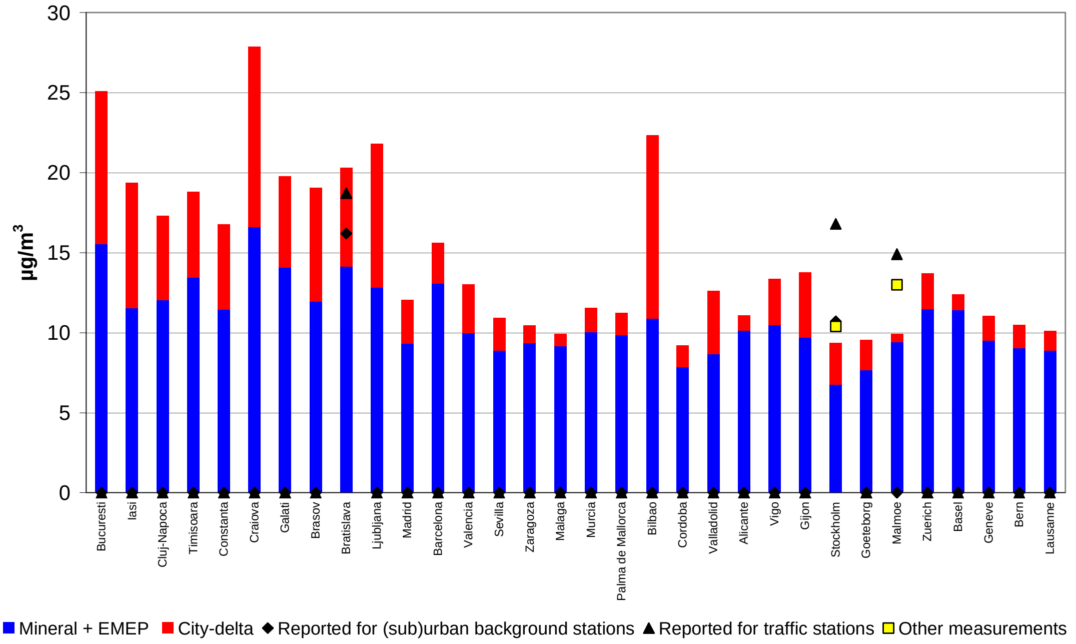


Figure 3.23: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for Romania, Slovakia, Slovenia, Spain, Sweden and Switzerland.

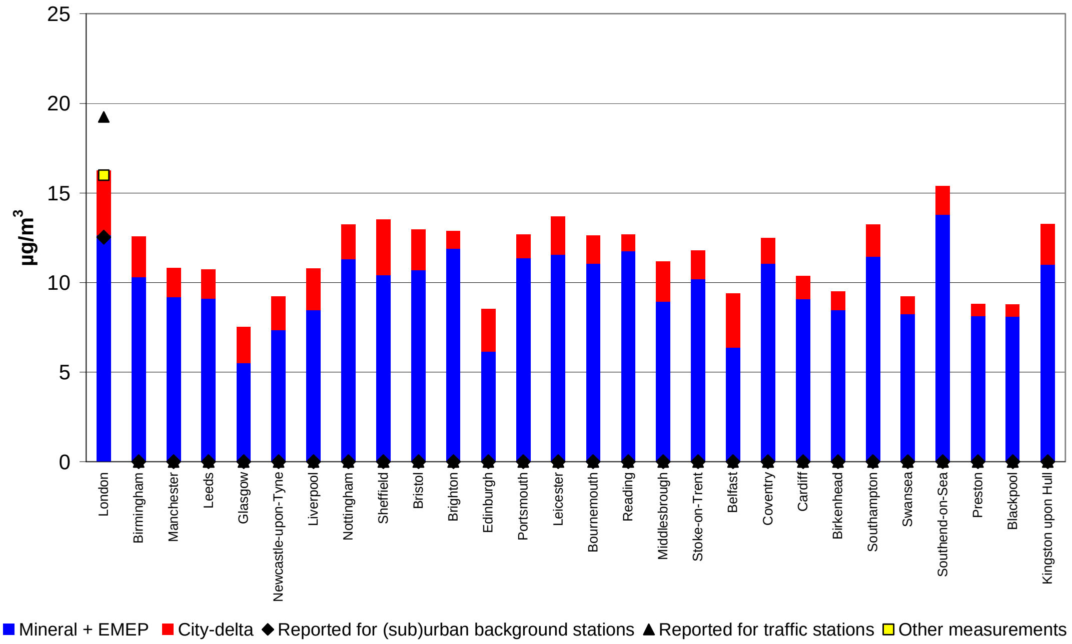


Figure 3.24: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for the United Kingdom.

4 Discussion and conclusions

The urban increments derived with the methodology outlined above aim, for the purposes of a Europe-wide health impact assessment, at the quantification of the influence of urban emissions on health-relevant metrics of urban air quality. Since, from a health perspective, the endpoint of interest lies in a population-weighted long-term exposure to fine particles, the chosen metric (annual mean PM2.5 concentration in urban background air) cannot be directly compared with observations that are usually conducted to judge compliance with air quality limit values. Thus, the methodology is unable to provide meaningful information about PM concentrations over short time periods, for specific locations (e.g., hot spots, street canyons), or for PM size fractions other than PM2.5. However, measurements taken at such locations or taken for other size fractions (such as PM10) can be used for validation of the methodology to a limited extent.

Based on atmospheric diffusion theory, the size of urban agglomerations, local wind speeds and the frequency of winter days with low ventilation, in addition to the emission densities of urban low-level emission sources, have been identified as critical factors that contribute to the “urban increments” in a given city. This information has been compiled from available sources for 473 European cities in Europe with more than 100,000 inhabitants. However, serious uncertainties that have critical influence on the estimated urban increments are associated with all these data. Most importantly, at the European level only limited information about the meteorological conditions within cities is available. Comparisons of local data with the information extracted from the Europe-wide databases reveals sometimes significant discrepancies. Furthermore, the available emission inventories for several source categories (e.g., road transport) exhibit substantial differences across countries which cannot always be explained to a satisfactory extent. Of particular relevance is the amount of fuel wood burned within cities, where the Europe-wide emission inventories provide insufficient information.

Compared to the CAFE analysis, the revised methodology and data that are used for the NEC assessment result in higher urban increments of PM2.5. While a robust validation against the available measurements is burdened with high uncertainties, the relatively low increments computed, e.g., for Germany and the UK, are mainly associated with the low densities of urban PM2.5 emissions that are used for the calculations, which are, however, in line with the nationally reported emission inventories. On the other hand, the uncertainties surrounding the issue of wood burning in cities might lead to potential overestimates of urban increments in countries with a high share of national total PM2.5 emissions from wood combustion (e.g., Austria, France. Finland). Furthermore, the lack of plant-specific information about the exact location and release height of industrial process emission sources might cause inaccuracies of the Europe-wide assessment for individual industrial cities.

More accurate information on city-specific meteorological data and information on the characteristics of local emission sources, as well as improved monitoring data, are important prerequisites for a further refinement of the methodology.

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Annex: Data for individual cities

The following table presents input data and computed urban increments for individual cities, as used in December 2006 for the first round of the NEC policy analysis. Note that these data are different from the dataset that has been distributed at the workshop on "Cost-effective control of urban air pollution", IIASA, Laxenburg, November 16 - 17, 2006

These data have been derived from the available Europe-wide datasets and might not in all cases reflect real conditions in individual cities. The authors would appreciate a review and corrections of these data in order to improve further computations.

Annex: Input data and computed urban increments for all cities as used for the NEC analysis. Meteorological conditions refer to the year 2004, and emissions to the year 2000.

