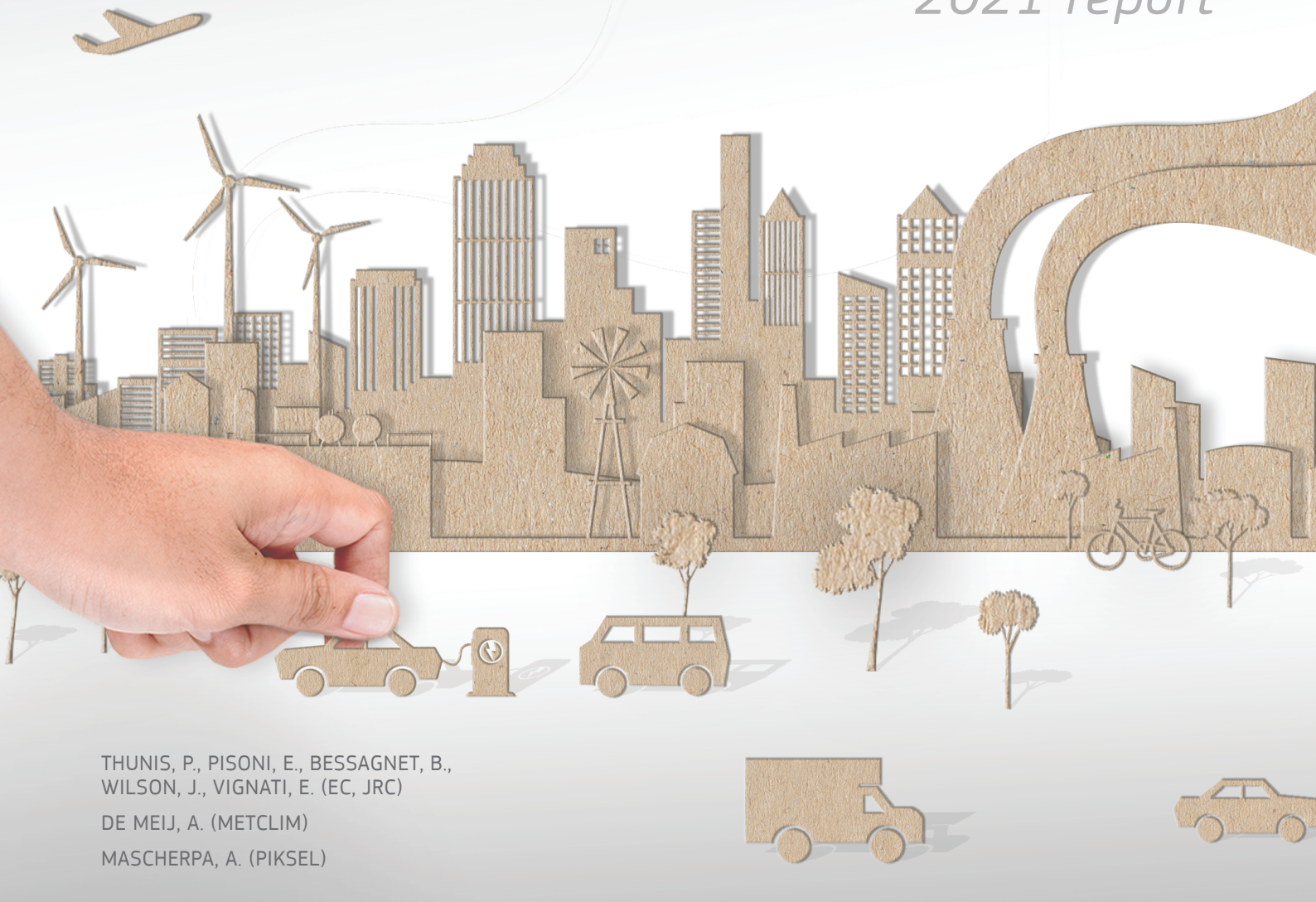
European Commission

JRC SCIENCE FOR POLICY REPORT

Urban PM2.5 Atlas

Air Quality in European cities
2021 report



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Contents

Abstract 1
Foreword 2
Acknowledgements 3
Executive summary 4
1. Introduction 7
2. Objective and structure of this $PM_{2.5}$ Urban Atlas 9
3. At which scale are actions most effective? 10
4. Which are the dominant emission sources in cities? 15
5. Why is the city's contribution to its' own air pollution often underestimated? 21
6. A closer look city by city 23
7. Conclusions 24
References 26
List of abbreviations and definitions 28
List of Figures 29
Annex 1. The SHERPA methodology 30
Annex 2: Uncertainties and limitations 32
Annex 3: A closer look city-by-city (150 city fiches) 34
Annex 4: Cities index 184

Abstract

Many European cities still suffer from poor air quality and exceed the EU air quality standards This is the case in particular for $PM_{2.5}$ (focus of this Atlas) which is responsible for adverse health effects and premature deaths. While air pollution legislation has undoubtedly resulted in an overall improvement of the air quality over the years, there are still problems, which are increasingly localised in specific regions and cities. A key issue is thus to determine at which scale to act in order to abate these remaining air pollution problems most effectively. In this Atlas, both the spatial (e.g. urban, country) and sectoral (transport, residential, agriculture…) contributions are quantified for 150 urban areas in Europe. The following conclusions are formulated: (1) for many cities, local actions at the city scale are an effective means of improving $PM_{2.5}$ air quality in that city; (2) target sectors and scales to abate air pollution are city specific; (3) for many cities, sectoral measures addressing agriculture at country - or EU - scale have a clear benefit on urban air quality and (4) because of methodological choices and assumptions, the responsibility of a city in generating its air pollution is often underestimated.

Foreword

The analysis presented in this Atlas uses the SHERPA screening tool. The SHERPA methodology has been fully peer-reviewed, nevertheless as in any model-based tool the quality of the results depends, among others, on the quality of the input data. Although state-of-the-art, neither the underlying air quality model nor the emission inventory that feed the model are uniformly accurate across Europe. This Atlas is therefore a valuable first step towards identifying and exploring options to abate urban air pollution at the different scales, using as it does consistent input and modelling results for all the major urban areas of the EU 27. However, given that uncertainties in both the underlying model and inputs are known to vary between regions and cities, any final policy design should be based, wherever possible, on full-scale modelling studies including local knowledge to confirm or otherwise the results presented here.

We believe that this Atlas contributes to improving the integration of Europe-wide assessments with local information about air pollution.

The authors.

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Map data are copyrighted OpenStreetMap and available from https://www.openstreetmap.org

Executive summary

Many European cities still suffer from poor air quality and exceed the air quality standards set in the Ambient Air Quality Directives (AAQDs, EC2008, EC2004) and the guidelines recommended by the World Health Organization (WHO). This is the case for the air pollutant fine particulate matter ($PM_{2.5}$), with concentrations exceeding the EU limit value and WHO guidelines in large parts of Europe, in 2018 (EEA, 2020). Although only 4% of the monitoring stations exceeded the EU $PM_{2.5}$ annual limit value (25 $\mu g/m^3$) in 2018 (EEA, 2020), about 70% of them exceeded the WHO guideline (annual average of 10 $\mu g/m^3$). $PM_{2.5}$ is responsible for adverse health effects and premature deaths, with current estimate suggesting approximately 400,000 premature deaths annually in 41 European countries and an average life loss of about 8 to 10 months in the most polluted European regions. This Atlas focuses on $PM_{2.5}$ (particles with diameters less or equal to 2.5 microns).

Policy context

Air pollution legislation has led to actions taken internationally, nationally and locally, to reduce air pollution. While they have undoubtedly resulted in an overall improvement of the air quality over the years, there are still problems, which are increasingly localised in specific regions and cities. A key issue is thus to determine at which scale to act in order to abate these remaining air pollution problems most effectively. Central to this for cities, is a quantitative assessment of the different origins of air pollution (urban, regional, national and transboundary) to support the design of efficient and effective air quality plans, which are a legal obligation for countries and regions whenever exceedances occur.

The "Screening for High Emission Reduction Potentials for Air quality" tool (SHERPA) has been developed by the Joint Research Centre to quantify the origins of air pollution in cities and regions (Thunis et al. 2016; Pisoni et al. 2017, Pisoni et al., 2019). In this Atlas, both the spatial (e.g. urban, country) and sectoral (transport, residential, agriculture…) contributions are quantified for 150 urban areas in Europe, where many of the current exceedances of the air quality EU limit values and WHO guidelines are reported.

With respect to the previous Urban $PM_{2.5}$ Atlas (Thunis et al. 2017), the main changes introduced here include the underlying air quality model (EMEP substituting CHIMERE) and emission inventory (CAMS V4.2 substituting the one developed by the EU LIFE project EC4MACS). Finally, the meteorological data used by the EMEP model is for 2015 (compared to 2009 in the previous Urban $PM_{2.5}$ Atlas). While these changes lead to results that are more representative of the present years, they are not expected to be more accurate. The differences between this version and the previous Urban $PM_{2.5}$ Atlas (2017) reflect the main modelling uncertainties.

Key conclusions

There is a need to provide information to improve air quality policy governance, to support authorities in choosing the most efficient actions at the appropriate administrative level and scale. In particular, actions at the local level focusing on the urban scale on the one hand and at national/international level on the other hand need to be carefully balanced. Key conclusions for $PM_{2.5}$ are:

- For many cities, local actions at the city scale are an effective means of improving $PM_{2.5}$ air quality in that city.

The overall conclusion is that many cities have a role to play by taking actions at their own scale. It is important to emphasise that city emissions contribute significantly to country and EU overall PM concentrations, reinforcing the important role of cities in reducing air pollution overall, through a multilevel approach.

- Target sectors and scales to abate air pollution are city specific.

  The impact of a given abatement measure on PM concentrations differs from city to city, even for cities in the same country. Actions taken at different geographical scales, or in different activity sectors therefore lead to impacts on air quality that are city-specific. Consequently, it is important to take into account these city-specific circumstances when designing air quality plans. Actions that are effective for one city are not necessarily effective for others.

- For many cities, sectoral measures addressing agriculture at country- or EU- scale have a clear benefit on urban air quality.

  Although most agricultural activities take place beyond "city" boundaries, agricultural emissions have a significant impact on PM concentrations, via formation of secondary particles, in many EU cities. The widespread impact of agriculture on PM concentrations in urban areas is indicative of the potential for EU- or country-wide measures addressing this sector. Similarly, measures applied to other sectors also have an important potential at the urban scale, when applied at EU or country scale. This is the case of road transport where the European emission standards are, in practice, most effective in the areas where traffic is most important, i.e. cities.

- Because of methodological choices and assumptions, the responsibility of a city in generating its air pollution is often underestimated.

  Many methodological choices and assumptions largely influence the quantification of geographical and sectoral contributions to city air pollution. These include the definition of the city, temporal (e.g. yearly vs. seasonal) and/or spatial averaging processes applied to the indicator ($PM_{2.5}$). These methodological choices and assumptions most often lead to a systematic and important underestimation of the city responsibility, with important policy implications.

Related and future JRC work

Future work will focus on the following aspects: Elevated $PM_{2.5}$, concentrations are a concern primarily during wintertime. It is therefore important to refine source apportionment results to determine seasonal trends. Another aspect is the spatial coverage of this Urban $PM_{2.5}$ Atlas. Only half of the reported EU exceedances occur in the 150 urban areas included in this study. It is therefore important to extend our analyses to include smaller urban areas and address their specificities. It will however be necessary to increase the spatial resolution of the model to do this.

Quick guide

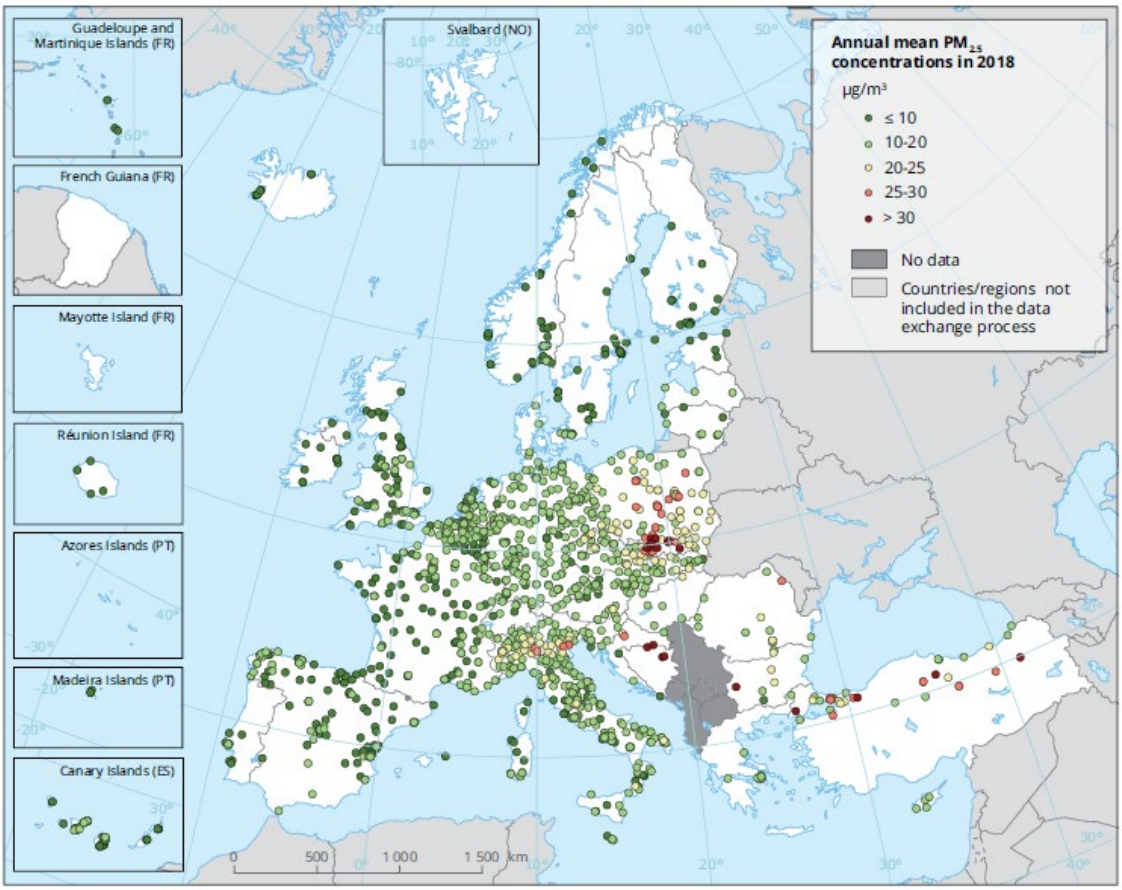
- Many European cities suffer from poor air quality and regularly exceed both the Ambient Air Quality Directive limit and target values and guidelines recommended by the WHO for air quality;
- A key issue is to balance action at the various geographic scales to abate remaining air pollution problems most effectively;

- The SHERPA tool, developed by the Joint Research Centre, is used to quantify the origins of air pollution to urban background fine particulate matter ($PM_{2.5}$). Both the spatial (urban, country…) and sectoral (transport, residential, agriculture…) contributions are quantified for 150 European urban areas in Europe;
- The results indicate that (1) for many cities, local actions at the city scale are an effective means of improving air quality in that city, as well as having regional benefits; (2) target sectors and scales to abate air pollution most effectively are city specific; (3) for many cities, sectoral measures addressing agricultural emissions at country or EU scale have a clear benefit on urban air quality and (4) methodological choices and assumptions related to source apportionment often lead to underestimating the responsibility of a city in generating its air pollution.

1. Introduction

Many European cities suffer from poor air quality and regularly exceed both the European standards prescribed by the Ambient Air Quality Directive (EEA, 2020) and guidelines recommended by the World Health Organization (WHO). This is particularly the case for particulate matter (PM_{10}), for which both the daily (50 µg/m^3 not to be exceeded on more than 35 days a year) and the yearly average limit values (40 µg/m^3) are often exceeded in many cities and regions in Europe. Even though no minimum threshold could be established below which there are no adverse health effects of particulate matter, the WHO guidelines represent global targets (for both industrialised and developing countries) above which increased mortality responses due to PM air pollution are expected, based on current scientific findings (WHO, 2006). For $PM_{2.5}$, the EU limit value (annual average of 25 µg/m^3) is generally met (EEA, 2020), but few cities manage to keep concentrations below the levels recommended by the WHO (10 µg/m^3 on an annual basis) as illustrated in Figure 1.

Figure 1: The red and dark red dots indicate stations reporting concentrations above the EU annual limit value for $PM_{2.5}$ (25 µg/m^3). The dark green dots indicate stations reporting values below the WHO AQG for $PM_{2.5}$ (10 µg/m^3). Only stations with > 75% of valid data have been included in the map.



Source: EEA, 2020.

Adverse health effects are the major consequence of poor air quality and current estimates suggest that exposure to $PM_{2.5}$ is responsible for an average life loss of about 8 to 10 months in the most polluted European regions (Southern Poland, Po Valley, Benelux…) and cities. The EEA recently estimated the burden of air pollution to 346 000 premature deaths in EU-27 in 2018. Consequently, air pollution remains the single largest environmental health risk in Europe according to WHO (WHO, 2015).

Actions have been proposed and taken at the international (Kiesewetter et al., 2015) national (e.g. D'Elia et al., 2009) and urban scales (e.g. Giannouli et al., 2011) to reduce air pollution. While they have undoubtedly resulted in an overall improvement of the air quality over the years (Maas and Grennfelt, 2016, EEA, 2020), there are still problems which are local to specific regions and many cities (Kiesewetter et al., 2015). A key issue is thus to determine at which scale to act in order to abate these remaining air pollution problems most effectively. Central to this for cities, is a quantitative assessment of the different origins of air pollution (urban, regional, national and international) and of their impacts to support the design of efficient and effective air quality plans, which are a legal obligation for countries and regions whenever exceedances occur.

Because of its important adverse health effects, this Atlas focus on urban background PM_{25}. Fine particulate matter is a pollutant that can be emitted directly (primary particulate) or be formed through series of complex chemical formation processes from other air pollutants (secondary species) (see the review by Fuzzi et al. 2015, Clappier et al. 2021). Depending on meteorological conditions, the residence time in the atmosphere is estimated to range from several days up to one week in the lower troposphere. It is worthwhile to note that for conditions other than the most stable low wind speed events, these residence times imply travel distances in the lower troposphere up to a thousand kilometres. In addition, air masses may follow complex trajectories. For example, under certain circumstances emissions from a city may react with precursors emitted elsewhere to form secondary particles that then return to the city. This is valid for PM, while for other pollutants (as NO_x and O_3) the behaviour will be different. On the other hand, it is important to distinguish anthropogenic sources from natural ones since the latter cannot be addressed by abatement measures.

Chemistry transport models (CTM) can account for these complex transport, diffusion and chemical transformation processes and can therefore be used to quantify the impact of cities on their air pollution levels by performing simulations where emissions are switched on or off in a city. Because these models require intensive computational resources, they are generally used to perform this detailed analysis for one city or region at the time.

To cope with this limitation, the "Screening for High Emission Reduction Potentials for Air quality" tool (SHERPA[1]) has been developed by the Joint Research Centre (Thunis et al. 2016). This simplified screening tool (see Annex 1 for details) mimics a CTM, but with a much faster time response. In this study, SHERPA is used to quantify the origins of air pollution in a large set of European cities. Both spatial (urban, country…) and sectoral (transport, residential, agriculture…) contributions are quantified for 150 European urban areas in Europe, from where many of the current exceedances to the Ambient Air Quality Directive (AAQD) limit and target values and guidelines recommended by the WHO are reported for $PM_{2.5}$.

(1) http://aqm.jrc.ec.europa.eu/sherpa.aspx

2. Objective and structure of this $PM_{2.5}$ Urban Atlas

The main purpose of this Atlas is to support policy makers in designing and assessing their air quality plans, with a focus on $PM_{2.5}$. One particular issue in this respect is governance, namely the selection of the most appropriate and cost-effective strategies within the geographical area under the control of the policy maker. While some abatement measures are taken at European or countrywide level (e.g. European emission standards for vehicles, Industrial Emissions Directive (EC, 2010) at EU level, fuel taxation and transport policies at national level, ...), others are the responsibility of regional or city authorities (e.g. establishment and/or implementation of low emission zones for vehicles). This $PM_{2.5}$ Urban Atlas provides detailed information regarding spatial allocation for 150 cities in the EU, for $PM_{2.5}$ yearly average concentrations. The focus is on urban background levels (meaning that local or microscale traffic impacts are not explicitly considered).

Policymakers also require information on the sectors in which abatement actions would be most effective and efficient on air quality. Similar to the spatial source allocation, this Urban $PM_{2.5}$ Atlas provides a ranking of the principle sectoral contributors (i.e. residential, transport, agriculture...) to urban air pollution for each city.

It is important to note that the most effective emission reductions in terms of geographical scales and sectors identified here might not be the most cost-efficient. This study focuses on the impacts on concentrations of emission abatement measures but does not assess their implementation costs.

The Air Quality Atlas is structured as follows. First, an overview of the analysis of all the 150 urban areas is presented both in terms of spatial (Section 3) and sectoral (Section 4) origins of their air pollution. Detailed city-by-city sectoral and spatial source allocation analyses are then presented in Section 5. Finally, the SHERPA screening methodology and a discussion of its associated assumptions, limitations and uncertainties are presented in the Annexes.

3. At which scale are actions most effective?

Knowing where urban pollution originates is of particular interest when designing air quality plans as it may help in choosing the right measures and the right spatial scale of implementation. To support this governance challenge, in this section we analyse the contribution from different spatial scales to city concentrations.

In terms of the spatial dimension, source allocation is analysed at three distinct scales: Europe (EU27 plus United Kingdom, Switzerland and Norway, referred in the following as Model Control Area [MCA]), the country and the "greater city" area. For the largest cities, an additional scale is considered with the split of the greater city into the "core city" and the peripheral "commuting zone".

Core cities are the local administrative units, with a population density above 1,500 km^2 and a population above 50,000, where the majority of the population lives in an urban centre (OECD, 2012).

Greater cities correspond to the functional urban areas (OECD, 2012) and consist of the core city plus the wider commuting zone, defined as the surrounding travel-to-work areas where at least 15% of the employed residents work in the city. Note that the commuting zone is limited in its extension to the country in which the city is located. It does not include transboundary commuting.

Given the SHERPA spatial resolution of 0.1x0.1° (~10 km^2 x ~10 km^2), only the largest core cities can be considered in the analysis. These include most of the EU27 capitals and other major urban areas within each country (Figure 2). The list of cities is available in Annex 4.

The source contributions calculated with SHERPA correspond to the impacts on air pollution that would result if emissions from a particular sector or spatial scale were switched off. SHERPA mimics the "dynamic" responses of a CTM for these emission reductions.

Figure 2: Overview of the Core cities (in red) and greater city areas (in blue) for all analysed cities.