Country	*City*	*Population [1000 people]*	*City diameter [km]*	*Area [km^2]*	*Annual mean wind speed [m/s]*	*Low wind speed days [# of days]*	*Emissions SNAP 2 Domestic combustion [tons/yr]*	*Emissions SNAP 3 Industrial combustion [tons/yr]*	*Emissions SNAP 4 Industrial processes [tons/yr]*	*Emissions SNAP 7 Road transport [tons/yr]*	*Emissions SNAP 8 Mobile machinery [tons/yr]*	*Total emissions [tons/yr]*	*Computed urban increment [µg/m^3]*
Austria	Wien	1878.8	17.1	283.9	2.8	12	1243	113	1996	1357	490	5199	10.7
Austria	Graz	302.2	11.1	148.0	1.5	111	252	30	95	218	105	700	4.7
Austria	Linz	274.6	8.0	103.5	1.3	36	231	70	631	198	151	1282	8.3
Austria	Salzburg	214.7	6.7	86.2	1.2	38	203	20	153	155	64	595	4.4
Austria	Innsbruck	185.9	6.8	69.5	1.9	19	244	10	278	134	61	728	4.8
Austria	Klagenfurt	101.5	5.4	74.6	1.3	131	165	4	63	73	59	365	3.8
Belgium	Bruxelles	1900.0	26.3	557.3	3.6	18	420	344	413	2435	615	4227	5.0
Belgium	Antwerpen	1125.0	21.0	376.0	3.2	11	251	254	505	1442	379	2831	4.5
Belgium	Gent	229.3	7.9	100.1	3.3	1	56	71	190	294	82	692	2.3
Belgium	Charleroi	200.6	6.6	106.2	3.9	2	45	96	361	257	63	823	2.2
Belgium	Liege	185.5	6.6	73.6	3.9	7	42	74	254	238	63	671	2.7
Belgium	Brugge	117.0	6.1	45.6	5.1	3	29	19	2	150	40	240	1.3
Belgium	Namur	106.2	7.1	91.2	3.8	9	26	35	101	136	34	333	1.2
Bulgaria	Sofia	1250.0	16.3	270.4	1.3	116	1570	257	1195	605	199	3826	19.0
Bulgaria	Plovdiv	341.5	6.6	82.4	2.4	85	413	52	134	165	18	781	5.2
Bulgaria	Varna	312.0	7.3	109.8	3.0	0	398	248	2368	151	24	3188	10.0
Bulgaria	Burgas	189.5	8.0	123.8	3.6	6	220	89	772	92	10	1183	3.3
Bulgaria	Ruse	158.2	6.0	80.2	2.1	33	245	63	450	77	12	847	4.7
Bulgaria	Stara Zagora	141.5	5.2	37.4	2.7	46	204	44	276	68	19	612	6.4
Bulgaria	Pleven	115.4	5.7	46.6	2.6	60	151	19	50	56	17	293	2.8
Croatia	Zagreb	691.7	11.1	189.3	1.5	97	1267	102	121	538	187	2215	11.1
Croatia	Split	188.7	5.5	38.5	3.6	15	341	38	85	147	23	634	4.9
Croatia	Rijeka	143.8	2.7	26.9	1.7	84	263	77	296	112	24	771	11.8
Czech R	Praha	1275.0	18.6	298.7	3.0	6	3262	166	239	1642	423	5732	10.9
Czech R.	Brno	369.6	8.0	87.9	2.7	25	1091	36	0	476	130	1733	8.6

Country	City	Population [1000 people]	City diameter [km]	Area [km^2]	Annual mean wind speed [m/s]	Low wind speed days [# of days]	Emissions SNAP 2 Domestic combustion [tons/yr]	Emissions SNAP 3 Industrial combustion [tons/yr]	Emissions SNAP 4 Industrial processes [tons/yr]	Emissions SNAP 7 Road transport [tons/yr]	Emissions SNAP 8 Mobile machinery [tons/yr]	Total emissions [tons/yr]	Computed urban increment [$\mu g/m^3$]
Czech R.	Ostrava	313.1	8.9	162.5	2.3	12	681	57	138	403	99	1378	3.9
Czech R.	Plzen	164.2	6.5	52.7	3.3	7	410	23	39	212	52	735	4.6
Czech R.	Olomouc	101.3	6.7	37.6	2.4	6	264	10	6	130	29	439	4.5
Denmark	Kobenhavn	1085.8	10.0	169.1	3.9	12	2614	49	72	1463	248	4446	10.0
Denmark	Arhus	295.0	8.8	146.5	3.8	2	387	12	42	397	202	1040	2.4
Denmark	Odense	185.9	8.8	115.0	4.6	1	400	8	106	250	98	863	2.3
Denmark	Alborg	163.2	7.3	111.5	4.1	3	195	86	28	220	146	674	1.8
Estonia	Tallinn	397.2	6.7	87.9	3.2	8	1744	24	37	248	38	2092	8.0
Estonia	Tartu	101.2	5.6	29.1	2.7	19	505	5	0	63	15	588	7.1
Finland	Helsinki	1125.0	10.0	377.4	3.2	6	904	146	152	994	818	3014	3.2
Finland	Tampere	270.8	4.4	188.5	2.1	51	354	125	79	239	227	1024	2.3
Finland	Turku	239.0	11.0	154.6	2.5	40	318	43	29	211	194	795	3.0
Finland	Oulu	157.6	12.1	142.4	2.1	51	254	162	40	139	131	726	3.5
Finland	Lahti	110.2	6.7	85.7	1.4	73	151	11	13	97	92	364	2.9
France	Paris	9644.5	31.9	1125.1	3.7	4	6411	339	575	11084	1738	20146	11.9
France	Marseille	1349.8	13.3	416.6	4.9	2	1834	229	220	1551	280	4113	3.6
France	Lyon	1348.8	18.9	350.6	3.0	31	2694	133	328	1550	271	4975	9.3
France	Lille	1000.9	8.9	191.0	4.2	2	1478	93	303	1150	159	3183	5.4
France	Nice	888.8	14.5	277.6	4.1	0	1140	16	119	1021	218	2515	3.8
France	Toulouse	761.1	19.2	382.7	3.3	21	2528	17	314	875	139	3873	6.0
France	Bordeaux	753.9	17.4	350.2	3.2	12	2443	90	133	866	206	3739	5.9
France	Nantes	544.9	12.1	166.0	3.5	2	1381	53	83	626	110	2253	5.6
France	Toulon	519.6	6.9	289.2	3.6	1	845	9	83	597	111	1645	1.8
France	Lens	518.7	13.1	239.0	4.4	4	865	56	158	596	97	1773	2.9
France	Strasbourg	427.2	6.7	94.8	3.0	4	1142	20	50	491	99	1802	6.4
France	Grenoble	419.3	8.2	116.6	2.7	4	911	30	227	482	118	1769	5.9
France	Rouen	389.9	8.9	117.2	4.1	5	1050	83	146	448	104	1832	5.2
France	Valenciennes	357.4	11.9	259.1	4.3	2	565	78	228	411	67	1349	1.9

Country	*City*	*Population [1000 people]*	*City diameter [km]*	*Area [km^2]*	*Annual mean wind speed [m/s]*	*Low wind speed days [# of days]*	*Emissions SNAP 2 Domestic combustion [tons/yr]*	*Emissions SNAP 3 Industrial combustion [tons/yr]*	*Emissions SNAP 4 Industrial processes [tons/yr]*	*Emissions SNAP 7 Road transport [tons/yr]*	*Emissions SNAP 8 Mobile machinery [tons/yr]*	*Total emissions [tons/yr]*	*Computed urban increment [μg/m^3]*
France	Nancy	331.4	6.7	102.7	2.7	11	1278	110	78	381	97	1944	7.0
France	Metz	322.5	11.1	188.2	2.9	27	1165	123	114	371	78	1851	4.9
France	Tours	297.6	6.7	109.5	3.6	3	1135	5	40	342	68	1591	4.4
France	Saint-Etienne	292.0	6.3	90.9	2.5	40	680	43	127	336	67	1253	6.0
France	Montpellier	288.0	6.7	100.1	4.2	2	569	15	148	331	65	1128	3.2
France	Rennes	272.3	6.7	48.6	3.5	14	766	10	44	313	80	1213	8.2
France	Orleans	263.3	8.0	114.2	4.0	6	1077	10	153	303	80	1622	4.6
France	Bethune	259.2	12.6	192.3	4.5	2	405	28	81	298	48	860	1.7
France	Clermont-F.	258.5	6.7	87.0	2.8	13	1226	14	90	297	54	1681	7.1
France	Avignon	253.6	8.9	158.2	3.7	41	399	61	109	291	86	947	2.6
France	Havre	248.5	4.0	31.3	4.9	0	630	335	95	286	56	1401	8.9
France	Dijon	237.0	6.7	69.5	3.4	11	1141	6	70	272	68	1557	7.3
France	Mulhouse	234.4	6.7	83.8	3.1	11	652	19	98	269	75	1114	4.6
France	Angers	226.8	6.6	82.6	3.1	19	616	5	85	261	45	1012	4.4
France	Reims	215.6	5.6	33.0	3.6	1	988	112	62	248	42	1451	12.1
France	Brest	210.1	5.6	70.5	3.7	0	671	5	44	241	50	1012	3.9
France	Caen	199.5	7.3	51.6	4.3	3	784	4	127	229	49	1192	6.8
France	Mans	194.8	5.3	55.3	2.8	27	544	6	78	224	46	899	5.7
France	Dunkerque	191.2	5.5	51.3	6.0	0	316	96	399	220	44	1075	4.4
France	Pau	181.4	8.9	117.7	2.4	31	655	3	14	208	52	932	4.0
France	Bayonne	179.0	10.5	136.1	3.1	10	549	17	312	206	41	1124	3.5
France	Limoges	173.3	7.8	96.4	3.3	5	1062	2	69	199	43	1376	4.9
France	Perpignan	162.7	5.5	85.3	4.8	0	355	3	97	187	61	703	2.0
France	Amiens	160.8	5.6	43.0	4.3	3	566	15	40	185	58	864	5.2
France	N?mes	148.9	5.7	67.7	4.3	1	287	10	68	171	37	572	2.2
France	Saint-Nazaire	136.9	9.8	140.7	3.9	4	429	28	25	157	40	679	1.7
France	Annecy	136.8	5.6	51.5	2.3	74	286	9	75	157	45	572	5.5
France	Besan?on	134.4	6.2	46.1	1.8	85	723	10	57	154	31	977	12.9

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France	Thionville	130.5	5.1	78.0	3.3	13	466	82	228	150	30	956	3.6
France	Troyes	128.9	5.9	49.3	3.1	9	712	13	22	148	44	939	6.1
France	Poitiers	119.4	6.7	65.3	3.7	2	619	2	13	137	37	809	3.7
France	Valence	117.4	6.2	65.6	3.6	14	249	7	36	135	28	455	2.2
France	Lorient	116.2	5.2	29.1	4.3	0	318	4	20	134	25	501	4.2
France	Rochelle	116.2	5.1	63.3	4.3	1	579	2	29	133	31	775	3.0
France	Chambry	113.5	7.3	99.3	3.7	18	463	13	11	130	40	657	2.3
France	Montbeliard	113.1	6.0	50.9	2.3	43	627	3	49	130	27	837	7.3
France	Annemasse	106.7	5.4	88.9	2.3	74	271	7	44	123	32	477	2.6
France	Calais	104.9	3.6	21.0	4.8	2	190	151	592	121	26	1079	9.9
France	Angouleme	103.7	6.3	87.2	3.3	7	541	27	8	119	32	727	2.7
Germany	Essen	5788.5	37.9	1653.7	3.3	19	1536	715	3082	2086	568	7987	4.0
Germany	Berlin	4170.5	26.4	623.0	3.6	3	1063	310	902	1503	515	4291	4.2
Germany	Stuttgart	2615.7	33.0	1264.9	2.8	34	684	153	268	942	387	2434	1.7
Germany	Hamburg	2532.6	25.8	708.2	3.5	6	531	121	222	912	371	2158	1.9
Germany	Muenchen	1920.1	23.7	479.5	2.9	27	497	141	396	692	419	2144	3.3
Germany	Frankfurt/M.	1902.8	18.5	612.0	3.0	17	484	127	315	686	340	1951	1.9
Germany	Köln	1827.5	21.0	517.2	3.2	24	485	224	962	658	223	2553	3.2
Germany	Mannheim	1575.4	18.9	574.3	3.4	15	399	117	344	568	193	1621	1.6
Germany	Düsseldorf	1318.4	15.7	324.0	3.3	18	357	202	956	475	147	2136	3.5
Germany	Nürnberg	1023.2	15.9	334.8	2.8	31	257	70	183	369	177	1056	2.0
Germany	Hannover	1000.2	17.7	401.0	3.6	6	269	57	86	360	224	997	1.3
Germany	Saarbrücken	953.9	19.9	683.6	3.6	13	263	158	763	344	158	1686	1.4
Germany	Bonn	893.6	19.7	293.7	3.0	27	237	98	395	322	108	1160	2.6
Germany	Bremen	855.8	18.0	364.1	3.9	5	225	95	386	308	179	1194	1.6
Germany	Wuppertal	840.6	11.8	199.3	3.3	17	226	86	323	303	82	1019	2.3
Germany	Wiesbaden	783.5	10.6	409.8	3.0	16	212	47	79	282	135	755	0.8
Germany	Dresden	685.8	15.4	256.9	4.0	6	191	69	251	247	156	915	1.6

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Germany	Aachen	597.5	16.9	263.0	3.4	17	159	125	660	215	77	1237	2.5
Germany	Karlsruhe	595.9	10.6	272.0	3.3	21	162	54	185	215	73	689	1.1
Germany	Bielefeld	585.3	18.4	368.0	3.4	14	147	55	204	211	89	706	1.1
Germany	Leipzig	572.5	11.8	161.2	3.3	10	156	80	364	206	117	924	2.5
Germany	Darmstadt	529.3	9.2	313.6	3.1	19	142	31	50	191	83	496	0.7
Germany	Mönchengl.	476.0	9.6	221.3	3.3	18	124	89	456	172	50	891	1.7
Germany	Augsburg	433.5	9.6	150.1	2.9	28	122	26	37	156	94	435	1.4
Germany	Chemnitz	423.5	13.4	235.5	3.8	8	118	52	216	153	79	617	1.1
Germany	Freiburg	380.0	13.4	251.9	3.1	29	119	23	23	137	77	380	0.8
Germany	Reutlingen	362.4	8.8	202.1	2.8	32	96	22	42	131	65	355	0.8
Germany	Koblenz	348.8	19.1	262.9	2.9	27	95	17	8	126	49	294	0.7
Germany	Braunschweig	346.9	10.2	164.8	3.5	7	47	13	38	125	29	251	0.6
Germany	Kassel	330.3	10.0	130.4	3.0	25	85	21	49	119	68	341	1.2
Germany	Kiel	329.4	6.4	111.6	4.5	0	98	24	50	119	81	372	0.9
Germany	Heilbronn	322.7	10.9	239.1	2.8	29	90	20	35	116	59	321	0.7
Germany	Osnabrück	312.0	11.6	176.0	3.3	12	84	29	99	112	58	383	1.0
Germany	Giessen	310.5	17.0	272.9	2.9	21	79	16	19	112	71	297	0.7
Germany	Halle	309.0	6.9	104.6	3.1	11	80	43	198	111	49	481	1.6
Germany	Lübeck	289.4	9.8	157.2	3.5	7	61	19	62	104	57	304	0.7
Germany	Muenster	289.0	8.2	133.9	3.3	16	83	16	14	104	66	283	0.8
Germany	Siegen	255.2	9.1	218.9	3.4	12	76	14	12	92	48	242	0.4
Germany	Magdeburg	253.8	6.8	87.9	3.2	10	66	13	17	91	61	248	1.0
Germany	Ulm	246.1	10.7	161.5	2.8	31	74	18	37	89	56	273	0.9
Germany	Zwickau	225.6	6.3	163.3	3.6	7	64	29	123	81	45	342	0.6
Germany	Rostock	211.7	5.9	68.0	4.5	0	60	18	52	76	66	272	1.0
Germany	Würzburg	207.5	7.2	90.8	2.6	31	49	20	80	75	44	268	1.3
Germany	Erfurt	206.0	6.6	105.7	3.6	9	59	14	29	74	59	236	0.7
Germany	Bremerhaven	195.4	4.0	68.2	4.6	3	54	15	42	70	55	236	0.7