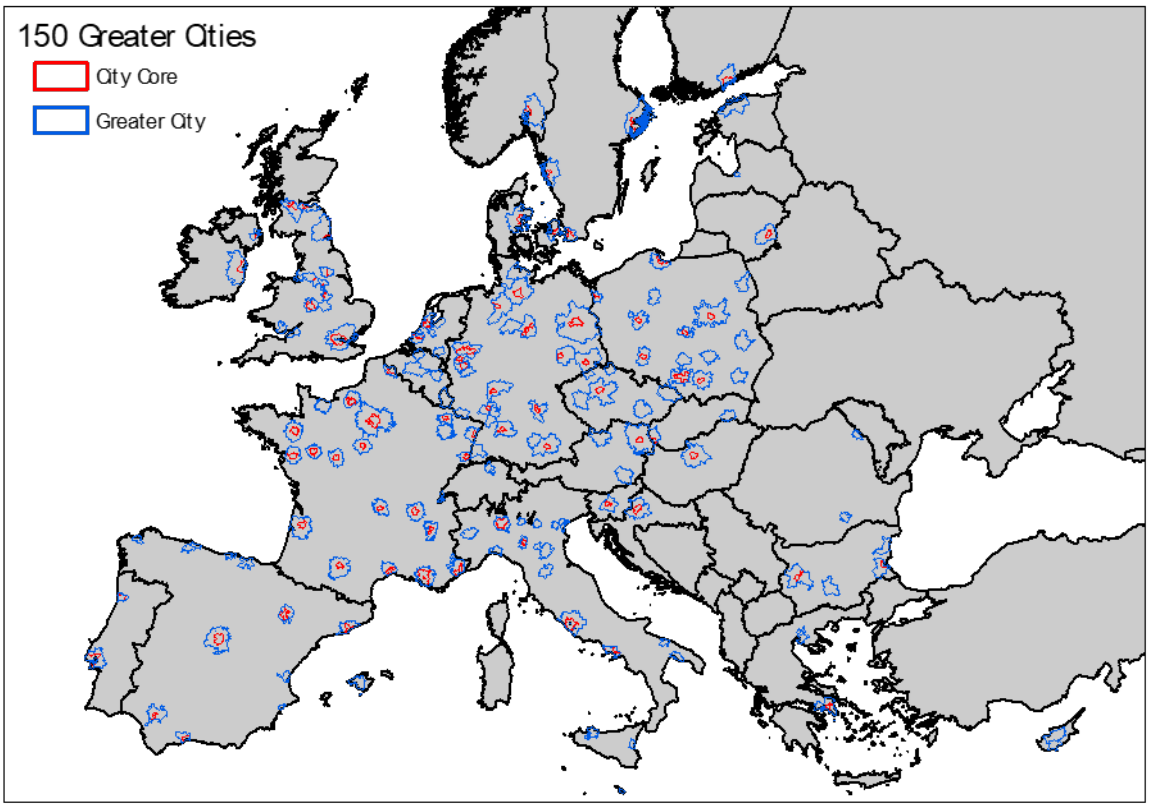


Figure 3 to Figure 5 show the core city, greater city and country contributions respectively, expressed in relative terms, i.e. as a percentage of the urban concentration. The concentration is estimated at the urban background location within the core city where the highest concentration level is found (see location in city fiches in section 5).

Figure 3: Contribution of city core emissions to urban PM_{25} concentration (the mapped 84 dots represent the urban areas where the core city is analysed).

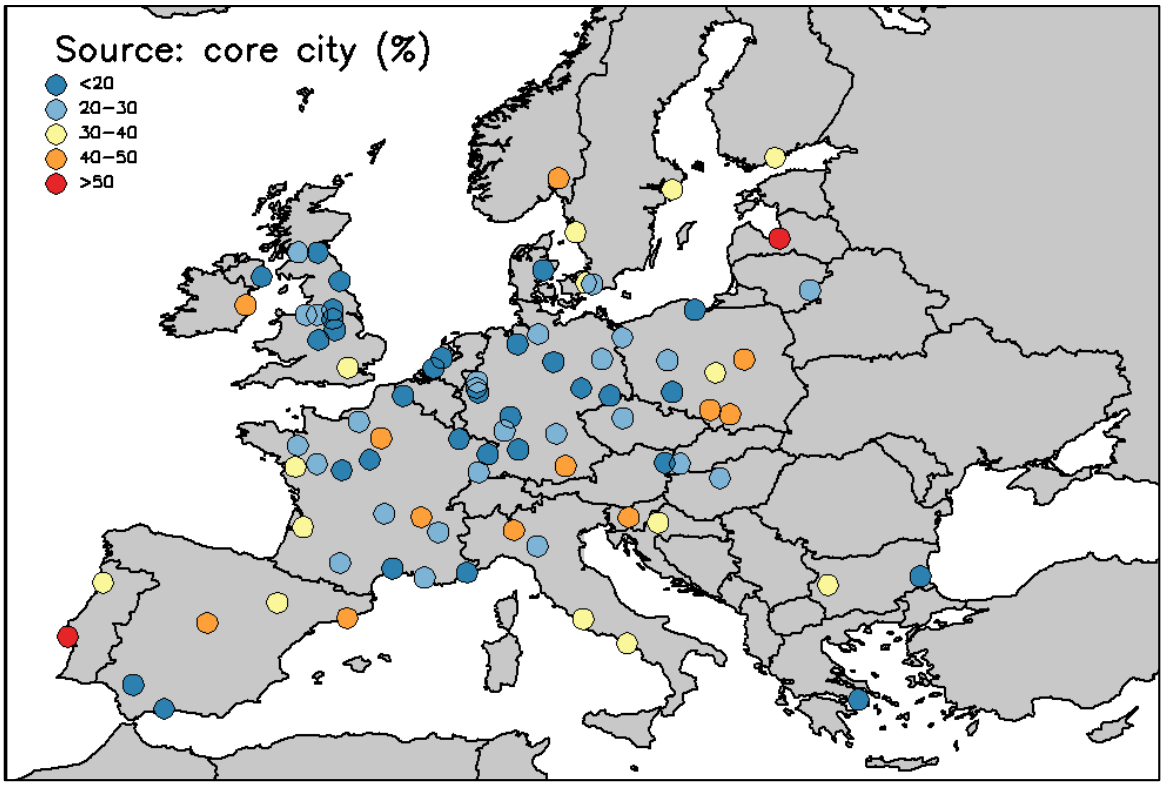


Figure 4: Contribution of greater city emissions to urban PM_{25} concentration (core city plus commuting zone).

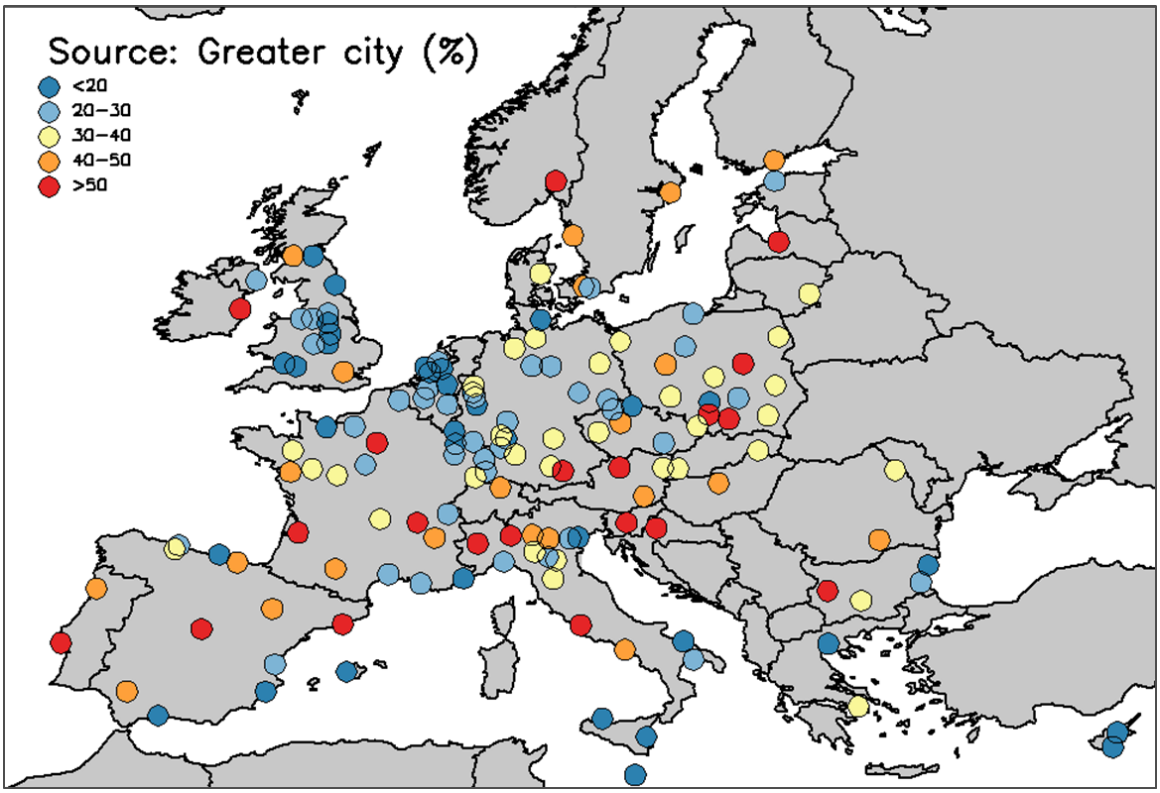
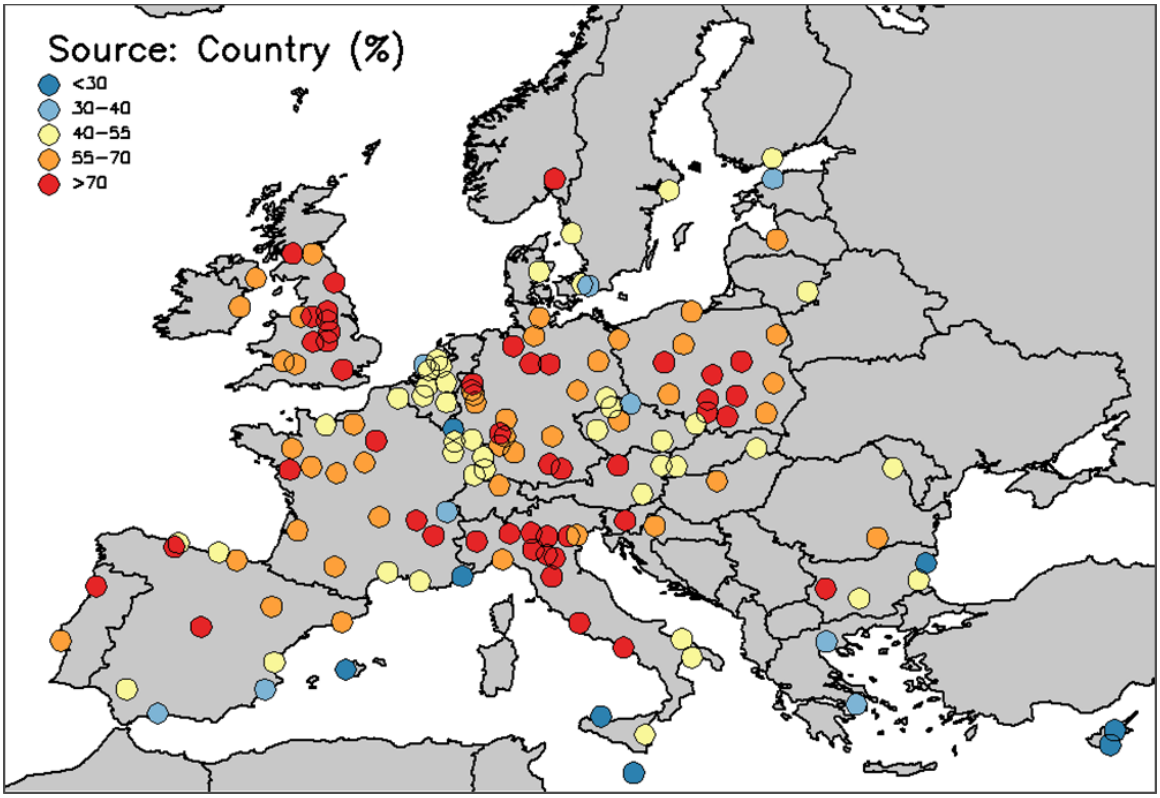


Figure 5: Contribution of the country emissions to urban $PM_{2.5}$ concentration.



Some key points arise from this analysis:

- The core city's own contribution to annual $PM_{2.5}$ concentrations (at its location with the highest concentration) is on average (over the 84 cities considered) around 26%. The largest contributions are found in Lisbon (55%), Riga (54%), Ljubljana (49%), Oslo and Paris (47%) whereas the lowest contributions are found in Dusseldorf, Dresden, Edinburgh, Frankfurt (Main) and Sheffield. In general, local emissions are a significant contributor to annual $PM_{2.5}$ concentrations in the largest EU cities or in cities isolated from other urban areas, stressing there the importance of local air quality planning.
- At the greater city scale (core city plus commuting zone), emissions contribution to annual $PM_{2.5}$ concentrations at the worst urban background spot is on average (over all 150 cities) around 32%[2]. The largest contributions are found in Oslo and Linz (68%), Ljubljana (67%), Sofia (64%) and Turin (63%), and the lowest in The Hague, Valetta, Nicosia, Limassol and Bari. Therefore, actions taken at the greater city scale have a lot of potential in many cities. About 30% of the 150 cities contribute to at least 40% of their air pollution if the greater city area is considered and about 50% of the 150 cities contribute to more than 30%.
- The contribution from the entire country (including core city and commuting zone) to annual $PM_{2.5}$ concentrations at the worst urban background spot in the city is on average (over all 150 cities) around 58%. The largest contributions are all found in the Italian Po Basin area with Brescia (92%), Verona (88%), Turin (87%), Milan (86%) and Parma (84%) and the lowest in Valletta, Limassol, Nicosia, Luxembourg and Palma de Mallorca (24%).