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Germany	Regensburg	195.0	6.7	76.1	2.4	44	47	10	14	70	48	190	1.2
Germany	Oldenburg	194.3	6.0	62.2	3.9	5	55	12	18	70	59	214	1.0
Germany	Paderborn	179.1	7.6	121.6	3.4	12	53	19	71	65	42	250	0.7
Germany	B. Oeynhausen	173.7	7.0	113.5	3.5	11	46	12	27	63	30	178	0.5
Germany	Pforzheim	171.1	7.3	69.0	3.0	30	50	11	19	62	23	166	1.0
Germany	Aschaffenburg	169.3	7.2	100.0	2.9	24	48	23	98	61	26	255	1.0
Germany	Lörrach	165.9	9.0	134.8	2.5	50	38	14	54	60	25	192	0.8
Germany	Ingolstadt	153.4	6.6	92.8	2.6	39	42	20	88	55	48	254	1.2
Germany	Göttingen	148.3	4.8	42.2	3.0	22	29	7	16	53	26	131	1.0
Germany	Baden-Baden	148.1	5.4	133.4	3.1	25	40	13	41	53	23	170	0.4
Germany	Hildesheim	146.8	6.1	87.1	3.6	7	30	6	10	53	22	121	0.4
Germany	Minden	145.9	6.5	102.7	3.5	9	42	13	43	53	38	190	0.6
Germany	Rosenheim	143.1	7.5	105.2	2.6	29	38	10	26	52	31	156	0.6
Germany	Trier	140.9	6.6	108.5	3.3	20	41	7	0	51	35	134	0.4
Germany	Düren	135.7	6.3	77.2	4.7	7	35	31	168	49	16	299	1.0
Germany	Kaiserslautern	129.5	7.2	70.6	3.8	9	33	13	47	47	22	162	0.7
Germany	Wolfsburg	128.6	6.1	90.4	3.3	8	17	5	12	46	14	94	0.3
Germany	Gera	128.2	6.6	70.9	3.6	8	35	12	42	46	27	163	0.7
Germany	Salzgitter-Bad	122.8	6.8	85.0	3.5	8	20	5	11	44	14	94	0.4
Germany	Herford	120.1	5.5	84.2	3.4	14	31	7	12	43	16	110	0.4
Germany	Cottbus	118.3	6.9	57.3	3.4	8	33	38	216	43	30	359	2.1
Germany	Flensburg	115.9	5.1	37.0	5.0	0	31	8	23	42	42	145	0.9
Germany	Wilhelmshaven	115.3	7.3	55.8	4.7	2	32	10	29	42	31	143	0.7
Germany	Detmold	110.1	6.9	81.4	3.4	12	28	6	10	40	17	101	0.4
Germany	Arnsberg	109.4	6.5	107.0	3.6	11	30	13	58	39	15	155	0.5
Germany	Schwerin	107.6	4.0	57.1	3.8	2	26	6	8	39	42	120	0.5
Germany	Bad Kreuznach	107.0	7.1	97.1	3.3	18	28	6	11	39	19	104	0.4
Germany	Bamberg	105.8	6.6	46.9	2.4	47	30	6	9	38	32	115	1.1

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Germany	Fulda	105.0	7.2	69.0	3.0	17	23	5	4	38	23	94	0.5
Germany	Jena	104.4	6.0	42.0	3.6	9	31	8	21	38	28	126	0.9
Germany	Villingen	103.0	6.2	92.4	3.2	19	36	7	7	37	28	115	0.4
Germany	Lüneburg	102.3	6.3	61.3	3.4	4	16	3	1	37	11	67	0.3
Germany	Mainz	185.5	6.6	48.4	3.1	18	49	12	25	67	31	184	1.4
Germany	Hamm	185.0	6.5	78.8	3.3	23	46	22	95	67	18	248	1.1
Germany	Solingen	164.5	6.6	48.8	3.3	18	47	16	52	59	20	194	1.4
Germany	Heidelberg	143.0	5.6	39.4	3.2	16	34	14	54	52	13	166	1.3
Germany	Remscheid	117.7	4.8	41.0	3.3	19	34	11	37	42	14	139	1.0
Germany	Moers	107.9	3.3	36.2	3.3	16	27	15	68	39	11	159	1.1
Germany	Erlangen	102.4	6.5	37.6	2.8	31	26	7	18	37	18	106	1.1
Germany	Dortmund	589.7	10.5	182.8	3.3	16	146	64	268	212	43	734	1.7
Greece	Athina	3187.7	16.7	237.4	2.6	50	1891	199	47	1959	672	4769	14.6
Greece	Thessaloniki	800.8	7.0	49.7	2.9	56	585	53	0	492	185	1315	12.1
Greece	Patra	185.7	5.8	76.6	2.5	52	172	16	0	114	41	343	2.0
Greece	Iraklio	144.6	5.7	63.5	4.8	0	140	13	0	89	49	290	1.1
Greece	Volos	125.0	4.3	64.0	3.2	29	136	12	0	77	67	292	1.4
Greece	Larissa	124.8	5.1	49.4	1.8	100	124	11	0	77	36	247	2.9
Hungary	Budapest	2300.0	25.5	514.6	2.5	17	2803	371	1468	1366	331	6339	9.6
Hungary	Debrecen	205.9	7.8	139.1	2.8	28	278	30	54	122	26	510	1.6
Hungary	Miskolc	180.3	6.7	69.3	2.4	23	225	95	951	107	22	1400	8.4
Hungary	Szeged	162.9	6.7	101.6	2.9	24	215	20	0	97	23	354	1.3
Hungary	Pecs	158.9	7.7	59.1	2.4	29	196	87	886	94	16	1279	10.1
Hungary	Gyor	128.9	6.7	112.2	2.1	12	163	19	51	77	22	332	1.2
Hungary	Nyeregyhaza	116.9	7.4	101.7	3.5	10	144	14	8	69	18	253	0.8
Hungary	Kecskemet	107.6	12.2	146.8	3.0	11	172	16	0	64	12	265	0.8
Hungary	Szekesfehervar	102.7	6.5	81.4	2.8	19	121	85	958	61	13	1239	5.7
Ireland	Dublin	1004.6	13.3	241.1	5.8	0	803	223	63	1311	378	2778	3.9

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Ireland	Cork	186.2	6.7	54.1	4.8	0	128	65	41	243	40	517	2.5
Italy	Milano	3850.0	30.4	839.1	1.6	125	1256	362	702	4933	1454	8706	17.5
Italy	Roma	3350.0	44.0	1617.6	2.2	63	1207	584	1798	4293	1393	9276	7.7
Italy	Napoli	3100.0	13.3	476.1	2.0	18	965	198	156	3972	928	6219	8.2
Italy	Torino	1725.0	18.9	422.9	1.6	132	568	125	132	2210	658	3693	11.7
Italy	Palermo	679.7	6.1	72.8	2.4	12	206	99	304	871	119	1598	8.2
Italy	Genova	601.3	4.1	83.7	3.9	1	254	195	721	771	297	2238	6.1
Italy	Bologna	373.5	7.9	58.1	2.7	30	130	23	1	479	162	795	6.1
Italy	Firenze	367.3	6.4	41.9	1.7	112	111	25	29	471	106	741	12.8
Italy	Bari	314.2	3.3	55.8	3.0	19	101	23	28	403	101	655	3.0
Italy	Catania	307.8	6.2	40.1	3.2	1	80	14	0	394	61	549	4.2
Italy	Venezia	271.7	6.7	122.0	2.3	72	89	50	166	348	85	738	3.2
Italy	Verona	258.1	7.8	90.1	1.3	145	92	16	0	331	109	548	6.1
Italy	Messina	248.6	5.7	72.8	2.6	20	92	86	335	319	35	867	4.3
Italy	Padova	208.9	6.1	65.9	1.3	141	64	32	101	268	61	526	7.1
Italy	Trieste	208.3	3.8	26.8	1.6	112	66	67	266	267	60	727	15.4
Italy	Taranto	199.1	3.7	59.2	3.6	1	69	57	213	255	67	660	2.5
Italy	Brescia	191.1	5.5	43.2	1.7	120	47	9	6	245	48	355	5.6
Italy	Reggio di Cal.	181.4	6.8	99.1	3.4	20	65	52	196	232	35	580	2.0
Italy	Modena	178.9	5.8	52.7	2.7	30	78	13	0	229	49	370	2.7
Italy	Prato	176.0	5.6	51.6	1.7	112	40	7	0	226	45	318	4.2
Italy	Parma	164.5	6.7	103.4	2.2	59	52	9	0	211	36	307	1.6
Italy	Cagliari	162.6	2.8	32.5	3.8	7	51	29	95	208	25	408	2.5
Italy	Livorno	155.9	5.6	43.9	2.3	58	42	18	50	200	44	353	3.8
Italy	Foggia	154.8	5.6	84.2	3.4	8	54	9	0	198	40	301	1.1
Italy	Perugia	153.9	11.1	158.6	2.4	43	52	19	49	197	63	381	1.4
Italy	Reggio n.Emill.	146.7	6.0	89.5	2.2	59	46	8	0	188	32	274	1.5
Italy	Ravenna	139.0	16.1	274.2	3.7	8	47	13	25	178	64	328	0.6

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Italy	Salerno	136.7	2.9	21.5	2.7	20	48	11	12	175	41	288	3.4
Italy	Rimini	131.8	6.4	51.5	2.3	60	47	8	0	169	38	262	2.6
Italy	Ferrara	131.1	12.6	175.1	2.0	86	40	7	1	168	49	265	1.3
Italy	Siracusa	123.0	5.3	52.2	3.5	1	51	123	542	158	22	895	4.7
Italy	Pescara	122.1	5.6	31.9	2.0	82	44	7	0	156	51	258	4.4
Italy	Sassari	121.8	12.1	161.8	5.5	0	49	8	0	156	27	240	0.5
Italy	Bergamo	114.2	3.3	17.3	1.7	120	40	7	2	146	49	244	7.5
Italy	Vicenza	111.4	5.7	76.9	1.3	145	34	6	0	143	44	227	2.5
Italy	Forli	110.2	6.4	94.7	2.1	73	40	12	23	141	40	256	1.5
Italy	Latina	110.0	6.1	84.2	1.2	127	54	9	0	141	36	241	2.5
Italy	Trento	108.6	5.2	52.2	1.6	121	43	7	0	139	52	241	3.2
Italy	Terni	108.4	6.1	87.3	2.5	40	48	12	19	139	42	260	1.3
Italy	Novara	102.3	5.5	39.8	1.4	135	36	6	0	131	29	203	4.0
Italy	Ancona	101.5	5.6	40.2	2.8	24	28	5	0	130	29	191	1.7
Latvia	Riga	764.3	8.9	133.3	3.0	7	2414	38	3601	422	112	6587	19.4
Latvia	Daugavpils	115.3	4.4	30.5	2.7	20	445	1	0	64	20	530	5.5
Lithuania	Vilnius	542.3	10.0	139.2	3.1	7	626	9	45	242	44	966	2.9
Lithuania	Kaunas	378.9	6.7	98.0	3.5	5	298	4	33	169	22	526	1.7
Lithuania	Klaipeda	193.0	4.3	35.5	4.3	3	155	4	11	86	12	268	1.7
Lithuania	Siauliai	133.9	5.6	38.0	2.5	20	211	4	0	60	14	288	2.8
Lithuania	Panevezys	119.7	4.4	22.9	2.8	14	146	3	0	53	10	212	2.7
Netherl.	Amsterdam	1017.3	12.2	170.4	4.1	4	149	13	77	768	146	1154	2.6
Netherl.	Rotterdam	998.4	14.4	185.1	4.4	4	141	10	0	754	518	1423	3.1
Netherl.	Gravenhage	615.2	6.8	97.2	4.8	4	91	6	8	464	240	809	2.3
Netherl.	Utrecht	410.6	7.8	120.6	3.2	4	54	4	19	310	70	457	1.3
Netherl.	Eindhoven	320.7	5.2	98.5	3.5	9	45	9	160	242	72	527	1.5
Netherl.	Leiden	254.2	4.1	48.5	4.8	4	37	3	12	192	64	308	1.3
Netherl.	Dordrecht	246.1	6.0	62.6	3.7	7	35	2	0	186	128	351	1.6

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Netherl.	Tilburg	221.2	6.5	63.7	3.5	7	29	2	2	167	66	267	1.3
Netherl.	Heerlen	211.0	5.6	84.1	3.6	7	31	2	0	159	32	225	0.8
Netherl.	Groningen	200.0	6.7	51.0	4.2	5	28	2	3	151	50	235	1.3
Netherl.	Haarlem	189.7	4.1	33.2	4.9	1	33	3	27	143	5	212	1.3
Netherl.	Amersfoort	163.7	5.5	51.5	3.5	9	22	2	5	124	44	196	1.1
Netherl.	Hertogenbosch	159.3	6.9	67.3	3.7	7	21	2	2	120	48	192	0.9
Netherl.	Arnhem	142.8	6.5	47.9	3.6	8	21	1	0	108	64	194	1.3
Netherl.	Geleen	140.8	7.9	77.0	4.1	7	21	5	85	106	19	236	1.0
Netherl.	Almere	174.8	5.4	63.3	3.6	4	23	2	12	132	33	201	0.9
Netherl.	Breda	167.9	6.5	77.5	3.5	7	25	6	99	127	85	341	1.4
Netherl.	Nijmegen	157.9	6.5	45.8	3.6	8	26	2	0	119	93	239	1.6
Netherl.	Apeldoorn	155.9	7.8	56.8	3.5	9	26	2	0	118	21	167	1.0
Netherl.	Enschede	153.6	6.5	59.0	3.4	8	19	1	0	116	25	161	0.9
Netherl.	Hoofddorp	131.9	4.8	66.4	4.9	1	19	2	10	100	17	147	0.5
Netherl.	Maastricht	121.6	3.9	30.4	4.1	7	20	1	0	92	11	125	0.9
Netherl.	Zoetermeer	115.6	3.4	20.5	4.4	4	16	1	0	87	60	165	1.6
Netherl.	Zwolle	111.8	12.5	36.1	3.3	2	19	1	0	84	20	125	1.5
Netherl.	Emmen	108.6	9.4	141.9	3.5	2	15	1	0	82	30	128	0.3
Netherl.	Ede	106.5	3.9	31.1	3.5	9	16	1	0	80	48	145	1.1
Netherl.	Leeuwarden	91.7	6.0	25.9	4.7	1	15	1	1	69	25	111	1.1
Poland	Katowice	2850.0	43.3	964.3	2.7	16	8737	904	2866	1130	525	14163	14.2
Poland	Warszawa	2400.0	20.4	456.7	3.8	2	6743	292	457	952	459	8902	10.1
Poland	Lodz	1100.0	13.1	236.9	3.4	7	3305	440	1507	436	225	5913	11.3
Poland	Krakow	757.4	10.6	169.6	2.7	37	2386	114	208	300	157	3164	9.8
Poland	Wroclaw	636.3	10.5	125.6	3.3	8	1856	74	97	252	98	2377	7.8
Poland	Poznan	570.8	6.8	100.2	3.8	3	1695	62	64	226	55	2102	6.3
Poland	Gdansk	459.1	5.2	87.8	3.6	3	1337	67	130	182	59	1774	5.4
Poland	Szczecin	411.9	6.5	84.6	4.0	3	1178	180	637	163	26	2185	7.3