(2) Here emissions contribution refers to the greater city emissions. And also, the worst urban background spot refers to the greater city area.

The remaining sources of emissions in this spatial analysis (transboundary and/or natural) play a significant role in cities that are, either close to internal country borders, close to the MCA borders or under the influence of Saharan dust events. The largest contributions are found in southern cities, subject to episodic dust events: Valletta (96%), Limassol (91%), Nicosia (91%) and Palma de Mallorca (76%).

4. Which are the dominant emission sources in cities?

Air pollutant emissions originate from different human activities (like residential heating, transportation, etc.) as well as from natural sources (e.g. dust, sea-salt, fires, etc.). The sectoral apportionment of $PM_{2.5}$ reported in this Atlas distinguishes and quantifies the contributions from anthropogenic activity sectors and from natural sources as follows:

Residential: this sector includes emissions from combustion in domestic heating appliances (open fireplaces, stoves, etc.), medium and single-house boilers, cooking and heating stoves in commercial, institutional and residential activities.

Transport: this sector includes exhaust and evaporative emissions from light and heavy-duty vehicles and motorcycles, non-exhaust PM emissions due to road abrasion of tyres and brake wear, as well as from the off-road emissions sector (e.g., agricultural and construction equipment).

Agriculture: this sector includes emissions from livestock, fertiliser use and field burning of agricultural residuals.

Industry: this sector combines emissions related to combustion in energy industries (including public power, cogeneration and district heating), industrial combustion and industrial processes.

Natural: This sector includes desert dust and sea salt.

Shipping: This sector includes sailing boats, motorboats, inland goods carrying vessels, international inland gateways as well as national and international sea traffic.

Others: The remaining emissions are grouped in a single category. They include activities such as extraction and distribution of fossil fuels, solvent use, other mobile sources (railways, aviation, etc.) and waste treatment and disposal. NO_x emissions from soils (fertilisers and natural) as well as biogenic emissions, computed by the EMEP model are also included in this category.

External: This sector includes all emissions occurring outside the MCA.

We analyse here the relative contribution of these sectors to the $PM_{2.5}$ urban background concentration levels reached in cities. The sectoral contributions are intended here as the overall impact of the emissions from a given sector, regardless of where these emissions originate (no spatial breakdown). For each urban area, results are presented at the location where the maximum concentration is reached within the core city. This location (receptor point) is visible in the city fiches presented in section 5.

The key points arising from this analysis are synthesised below:

- The average contribution from the residential sector (Figure 6) in the 150 urban areas is 13%. The largest contributions are found in Ljubljana (45%), Turin (41%), Sofia (40%), Zagreb (38%) and Budapest (33%) and the smallest in The Hague, the Ruhr area, Dusseldorf, Hamburg and Nicosia. In general, the impact of residential heating is more important in the northern part of Italy and in some eastern countries. Cities in North-western Europe (e.g. Sweden, UK, Belgium, Germany…) do not show a large contribution from this sector.
- The average contribution from the road transport (Figure 7) in the 150 urban areas is 14%. The largest contributions are found in Malmo (39%), Brescia (28%), Parma (27%), Angers and Verona (26%) and the smallest in Oviedo, Kosice, Limassol, Gijon

and Lisbon. As expected, transport emissions represent an important contribution in some of the largest cities (Paris, London). However, they are also a key contributor in densely populated areas like Belgium and the Netherlands. It is important to note that the numbers concern the transport contribution to urban background concentrations. At traffic stations (not analysed here), the contribution is proportionally larger (Degraeuwe et al., 2021).

- The average contribution from agriculture (Figure 8) in the 150 urban areas is 19%. The largest contributions are found in the UK and Germany: Newcastle (34%), Wolfsburg (32%), Hannover (31%), Kiel and Bonn (30%) and the smallest in Southern Europe: Valletta, Palermo, Limassol, Lisbon and Nicosia. Agricultural activities and related emissions do not normally take place within the urban boundaries, although the greater city areas may include some agricultural areas. Nevertheless, the sector is responsible for a large fraction of the $PM_{2.5}$ concentrations (secondary pollution) in many EU cities, especially in Western Europe. This finding is in agreement with other works investigating the impact of agricultural emissions (Bessagnet et al. 2014; Bauer et al. 2016).
- The average contribution of industry (Figure 9) in the 150 urban areas is 27%. The largest contributions are found in Linz (55%), Riga (47%), Katowice (47%), Kosice and Oviedo (44%) and the smallest in Brescia, Roma, Turin, Nice and Napoli. Industry plays a key role mostly in some of the Eastern countries (Bulgaria, Romania and Greece) as well as in the western part of Germany, Portugal and some parts of Spain.
- The average contribution of natural sources (Figure 10) in the 150 urban areas is 9%. $PM_{2.5}$ concentration peaks in cities in the Mediterranean area are associated with episodic dust events. The largest contributions are found in Seville (49%), Nicosia (47%), Valletta (45%), Limassol (45%) and Malaga (42%) and the smallest in Oslo, Krakow, Warsaw, Lodz and Katowice.
- The largest shipping contributions (Figure 11) are found in Valetta (33%), Palermo (29%), Palma de Mallorca (26%), Athens (24%) and Bari (21%).

External sources of emissions, i.e. from outside the MCA (Figure 12) play a significant role in many cities located at its edge (e.g. Lisbon) but also in cities close to national borders (e.g. Zurich, Geneva) because the FUA definition only includes national territory.

This variability in terms of sectoral impact, even within a single country, illustrates the scope for targeting air quality plans on a city-by-city basis, as illustrated in the city fiches (Section 5).

Figure 6: Contribution of the residential sector to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area.

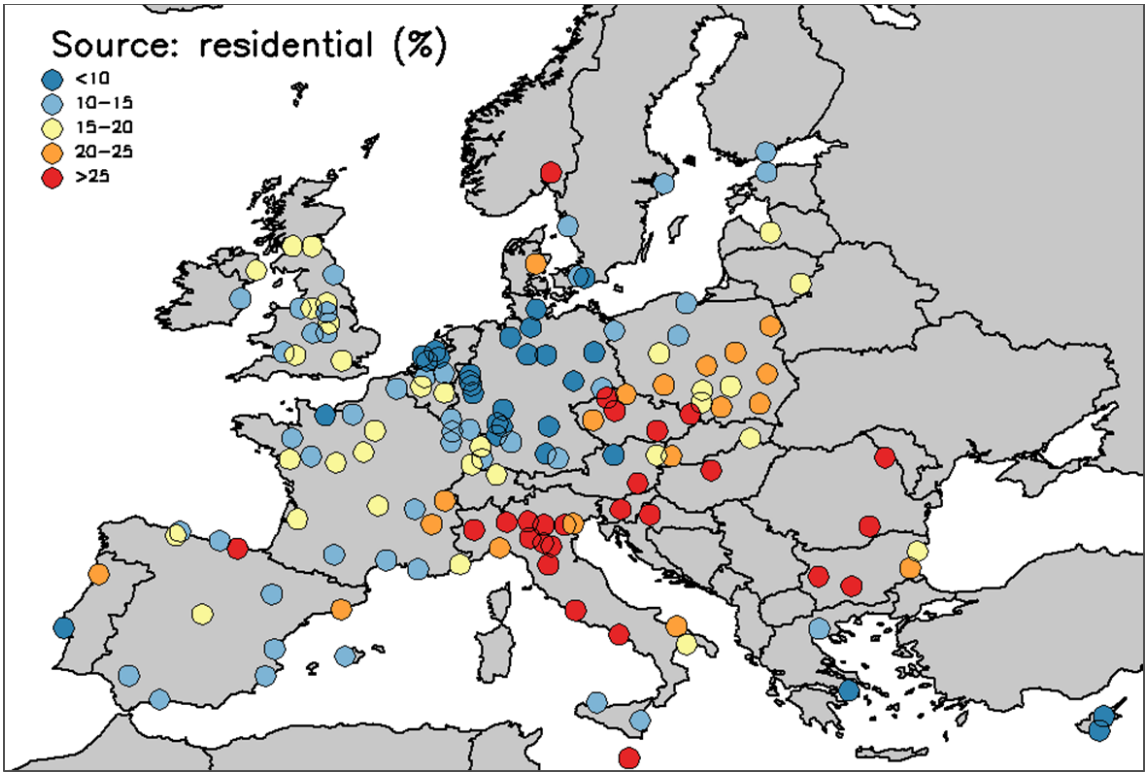


Figure 7: Contribution of the road transport sector to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area.

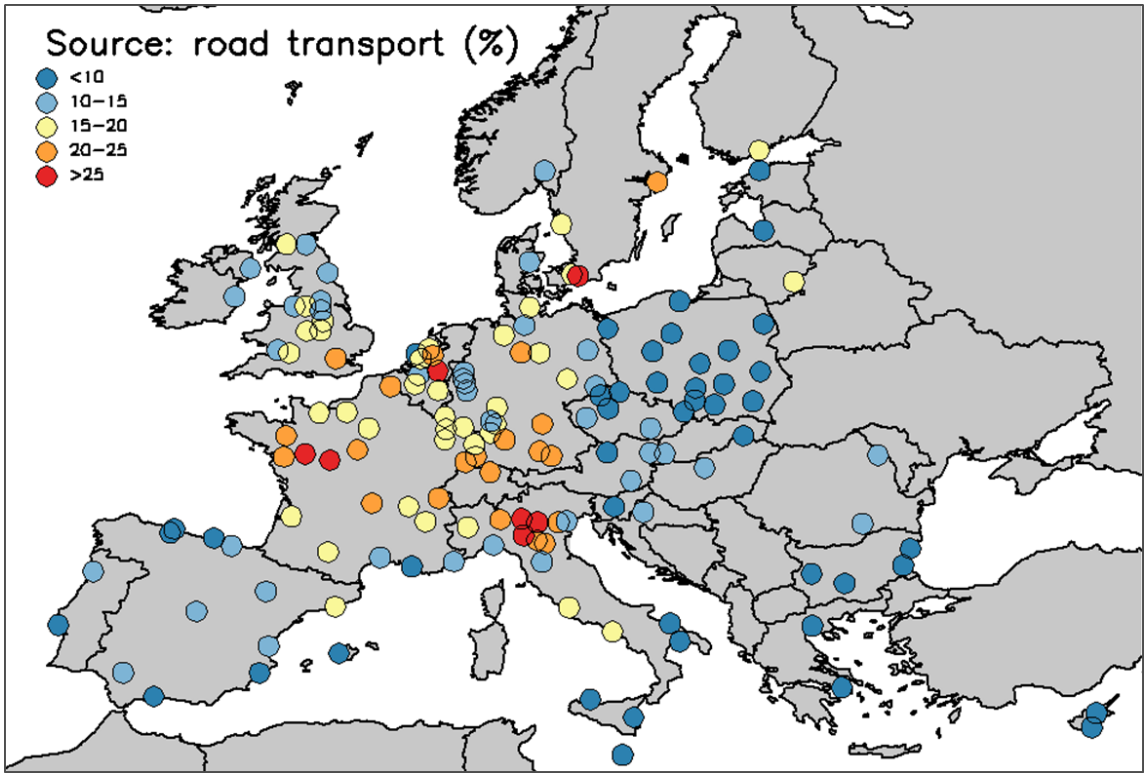


Figure 8: Contribution of the agricultural sector to the PM_{25} urban background concentration. Each dot represents one urban area.

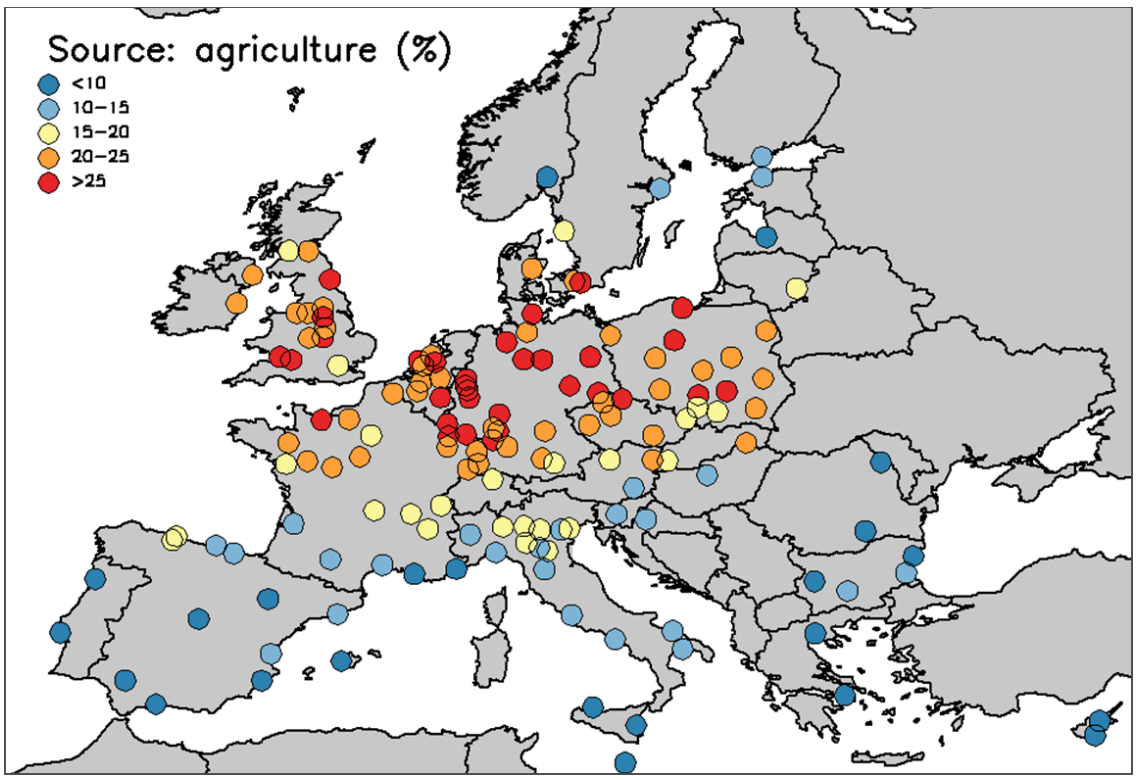


Figure 9: Contribution of the industrial sector to the PM_{25} urban background concentration. Each dot represents one urban area.

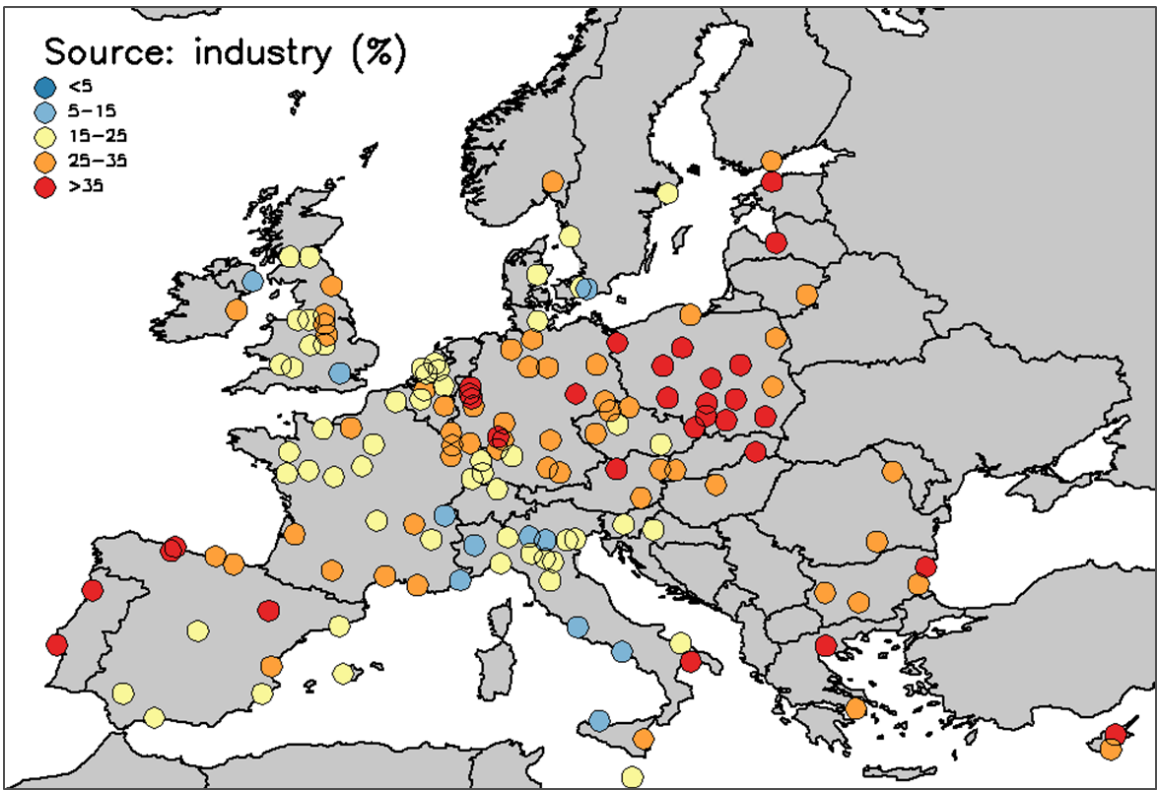


Figure 10: Contribution of the natural sources to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area

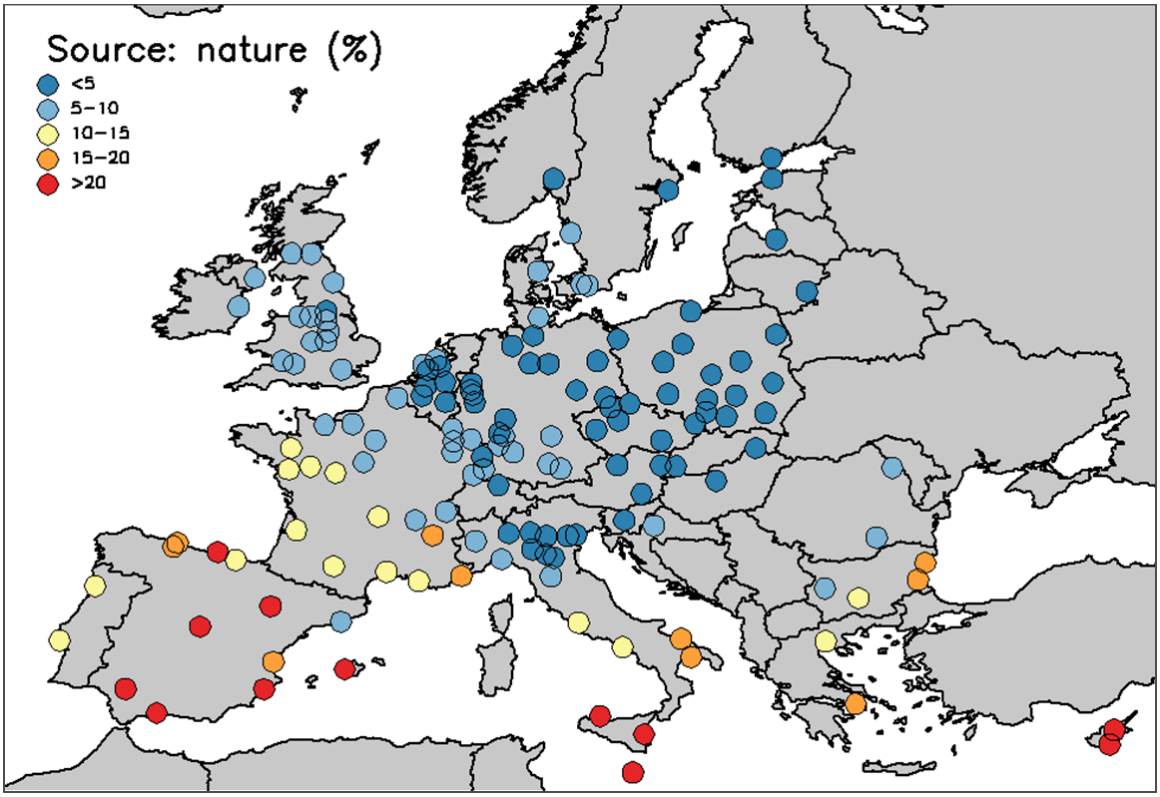


Figure 11: Contribution of the shipping sources to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area.

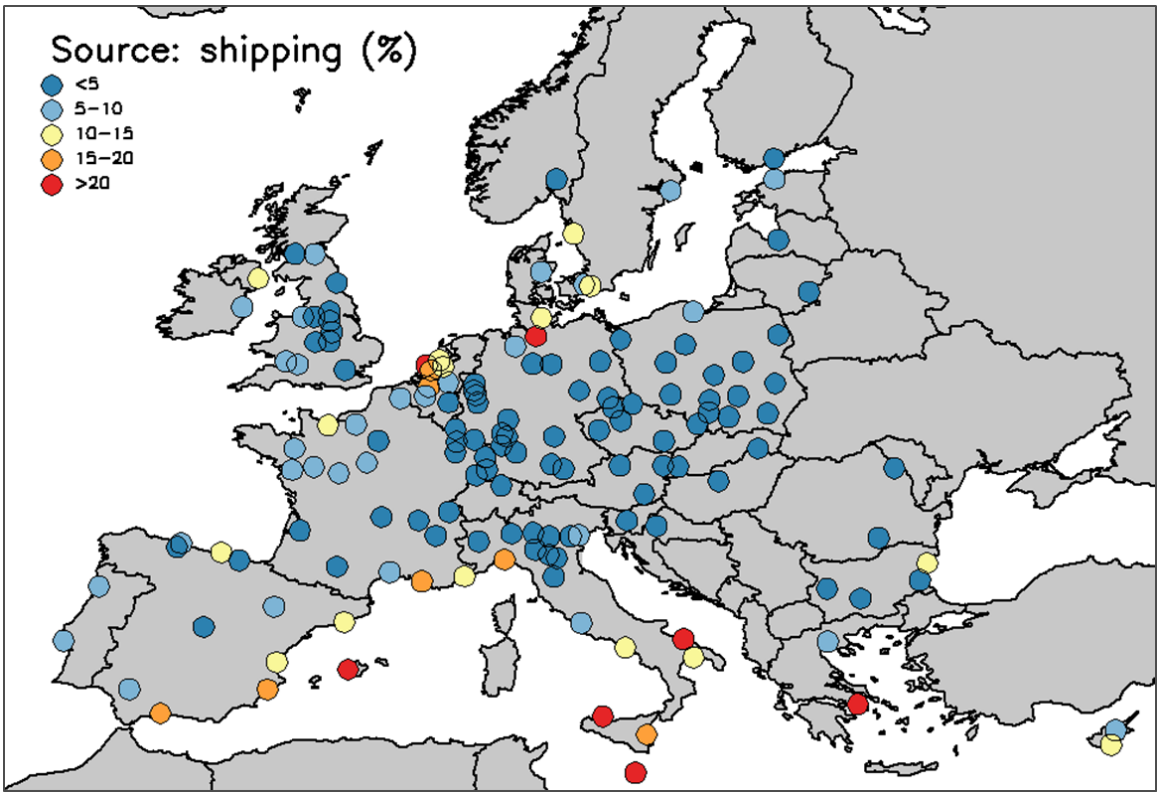
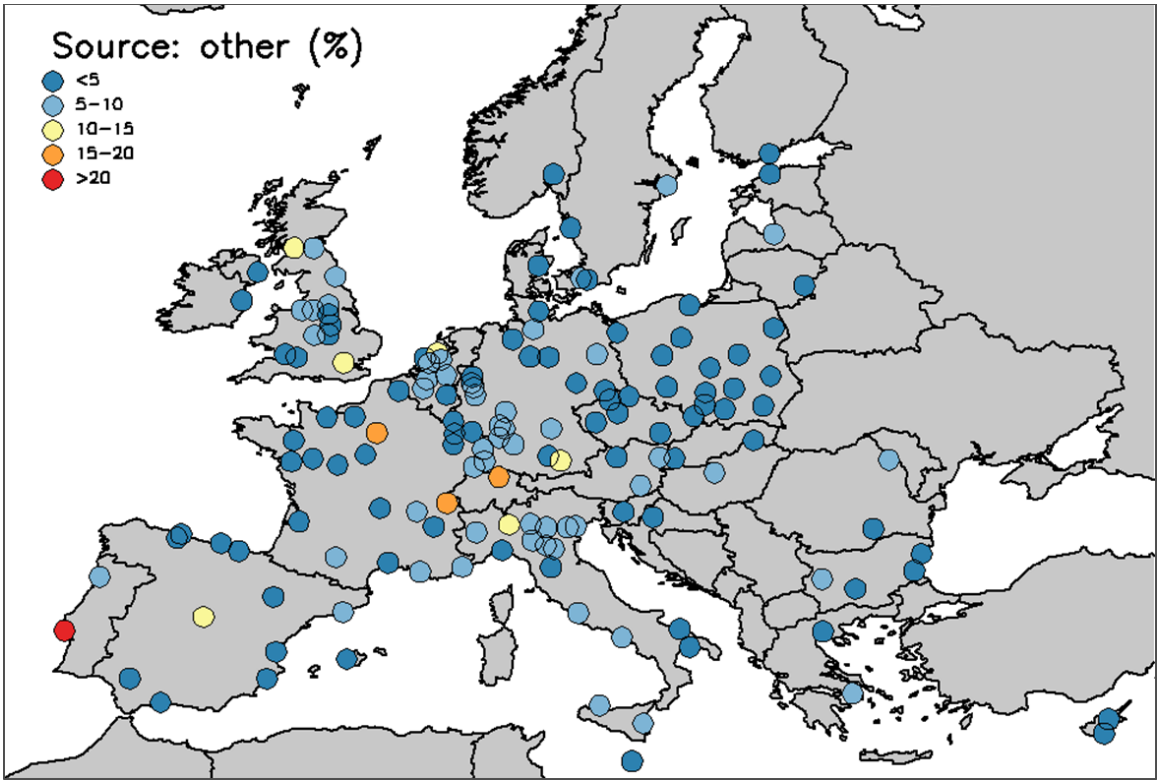