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Poland	Bydgoszcz	368.2	5.7	60.0	3.2	9	1276	77	179	146	38	1716	8.9
Poland	Lublin	356.0	7.0	46.4	3.1	6	970	35	37	141	60	1243	9.1
Poland	Bialystok	292.2	6.7	52.6	2.7	14	855	49	109	116	26	1154	8.2
Poland	Gdynia	253.3	6.5	60.9	3.7	5	738	37	72	100	32	979	4.8
Poland	Czestochowa	248.0	7.0	76.4	1.8	6	753	28	32	98	30	940	5.5
Poland	Radom	227.6	6.1	48.5	3.4	8	719	25	21	90	28	883	5.6
Poland	Kielce	209.5	6.3	56.1	3.0	12	610	19	7	83	25	744	4.5
Poland	Torun	208.3	6.7	43.1	2.9	11	630	29	51	83	30	824	6.8
Poland	Bielsko-Biala	177.0	7.9	57.3	2.1	10	538	57	182	70	33	880	6.9
Poland	Olsztyn	173.9	4.6	27.7	2.1	6	484	16	11	69	19	599	7.3
Poland	Rzeszow	159.0	5.7	32.5	3.8	4	471	15	9	63	25	584	4.9
Poland	Rybnik	141.8	7.4	132.3	3.3	7	440	47	149	56	34	725	1.9
Poland	Opole	128.9	7.0	56.3	2.7	13	450	28	68	51	22	619	4.2
Poland	Plock	127.8	5.4	43.5	3.5	5	399	19	37	51	20	526	3.4
Poland	Elblag	127.7	4.4	22.4	3.4	7	402	17	24	51	21	513	6.1
Poland	Walbrzych	127.6	5.2	40.6	2.8	30	424	13	6	51	21	515	4.5
Poland	Gorzow W.	125.6	4.7	27.7	2.8	4	397	18	30	50	24	518	5.5
Poland	Wloclawek	120.4	4.4	27.0	3.3	3	386	15	19	48	25	492	4.8
Poland	Zielona Gora	118.5	6.2	22.1	3.1	4	347	12	10	47	20	435	6.2
Poland	Tarnow	118.3	4.3	33.3	1.8	21	355	21	48	47	22	493	5.7
Poland	Kalisz	108.8	6.9	33.6	4.0	2	299	9	3	43	16	370	3.2
Poland	Koszalin	107.8	3.3	23.1	3.6	4	311	9	0	43	10	372	3.5
Poland	Legnica	106.1	6.3	30.2	2.5	1	311	9	0	42	21	382	4.5
Portugal	Lisboa	2900.0	45.5	1618.7	3.3	2	4851	1173	12492	2948	989	22453	11.5
Portugal	Porto	1375.0	12.6	451.9	3.1	7	1975	290	1247	1398	458	5369	5.5
Portugal	Braga	152.5	5.9	55.4	2.6	16	222	26	0	155	64	467	3.1
Portugal	Coimbra	138.1	8.9	104.7	2.3	12	209	32	165	140	49	596	2.6
Portugal	Setubal	100.6	4.4	35.7	3.5	2	256	134	2135	102	40	2667	18.7

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Romania	Bucuresti	2100.0	12.3	178.1	1.9	33	2035	91	0	725	124	2975	11.1
Romania	Iasi	320.9	5.3	32.7	2.8	9	648	29	0	111	43	831	8.1
Romania	Cluj-Napoca	318.0	7.6	66.8	2.1	36	569	25	0	110	26	730	5.6
Romania	Timisoara	317.7	7.0	51.7	2.5	16	563	25	0	110	32	729	5.7
Romania	Constanta	310.5	6.7	39.9	3.8	14	529	25	12	107	23	696	5.5
Romania	Craiova	302.6	5.6	40.6	3.1	6	546	97	827	104	21	1595	11.9
Romania	Galati	298.9	6.7	97.9	3.1	2	585	120	1075	103	36	1920	6.4
Romania	Brasov	284.6	7.0	51.8	2.1	78	496	22	0	98	28	645	7.4
Romania	Ploiesti	232.5	5.1	28.8	2.8	22	750	74	469	80	74	1448	17.1
Romania	Braila	216.3	5.6	20.0	3.1	2	399	18	0	75	17	509	7.6
Romania	Oradea	206.6	6.7	48.8	2.8	19	405	29	121	71	19	646	5.0
Romania	Bacau	175.5	4.4	14.4	2.8	19	295	15	17	61	16	404	8.6
Romania	Arad	172.8	10.0	127.4	2.0	28	307	14	0	60	17	397	1.8
Romania	Pitesti	168.5	4.2	21.9	2.0	45	264	20	98	58	15	456	8.5
Romania	Sibiu	154.9	4.1	37.0	2.2	67	290	13	0	53	17	373	4.2
Romania	Tirgu Mures	150.0	4.1	25.5	2.2	34	267	12	0	52	15	346	4.9
Romania	Baia Mare	137.9	4.7	35.8	1.4	125	264	12	2	48	16	342	6.7
Romania	Buzau	134.2	2.7	20.9	3.3	12	242	11	0	46	17	316	3.2
Romania	Satu Mare	115.1	5.4	39.8	1.7	73	210	9	0	40	12	271	3.9
Romania	Botosani	115.1	2.2	9.1	2.8	27	177	8	0	40	12	237	6.0
Romania	Rimnicu Vilcea	107.7	5.6	42.7	1.9	15	185	8	0	37	15	245	2.4
Romania	Suceava	105.9	4.2	28.3	3.2	9	169	8	0	37	10	223	2.1
Romania	Piatra Neamt	104.9	2.9	15.2	2.9	19	178	8	0	36	13	235	3.8
Romania	Drobeta	104.6	7.1	23.7	2.1	82	196	9	0	36	12	252	6.5
Romania	Focsani	101.9	3.5	15.5	3.2	4	190	9	0	35	13	247	3.8
Slovakia	Bratislava	425.5	5.3	81.6	3.2	12	967	51	115	589	33	1755	6.5
Slovakia	Kosice	235.3	4.4	39.1	2.3	32	549	68	272	326	21	1237	11.5
Slovenia	Ljubljana	258.9	7.7	109.6	1.2	140	433	16	0	485	73	1006	9.5