Figure 12: Contribution of the remaining sources (those outside MCA) to the PM_{25} urban background concentration. Each dot represents one urban area.

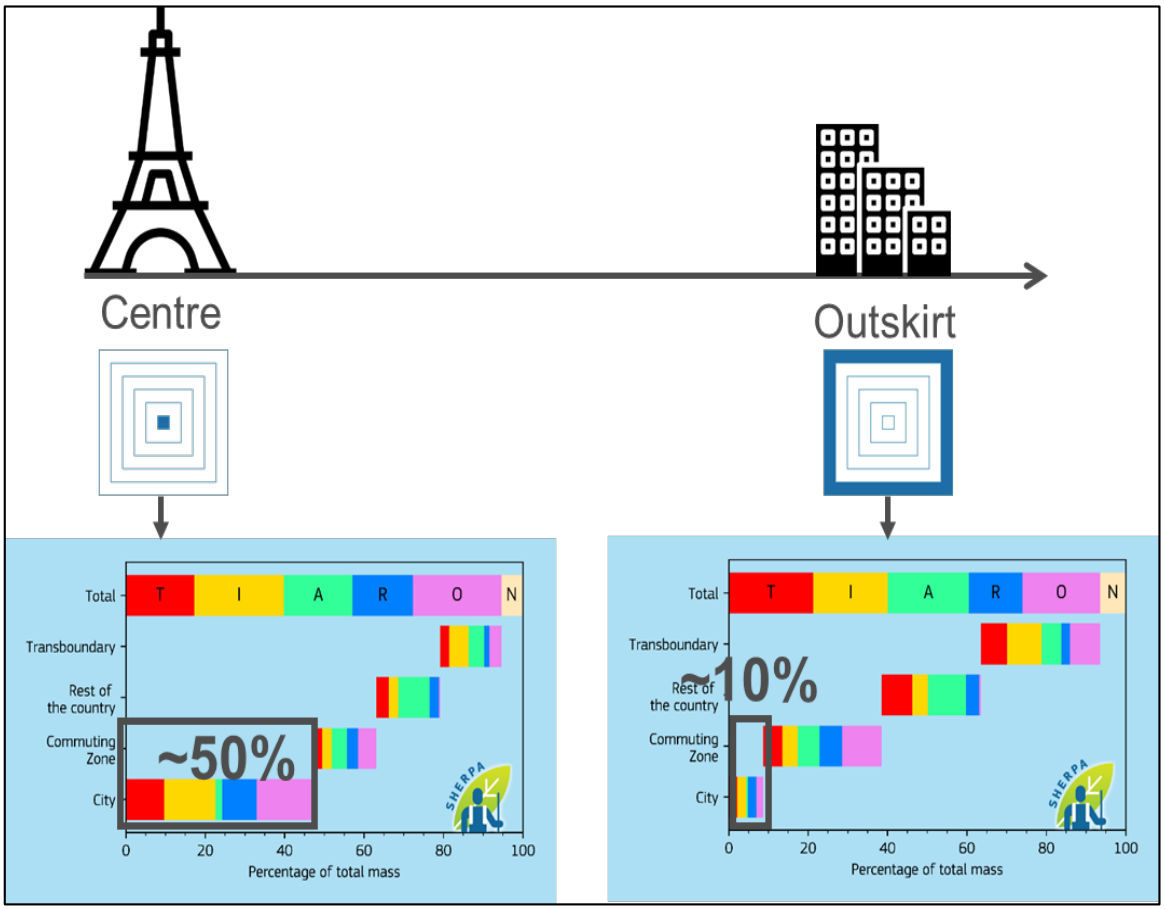


5. Why is the city's contribution to its' own air pollution often underestimated?

Quantifying the contribution of a city to its' own air pollution is a typical outcome of source apportionment (SA) studies. However, many source apportionment methods exist, each with many setting options. Consequently, the same underlying measurements can be used to produce results and interpretations that range from cities being major to minor contributors to their own air pollution, depending on the apportionment method applied to them. This explains why some authors stress the importance of local actions (Thunis et al., 2018, Wu et al. 2011, Raifman et al., 2020), while others stress the need for regional, national or even continental actions (ApSimon et al. 2021, Liu et al., 2013). These differences in conclusions have consequences in terms of policy decisions. Blaming external pollution sources for urban pollution can be a convenient justification for local inaction by decision-makers and vice versa.

In this section, we illustrate one of the possible issues, associated to spatial averages and take the city Paris as example (Figure 13). The source apportionment obtained for the core city and suburbs show striking differences, in particular in terms of core city contribution that drops from about 50% at its centre to about 10% in the suburbs. This highlights that target sectors and scales not only differ from one city to the other, but also strongly depend on the location within a single city. While the exact numbers differ from city to city, the principle is general and applies to any city. In some works, these different source apportionments are however spatially averaged at the city scale (e.g. average population exposure in Amann et al. 2017). It is important to stress that this averaging process frequently favours the suburban conditions over those found for the city centre, as a simple consequence of the larger number of suburban locations contributing to the average (see coloured squares in (Figure 13).

Figure 13: Comparison of two source apportionment breakdowns obtained for the same city of Paris, obtained at the city centre (left, represented by the Eiffel tower) and at its outskirts (right, represented by few buildings). The coloured squares represent the location(s) for which the SA are representative for.



On average over the 150 cities, the city responsibility drops by more than a factor 2 when spatial averages are applied. Spatially averaging (weighted by population or not) tends to significantly reduce the city responsibility, potentially underestimating the possibility of the city to reduce pollution levels via local controls. The larger the city, the more important this shift will be.

Similar considerations apply to temporal averages. While Madrid core city's contribution is about 40% on a yearly average basis, this number hides important seasonal differences between winter and summer contributions that lie around 75% and 35%, respectively.

As seen from these examples, underestimations of a factor of two can easily result from source apportionment setting choices, and underestimations resulting from different setting choices generally add-up.

6. A closer look city by city

In Sections 3 and 4, the contributions to urban $PM_{2.5}$ concentration levels have been analysed in terms of their geographical or sectoral origin respectively. Both aspects are combined here to give a single source allocation overview for each of the 150 cities on a city-by-city basis (see Annex 3).

The first part of this "city fiche" analysis provides some general information regarding the location of the urban area, its population, and the geographical extension of its core city and greater city areas. The black triangle in each city map (top-left) represents the location where source allocation is performed.

Information on measured $PM_{2.5}$ and PM_{10} concentration levels and on their compliance with the standards in the EU AAQD and the WHO air quality guideline is given in the top-right of the fiche. The histogram in each fiche provides an overview of reported PM concentrations in the considered cities[3], while the colour coded dots indicate the values measured at all background monitoring stations located in the greater city area (green: below WHO guidelines: red: above AAQD limit values; orange: in between).

The central panel of the fiche contains the summary source allocation diagram. This diagram breaks down contributions in terms of their spatial (along the vertical axis) and sectoral (along the horizontal axis) origins. All values are expressed as relative percentages of the urban concentration (at the receptor point). The top bar provides the 'total sectoral breakdown', i.e. the contribution of different sectors to the total concentration of the urban background yearly average $PM_{2.5}$ concentrations. Note that the sum of all contributions, including the natural one, is usually less than 100%. The contributions that cannot be allocated are therefore attributed to 'external' emissions from outside the MCA. Because of uncertainties the sum of all contributions, including the natural one, are in a few cities slightly larger than 100%. In such cases, contributions are rescaled to sum up to 100%, for consistency. The bars beneath provide similar information but in terms of spatial dimensions. For the largest cities, four spatial areas are considered (core city, commuting zone, rest of country, transboundary) while for smaller cities, the first two scales are merged.

The lower and central-right panel provides an overview of the emission breakdown used for the calculations for primary particulate matter ($PPM_{2.5}$), nitrogen oxides (NO_x), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOC), and ammonia (NH_3). Each of the graphs shows the dominant sectors for each emitted air pollutant in the core city (red, when available) and the greater city (blue).

(3) Data source: http://aidef.apps.eea.europa.eu/.

7. Conclusions

There is a need to provide information to improve air quality policy governance, to support authorities in choosing the most efficient actions at the appropriate administrative level and scale. In particular, an appropriate balance between local actions focusing on the urban scale and actions requiring national/international efforts needs to be found. The purpose of this Air Quality Atlas is to provide, based on the SHERPA tool (Thunis et al. 2016), city specific source allocation information on annual $PM_{2.5}$ concentrations in terms of sector and spatial dimensions for 150 cities in the EU. The main findings of this Urban $PM_{2.5}$ Atlas are:

For many cities, local actions at the city scale are an effective means of improving air quality in that city.

Almost half of the considered cities (79 out of 150) have the potential to reduce their annual $PM_{2.5}$ concentrations by 30 % or more through local (greater city) action. In fact, there is a significant number of cities where the share of their own contributions to $PM_{2.5}$ concentrations is even higher: > 40% impact (45 cities) and > 50% impact (22 cities). Long-range transport is important, particularly in cities located near the MCA boundaries. However, the overall finding is that cities have an important role to play by taking actions at their own scale.

It is important to emphasise that the emissions in cities contribute significantly to country and EU overall PM background concentrations, reinforcing the important role of cities in reducing air pollution as part of a multilevel approach.

Target or key sectors and scales to abate air pollution are city specific.

Cities differ in the way in which their $PM_{2.5}$ concentrations respond to abatement measures, even when located in the same country. Actions taken at different scales or in different activity sectors lead to impacts that depend on the individual characteristics of the city concerned. Given that measures have such varied effects in different cities, there is a clear need to take into account these city-specificities when designing air quality plans. Actions that are efficient in one city might not be efficient in others.

For many cities, sectoral measures addressing agriculture at country or EU scale would have a clear benefit on urban air quality

Although agricultural activities take place mostly outside the "city" boundaries, as defined here, agriculture emissions considerably impact air quality in many EU cities. Agriculture contributes to more than 25% of $PM_{2.5}$ concentrations in about 21% of the cities analysed (out of 150) and to more than 20% in 51% of the cities. The extent of the impact of agriculture on air quality is indicative of the potential of EU- or country-wide measures addressing this sector.

Moreover, other sectoral measures can have an important potential at the urban scale even though they are applied at EU or country scale. This is the case i.e. of road transport where the European emission standards for vehicles are, in practice, most effective in the areas where traffic is most important, i.e. cities.

Because of methodological choices and assumptions, the responsibility of a city in generating its pollution is often underestimated.