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Spain	Madrid	5600.0	39.8	1709.9	3.0	53	781	383	497	3466	1571	6697	4.1
Spain	Barcelona	3800.0	23.3	668.1	3.6	1	601	318	243	2352	779	4291	3.6
Spain	Valencia	1450.0	16.0	259.2	3.1	4	236	126	108	897	381	1748	3.5
Spain	Sevilla	1225.0	29.8	811.3	2.4	69	328	82	306	758	210	1684	2.3
Spain	Zaragoza	647.4	26.3	513.8	4.2	34	209	101	201	401	119	1030	1.3
Spain	Malaga	558.3	7.1	162.3	3.6	3	60	18	0	346	73	496	1.0
Spain	Murcia	409.8	15.8	244.2	2.4	19	112	73	49	254	135	622	1.6
Spain	Palma de Mall.	375.8	5.6	115.1	2.8	40	106	34	0	233	101	473	1.6
Spain	Bilbao	353.2	3.4	20.7	2.8	16	42	137	420	219	112	930	11.8
Spain	Cordoba	321.2	23.7	441.5	2.0	91	135	157	23	199	68	582	1.5
Spain	Valladolid	321.0	5.6	34.1	2.7	34	112	16	0	199	41	368	4.1
Spain	Alicante	319.4	5.4	91.0	3.2	9	46	22	0	198	66	332	1.1
Spain	Vigo	293.7	4.4	58.5	2.2	48	172	18	0	182	77	449	3.1
Spain	Gijon	273.9	4.8	63.6	3.2	3	69	254	471	170	33	997	4.3
Spain	Coruna	243.3	4.1	26.0	3.6	1	120	212	20	151	50	552	5.0
Spain	Granada	237.0	1.8	24.6	2.2	2	29	7	5	147	24	212	1.7
Spain	Vitoria-Gasteiz	226.5	7.2	109.5	2.4	20	91	109	714	140	123	1177	4.6
Spain	Elche	215.1	6.6	118.3	3.2	9	37	18	1	133	53	242	0.7
Spain	Oviedo	212.2	4.8	36.8	1.9	3	71	222	525	131	34	984	9.7
Spain	Cartagena	203.9	7.6	156.4	3.6	9	40	56	24	126	45	291	0.6
Spain	Alcala de H.	197.8	4.4	24.4	2.4	54	38	18	28	122	86	292	4.7
Spain	Sabadell	197.0	3.3	21.3	2.4	27	16	9	7	122	21	174	2.5
Spain	Jerez de la F.	196.3	6.7	46.5	2.4	74	46	11	49	121	49	277	3.1
Spain	Tarrasa	194.9	5.3	33.3	2.4	27	16	9	7	121	21	172	2.0
Spain	Pamplona	193.3	3.4	17.2	3.3	42	129	55	61	120	61	425	7.0
Spain	Santander	184.0	4.0	25.1	2.9	37	17	6	41	114	15	193	2.5
Spain	San Sebastian	182.9	3.3	17.1	3.2	18	26	73	318	113	61	592	8.7
Spain	Almerea	181.7	4.4	37.5	3.8	6	34	196	0	112	38	381	2.5

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Spain	Burgos	172.4	6.6	55.7	4.8	2	140	29	7	107	63	345	1.6
Spain	Castellon d l P.	167.5	3.3	26.5	3.0	4	11	54	11	104	17	196	1.8
Spain	Salamanca	160.3	5.0	25.2	3.1	23	56	12	9	99	20	196	2.5
Spain	Albacete	159.5	16.9	405.8	3.0	30	51	11	0	99	35	196	0.3
Spain	Huelva	145.2	4.3	35.4	3.1	4	15	98	97	90	14	314	2.4
Spain	Logrono	144.9	6.6	82.0	2.7	26	116	106	270	90	69	651	3.1
Spain	Badajoz	143.0	9.5	190.3	2.8	53	36	6	25	89	12	167	0.5
Spain	Leon	136.4	4.4	21.8	3.2	48	162	135	51	84	59	491	7.5
Spain	Cadiz	131.8	0.9	5.0	2.4	74	16	4	18	82	19	138	5.3
Spain	Tarragona	128.2	2.2	23.3	3.3	0	37	98	6	79	51	271	2.1
Spain	Lerida	124.7	7.2	107.1	3.0	22	66	14	1	77	44	203	0.7
Spain	Marbella	124.3	2.9	54.6	3.6	3	70	20	15	77	85	267	1.0
Spain	Mataro	116.7	3.1	13.9	4.8	0	57	28	23	72	73	253	3.3
Spain	Jaen	116.5	8.8	124.9	2.1	67	40	11	0	72	22	145	0.7
Spain	Dos Hermanas	112.3	4.3	33.4	2.4	69	13	3	11	69	8	105	1.3
Spain	Algeciras	111.3	2.9	15.0	4.9	6	37	179	41	69	44	370	4.4
Spain	Orense	108.4	2.8	13.7	2.7	16	61	11	0	67	24	162	3.0
Sweden	Stockholm	1872.9	20.0	484.9	2.6	29	617	112	229	1111	297	2365	3.5
Sweden	Goeteborg	872.2	23.3	559.9	2.8	28	351	95	448	517	249	1660	2.2
Sweden	Malmoe	599.0	23.5	606.0	4.1	5	206	37	73	355	154	825	0.7
Sweden	Uppsala	182.1	14.4	203.3	3.3	10	88	27	148	108	86	458	1.1
Sweden	Linkoeping	136.9	21.5	357.0	3.6	5	70	18	82	81	58	310	0.5
Sweden	Vasteras	131.0	7.2	106.8	2.7	17	63	20	114	78	44	319	1.2
Sweden	Orebro	127.0	15.0	220.1	2.7	26	51	14	71	75	55	267	0.7
Sweden	Norrkoeping	124.4	14.7	250.3	2.3	38	66	25	160	74	51	376	1.0
Sweden	Helsingborg	121.2	6.1	74.5	3.5	7	53	8	2	72	42	177	0.7
Sweden	Joenkoeping	119.9	10.1	208.0	3.8	3	50	7	0	71	43	172	0.3
Sweden	Umea	109.4	14.0	269.0	3.2	22	47	19	129	65	74	334	0.6

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Sweden	Lund	101.4	8.7	109.9	4.0	3	36	7	15	60	24	142	0.4
Switzerl.	Zürich	1080.7	17.4	396.2	2.1	69	138	101	205	378	259	1081	2.5
Switzerl.	Basel	479.3	12.0	161.7	2.4	11	78	22	0	168	87	354	1.2
Switzerl.	Geneve	471.3	13.5	164.9	2.3	74	64	18	0	165	116	363	1.7
Switzerl.	Bern	349.1	9.4	144.1	1.8	62	47	24	37	122	88	318	1.5
Switzerl.	Lausanne	311.4	4.0	83.2	1.6	65	36	10	0	109	77	232	1.4
Switzerl.	Luzern	196.6	7.6	83.3	1.6	24	25	7	0	69	49	149	1.0
Switzerl.	Sankt Gallen	146.4	6.7	77.7	2.1	42	19	5	0	51	35	110	0.7
Switzerl.	Winterthur	123.4	6.8	42.5	2.0	69	19	19	44	43	27	152	2.1
Switzerl.	Lugano	120.8	6.7	40.3	1.0	170	8	2	0	42	31	84	2.4
Switzerl.	Baden	106.7	2.7	60.9	2.1	63	14	13	30	37	25	119	0.7
Switzerl.	Olten	101.9	3.8	79.5	2.1	63	13	8	15	36	23	94	0.5
UK	London	8278.3	37.4	1125.9	3.8	3	1062	310	342	4762	1159	7634	4.8
UK	Birmingham	2284.1	27.3	645.6	3.7	5	521	176	388	1314	593	2991	2.8
UK	Manchester	2244.9	21.1	536.4	4.1	2	439	218	240	1291	457	2646	2.5
UK	Leeds	1499.5	24.3	509.2	3.6	13	336	110	142	863	303	1754	2.1
UK	Glasgow	1168.3	25.6	352.1	4.1	8	263	58	151	672	310	1455	2.4
UK	Newcastle u/T.	880.0	14.4	265.0	3.3	14	225	76	127	506	238	1172	2.2
UK	Liverpool	816.2	14.2	155.2	3.8	1	152	37	122	470	168	949	2.6
UK	Nottingham	666.4	10.0	172.6	3.6	1	252	55	141	383	194	1025	2.2
UK	Sheffield	640.7	11.0	169.4	3.6	13	207	120	271	369	499	1466	3.6
UK	Bristol	551.1	10.5	139.2	4.1	4	171	38	132	317	328	986	2.6
UK	Brighton	461.2	4.4	119.3	3.6	7	99	25	28	265	93	510	1.1
UK	Edinburgh	452.2	7.5	89.2	4.4	9	225	26	81	260	174	767	2.6
UK	Portsmouth	442.3	6.4	106.1	5.9	1	99	21	49	254	211	635	1.4
UK	Leicester	441.2	7.3	89.2	4.3	1	137	46	137	254	150	724	2.4
UK	Bournemouth	383.7	8.4	116.4	4.2	0	95	18	56	221	224	614	1.7
UK	Reading	369.8	6.7	118.5	3.7	10	62	15	23	213	92	405	1.1