Methodological choices and assumptions influence the quantification of geographical and sectoral contributions to city pollution. These include the definition of the city, temporal (e.g. yearly vs. seasonal) and/or spatial averaging processes (hot-spot location vs. city average) applied to the indicator ($PM_{2.5}$). It is important to stress that methodological choices and

assumptions frequently lead to a systematic and important underestimation of the city responsibility, with important policy implications. Documenting methodological choices and assumptions is a crucial element to put numbers into context and prevent any possible misinterpretations.

This report analyses the situation of 150 big cities in Europe. However, many smaller urban areas are not considered in this Atlas. It is therefore important to extend this work in the future to these smaller urban areas as they may have their own specific characteristics. Downscaling methodologies should be improved in parallel with the development of more accurate emission inventories consistent with the target resolution. Similarly, within cities, a proper estimate of the contributions at traffic stations would complete this analysis at the local scale.

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List of abbreviations and definitions

AAQD	Ambient Air Quality Directive
CHIMERE	French national Chemistry Transport Model
CTM	Chemistry Transport Model
EEA	European Environmental Agency
EMEP	European Monitoring and Evaluation Programme
EU	European Union
MCA	Model Control Area, defined as EU27 + UK + Switzerland + Norway
EURO	European emission standards for vehicles
GAINS	Greenhouse Gas - Air Pollution Interactions and Synergies
NH3	Ammonia
NMVOC	Non Methane Volatile Organic Carbons
NOx	Nitrogen oxides
PM	Particulate matter
$PM_{2.5}$	Particulate matter with diameter inferior to 2.5 µm
PM_{10}	Particulate matter with diameter inferior to 10 µm
PPM	Primary Particulate Matter
RM	Receptor model
SHERPA	Screening for High Emission Reduction Potential on Air quality
SO_2	Sulphur Dioxide
SRR	Source Receptor Relationships
WHO	World Health Organisation

List of Figures

Figure 1: The red and dark red dots indicate stations reporting concentrations above the EU annual limit value for $PM_{2.5}$ (25 µg/m^3). The dark green dots indicate stations reporting values below the WHO AQG for $PM_{2.5}$ (10 µg/m^3). Only stations with > 75% of valid data have been included in the map..... 7

Figure 2: Overview of the Core cities (in red) and greater city areas (in blue) for all analysed cities..... 11

Figure 3: Contribution of city core emissions to urban $PM_{2.5}$ concentration (the mapped 84 dots represent the urban areas where the core city is analysed)..... 12

Figure 4: Contribution of greater city emissions to urban $PM_{2.5}$ concentration (core city plus commuting zone)..... 12

Figure 5: Contribution of the country emissions to urban $PM_{2.5}$ concentration..... 13

Figure 6: Contribution of the residential sector to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area..... 17

Figure 7: Contribution of the road transport sector to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area..... 17

Figure 8: Contribution of the agricultural sector to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area..... 18

Figure 9: Contribution of the industrial sector to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area..... 18

Figure 10: Contribution of the natural sources to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area..... 19

Figure 11: Contribution of the shipping sources to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area..... 19

Figure 12: Contribution of the remaining sources (those outside MCA) to the $PM_{2.5}$ urban background concentration. Each dot represents one urban area..... 20

Figure 13: Comparison of two source apportionment breakdowns obtained for the same city of Paris, obtained at the city centre (left, represented by the Eiffel tower) and at its outskirts (right, represented by few buildings). The coloured squares represent the location(s) for which the SA are representative for..... 22

Annex 1. The SHERPA methodology

SHERPA (Screening for High Emission Reduction Potential on Air quality) is a Java/Python tool, developed for the rapid exploration of potential air quality improvements resulting from national/regional/local emission reduction measures. With respect to a full chemistry transport model (CTM), SHERPA relies on simplifying assumptions to speed up the computing time. It uses EU-wide data on emissions and source-receptor models (see below for details), so that it is easy to start working on any region/local domain in Europe. SHERPA has been developed to address the following tasks:

- Source allocation: this step aims to assess the level of control policymakers have on air pollution over a predefined area. If most of the pollution is imported from outside the region's borders, the level of control will be low (and vice-versa). During this step, SHERPA provides information on (1) the amount of pollution originating from outside the control region and (2) the allocation in terms of activity sectors and precursors for the pollution originating from inside the control region.
- Governance: This step identifies spatially the key contributors (i.e. regions, countries) to the pollution at one given location. The methodology is designed to identify and rank the contributions (to air pollution levels) of all neighbouring and non-neighbouring regions for a specific sector of activity. This step sets the basis for fixing priorities in terms of regional collaboration with a view to increase the efficiency of abatement strategies on a sectorial basis.
- Scenario: The scenario analysis represents the final stage in the process, once the key sectors of activity and their respective impact areas have been identified through the first two steps. Based on these first two steps, the policymaker can decide the desired sector-specific emission abatement in terms of intensity (i.e., percentage reduction) and spatial coverage and test the impact of this specific emission scenario on air quality levels.

SHERPA is based on Source-Receptor Relationships (SRR). These SRR are a simplified version of a Chemistry Transport Model (CTM), used to simulate the contribution to concentration levels due to all precursor emissions (NO_x, NMVOC, PPM, SO_2 and NH_3) from one particular area of the domain (Clappier et al. 2015). They are used to estimate the effect of changes in precursor emissions on pollutant concentrations. In general, a SRR model consists of algebraic relationships between gridded precursor emissions and concentrations.

The most precise way to use a CTM to produce SRR for the model domain would be with a grid cell-to-grid cell approach. This involves simulating independently the effect of emissions changes in each single grid cell in the model domain. It would require changing precursor emissions in individual grid cells (source cells) one at a time and looking at the resulting change in concentrations in each receptor cell. While theoretically very simple, the resulting number of unknown parameters, describing the transfers between source and receptor cells that need to be identified is very large. Because each of these unknowns requires a specific equation, itself deriving from an independent CTM run, this grid cell-to-grid cell option is very costly, and simplifying assumptions that reduce the number of CTM runs are required.

In SHERPA, an approach is taken that reproduces the grid cell-to-grid cell approach, but does not require anywhere near as many CTM model runs. Instead, SHERPA assumes that the unknown parameters, describing the transfers between source and receptor cells, vary on a cell-by-cell basis but are no longer independent of each other. Instead, the transfer coefficients are related through a bell shape function, assuming that the impact of emissions

(within a source cell) on the concentration at a receptor cell decrease with distance between the source and receptor cells (Clappier et al. 2015, Pisoni et al. 2017, Pisoni et al., 2019).

Given its cell-to-cell characteristics, the SHERPA SRR formulation can be used to assess the impact of emission reductions over any given set of grid cells. Cities, regions or countries can therefore be freely defined in terms of boundaries, to test the effect of emission reduction policies on concentrations. At a given location, the contributions (primary or secondary, or sectoral) from the grid cell emissions belonging to the selected area (city, region or country) are calculated explicitly. These contributions correspond to the impacts on air pollution that would result if emissions from a particular sector or spatial scale were switched off. In other words, SHERPA mimics the "dynamic" responses of a CTM for such emission reductions. It is important to note that this approach, referred to as "potential impacts" (Thunis et al., 2020) differs from others like tagging (reference) that correspond to a "static" decomposition of the current air pollution levels. As shown by Clappier et al. (2017) and Thunis et al. (2019), the differences between the two approaches can be important when quantifying the contributions of precursors involved in chemical reactions leading to secondary particulate matter. Detailed information about the formulation of the source-receptor relationships, their accuracy, robustness and their validation process is available in Clappier et al. (2015), Thunis et al. (2016), Pisoni et al. (2017) and Pisoni et al. (2019).

In its current configuration, SHERPA is based on the EMEP (Simpson et al. 2012) model covering the whole of Europe at 0.1 x 0.1 longitude/latitude (~ 10 x 10 km^2) spatial resolution. The anthropogenic emissions underlying the model simulations are based on CAMS V4.2 emissions per country-pollutant-sector for 2015. The CAMS regional anthropogenic emission inventory covers emissions for UNECE-Europe for the main air pollutants and greenhouse gases (Kuenen et al., 2014, Granier, et al., 2019). Meteorological input data are based on 2015 forecasts from the Integrated Forecast System (IFS), a global operational forecasting model from the European Centre for Medium-Range Weather Forecasts (ECMWF). Meteorological fields are retrieved at a 0.1× 0.1 degree in longitude and latitude resolution (choice discussed further in Annex 2).

Because of its simplifying assumptions and spatial resolution, SHERPA only calculates yearly average concentration levels of $PM_{2.5}$ for relatively large cities (covering a sufficient number of grid-cells).

Annex 2: Uncertainties and limitations

SHERPA

As mentioned in Annex 1, SHERPA relies on simplifying assumptions to speed up the computing time and enable a generalisation of its results to most EU cities. The two main assumptions of the approach are: (1) linearity between concentration and emission changes (i.e. a doubled emission reduction will generate a doubled impact) and (2) a simple "bell shape" function to spatially relate emission and concentration changes. These assumptions have been extensively assessed. The validation process, covering test cases in many EU cities, regions and countries, showed good agreement between the SHERPA SRR and the full CHIMERE model (Pisoni et al. 2019). However, these assumptions are not valid for short-term concentration averages and this is why the present analysis is limited to yearly average PM_{25} concentrations. Additional information about the formulation of the source-receptor relationships, their accuracy, robustness and their validation process is available in the references listed in Annex 1.

Spatial resolution

SHERPA and its underlying CTM both run with a 0.1° (approximately 10 km) spatial resolution. Schaap and al. (2015) showed that a resolution close to 10 km was accurate enough to capture urban background concentrations given the current uncertainties associated to emission inventories. This spatial resolution however limits the analysis to the largest EU cities as smaller cities might cover too few grid cells. This is why a threshold of about 300 km^2 (~ 6 grid cells) is applied on the city selection. Note that emissions within a grid-cell, crossed by the city (or greater city, country) boundaries, are attributed to the city proportionally to the city area included within the grid cell.

The underlying Chemistry Transport Model

The SHERPA results strongly depend on the CTM used to define its SRR. The approaches to represent meteorological and chemical processes indeed vary from one model to the other, leading to potential uncertainties. Although the EMEP CTM, in a similar configuration, has been extensively validated against observations (Bessagnet et al., 2016), it is not possible to validate CTMs for model-responses to emission changes. This is the reason why CTMs are regularly tested in the frame of inter-comparison exercises (Cuvelier et al., 2007; Vautard et al. 2007; Bessagnet et al., 2016; Vivanco et al., 2017). The robustness of the results can also be assessed by comparing SHERPA responses to responses obtained in specific regional areas with other models, at the same or different resolutions. This process of inter-comparison is on-going, to increase the reliability and robustness of the whole approach.

Data reported as relative fractions

One of the findings of past modelling inter-comparison exercises (e.g. CityDelta, EuroDelta, Cuvelier et al., 2007, Thunis et al., 2007) is that relative fractions (i.e. concentration change divided by concentration) are generally more robust than absolute values (concentration). This is because concentration changes and concentrations are generally correlated (an overestimation of the concentration is likely to lead to an overestimation of the concentration change as well). All results are therefore expressed in terms of relative fractions.

Emissions

The results presented here strongly depend on the quality of the underlying emission inventory. Uncertainties in emission inventories are known to be high, especially at the urban scale, as highlighted by Trombetti et al. (2018) who compared different EU wide top-down

inventories in different cities. Because results directly depend on this input data, the city "fiches" include information on the emissions feeding the model for each urban area. In this respect, we hope that the results presented here (emissions and source allocation) can be used to trigger the discussion with local air quality managers to detect possible inconsistencies and support the improvement of the underlying emission inventory. Another source of uncertainty is related to the reference year (2015) which does not account for emission changes that occurred in the most recent years.

In the previous atlas version, the emissions from Terrenoire et al. (2015) were used. Although the country totals slightly differ, the main differences (in comparison to emissions used in this new Atlas) originate from the spatialisation of the country emissions to the different cities, that uses now different proxies. For some sectors, differences can be large. For example, the industrial PPM emissions allocated to urban areas according to the current inventory are in average larger (40% vs. 27%). The same holds for the residential PPM emissions (30% vs. 22%). These average differences hide stronger discrepancies in some cities, which impact the source apportionment results.

Uncertainties are also related to our incomplete representation of the day to day emission variability in CTMs (e.g. the temperature dependence of residential emissions or the spring burst of the ammonia emissions during short span of fertiliser applications). The future inclusion of emissions of condensable species (in the residential sector) will likely improve future assessments (Simpson et al., 2020).