Country	*City*	*Population [1000 people]*	*City diameter [km]*	*Area [km^2]*	*Annual mean wind speed [m/s]*	*Low wind speed days [# of days]*	*Emissions SNAP 2 Domestic combustion [tons/yr]*	*Emissions SNAP 3 Industrial combustion [tons/yr]*	*Emissions SNAP 4 Industrial processes [tons/yr]*	*Emissions SNAP 7 Road transport [tons/yr]*	*Emissions SNAP 8 Mobile machinery [tons/yr]*	*Total emissions [tons/yr]*	*Computed urban increment [µg/m^3]*
UK	Middlesbrough	365.3	7.6	138.9	3.7	11	79	100	258	210	420	1067	2.6
UK	Stoke-on-Trent	362.4	9.2	127.0	4.0	3	140	41	75	208	177	642	1.7
UK	Belfast	350.0	7.8	107.3	3.7	0	670	17	55	201	199	1142	3.4
UK	Coventry	336.5	6.5	68.5	3.7	6	58	17	39	194	43	351	1.5
UK	Cardiff	327.7	6.5	88.4	4.1	0	73	12	86	189	97	456	1.4
UK	Birkenhead	319.7	6.5	99.5	3.8	1	56	10	70	184	82	402	1.2
UK	Southampton	304.4	7.0	78.6	3.3	6	65	13	39	175	154	447	1.9
UK	Swansea	270.5	6.2	124.9	4.4	0	111	23	172	156	95	556	1.2
UK	Southend-on-S.	269.4	6.2	69.1	4.4	1	48	17	50	155	191	462	1.8
UK	Preston	264.6	6.5	93.5	5.1	1	53	16	20	152	40	280	0.8
UK	Blackpool	261.1	3.3	65.6	5.4	4	52	15	19	150	46	283	0.8
UK	Aldershot	243.3	7.9	102.0	3.6	10	36	8	12	140	42	237	0.8
UK	Derby	236.7	6.7	69.3	3.6	5	79	21	62	136	95	393	1.8
UK	Luton	236.3	5.4	57.2	3.9	7	41	23	12	136	38	250	1.2
UK	Gillingham	231.7	6.3	53.9	4.4	1	42	15	43	133	164	397	2.0
UK	Barnsley	207.7	5.9	104.9	3.6	13	59	22	41	119	83	325	0.9
UK	Aberdeen	197.3	6.7	50.9	4.5	7	78	18	19	114	108	337	1.9
UK	Northampton	197.2	6.3	57.5	4.3	1	62	12	27	113	59	274	1.3
UK	Norwich	194.8	6.7	54.7	4.5	0	99	13	20	112	72	316	1.6
UK	Milton Keynes	184.5	7.0	73.7	3.8	2	39	16	11	106	33	204	0.8
UK	Sunderland	183.0	5.4	83.7	3.3	14	43	8	18	105	40	214	0.8
UK	Crawley	180.2	3.9	39.5	3.4	7	21	4	7	104	19	155	1.0
UK	Wigan	166.8	7.9	115.2	5.1	1	23	13	12	96	21	164	0.4
UK	Warrington	158.2	5.6	71.4	5.1	1	30	12	20	91	32	185	0.6
UK	Mansfield	158.1	6.7	58.5	3.6	2	61	20	42	91	84	298	1.5
UK	Burnley	149.8	4.6	48.1	4.6	2	23	10	15	86	25	159	0.7
UK	Slough	141.8	4.8	40.7	3.6	10	24	6	9	82	35	155	1.0
UK	Newport	139.3	3.9	50.6	3.7	1	40	11	95	80	38	264	1.2

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UK	Telford	138.2	6.1	54.6	3.6	9	30	11	17	80	38	176	1.0
UK	Blackburn	136.7	4.9	46.0	5.1	1	27	8	10	79	21	145	0.7
UK	Gloucester	136.2	3.3	33.6	2.9	3	47	8	21	78	55	209	1.5
UK	Nuneaton	132.2	4.4	46.6	3.7	6	31	10	27	76	30	175	0.9
UK	Cambridge	131.5	5.7	34.8	3.9	7	42	9	13	76	43	183	1.5
UK	Doncaster	127.9	5.5	58.7	3.6	13	68	13	24	74	47	225	1.1
UK	Hastings	126.4	5.6	26.5	2.9	20	43	9	8	73	44	177	2.3
UK	Margate	119.1	5.2	33.1	4.9	0	38	6	9	69	233	355	2.4
UK	High Wycombe	118.2	5.2	41.4	3.7	10	20	5	7	68	29	130	0.9
UK	Southport	115.9	4.6	34.4	5.1	1	23	7	9	67	17	123	0.8
UK	Saint Albans	114.7	4.8	35.2	3.6	7	20	11	6	66	18	121	0.9
UK	Torquay	110.4	4.8	36.2	5.8	0	28	7	13	63	96	207	1.1
UK	Cheltenham	110.3	4.4	31.2	3.5	3	38	6	17	63	45	169	1.4
UK	Lincoln	104.2	4.9	31.8	5.2	1	47	15	32	60	31	185	1.3
UK	Bedford	101.9	5.2	25.8	4.5	3	22	9	7	59	21	117	1.1
UK	Basildon	101.5	6.9	45.3	4.4	1	12	3	6	58	23	104	0.6
UK	Chesterfield	100.9	6.2	51.7	4.2	2	33	19	43	58	79	231	1.2
UK	Kingston u/H.	301.4	7.2	84.7	4.1	5	74	12	116	173	335	710	2.5
UK	Plymouth	243.8	6.4	64.5	5.1	8	76	10	22	140	111	359	1.4
UK	Swindon	155.4	5.6	43.0	3.4	15	67	7	14	89	60	237	1.7
UK	Dundee	154.7	7.4	38.9	4.7	3	61	10	16	89	46	222	1.6
UK	Oxford	143.0	3.3	43.6	3.4	15	48	6	14	82	72	222	1.2
UK	Ipswich	138.7	6.2	38.7	4.6	0	52	9	12	80	231	384	2.5
UK	York	137.5	6.5	32.0	3.7	16	72	6	30	79	58	245	2.5
UK	Peterborough	136.3	6.1	57.8	4.6	3	69	11	28	78	72	258	1.2
UK	Exeter	106.8	4.0	23.4	5.5	0	33	6	13	61	89	202	1.6
UK	Eastbourne	106.6	4.9	27.3	2.9	20	19	4	4	61	10	99	1.2
UK	Colchester	104.4	6.2	35.8	4.2	0	38	5	9	60	198	310	2.3