SHERPA distinguishes sectoral impacts, but point sources (for which the release height becomes an important element) and surface sources are treated similarly. Pisoni et al. (2019) showed however that the uncertainty related to this grouped treatment remains acceptable in terms of error.

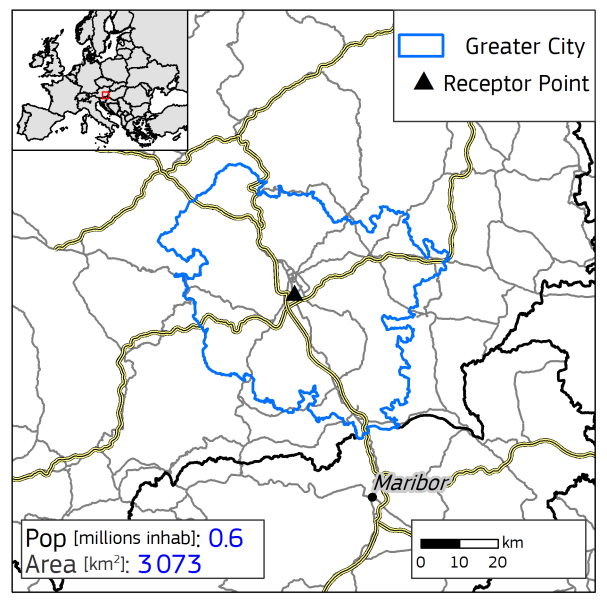
Meteorological variability

The results presented in this report are based on a single meteorological year (2015) that might not be fully representative for other years. 2015 showed higher temperatures over northern, central and southern Europe and larger precipitation amounts over north-western Europe than the 2005-2014 average. However, years around 2015 are similar to or hotter than 2015.

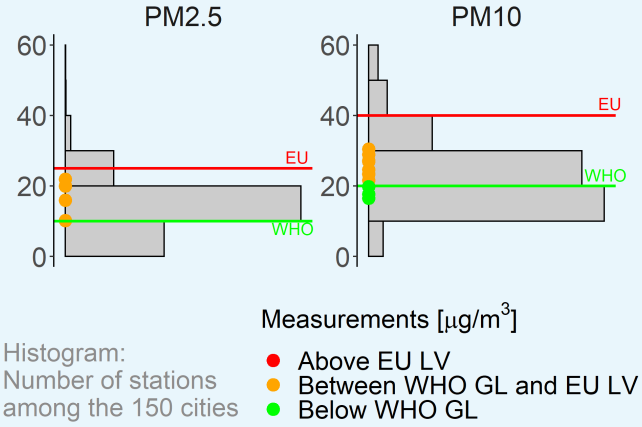
In this respect, repeating the analysis with other years would increase the robustness of the results. The fact that all results are presented in terms of relative fractions, however, reduces the possible impact of inter-annual variability.

Annex 3: A closer look city-by-city (150 city fiches)

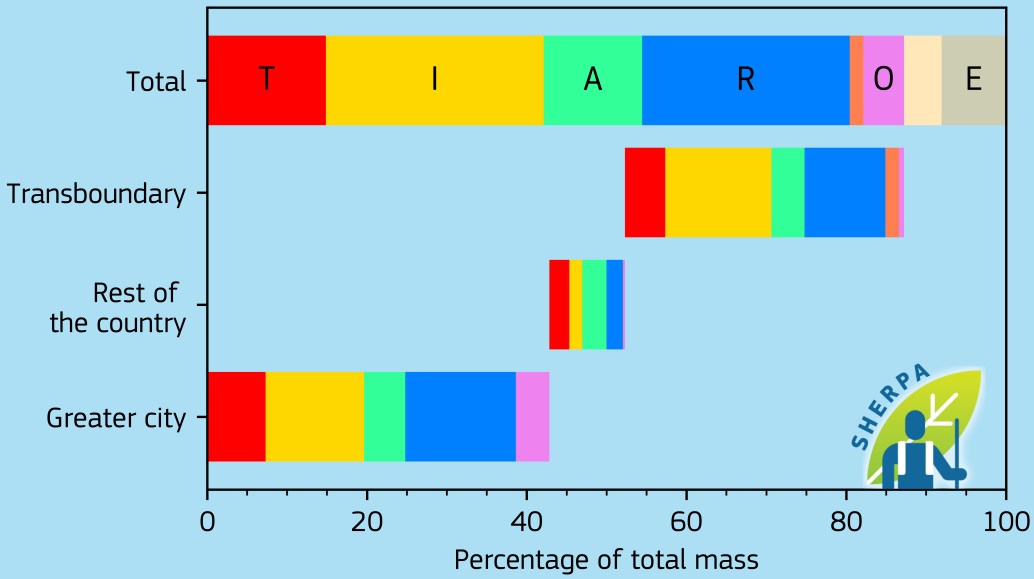
Austria, Graz



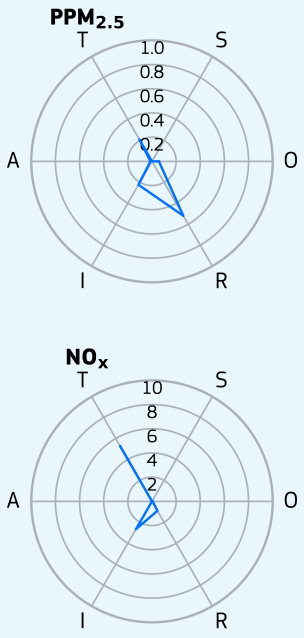
Yearly average urban concentrations (2018)

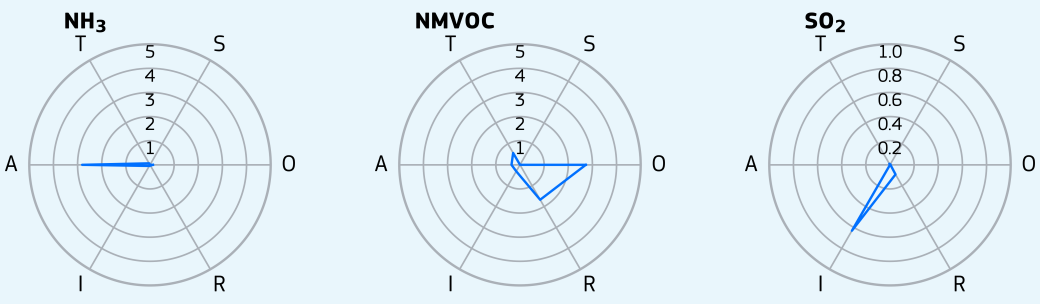


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



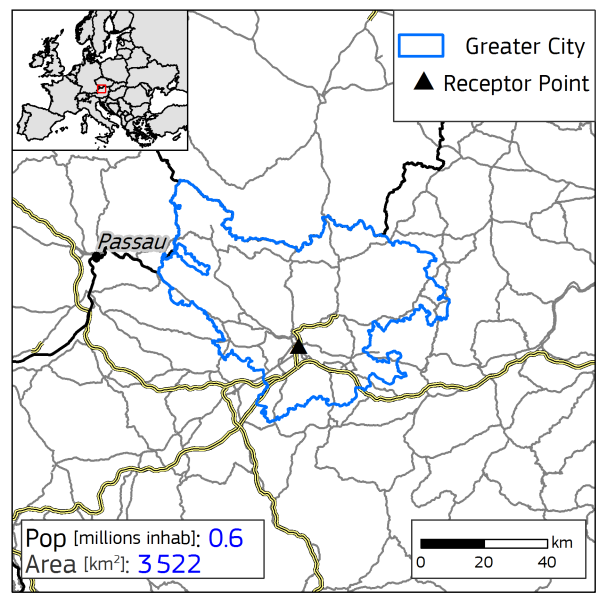
Emissions [kton/year]



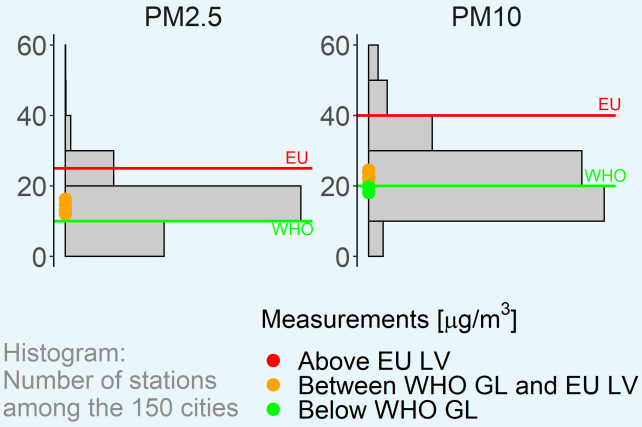


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

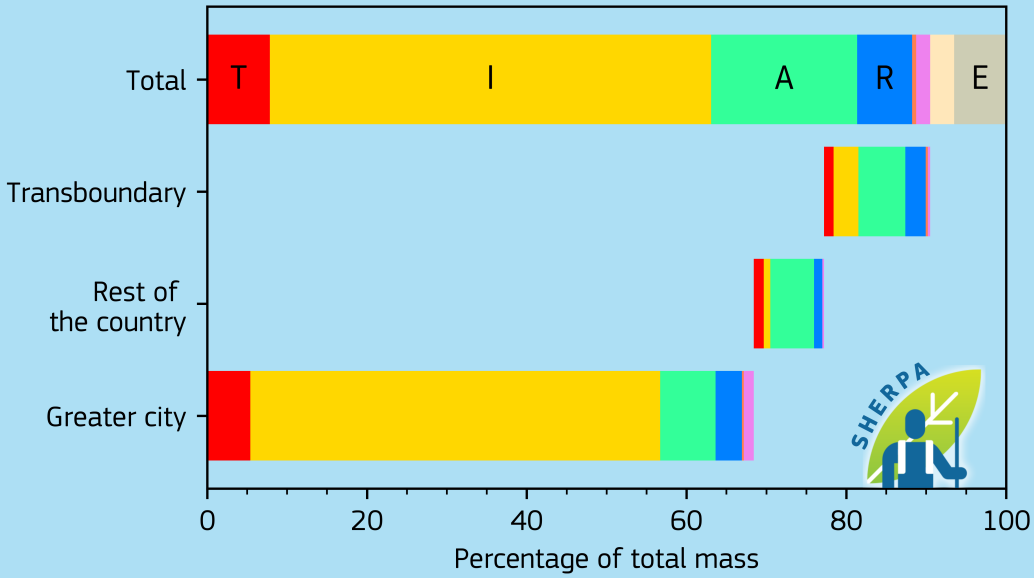
Austria, Linz



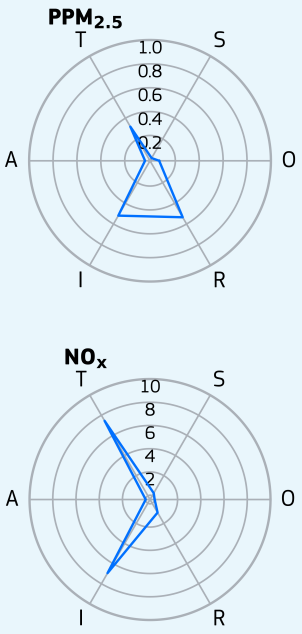
Yearly average urban concentrations (2018)

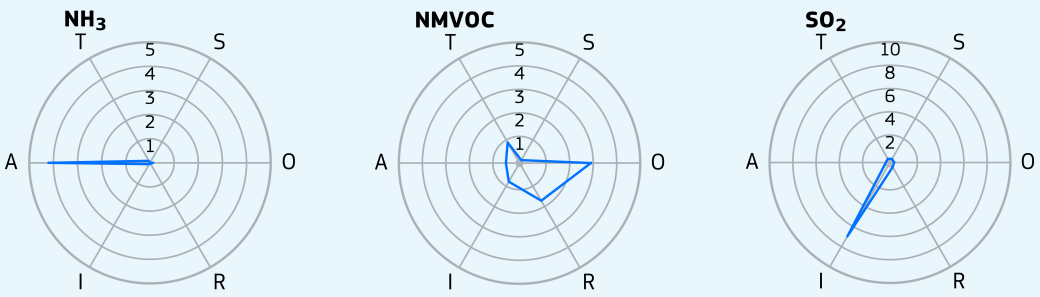


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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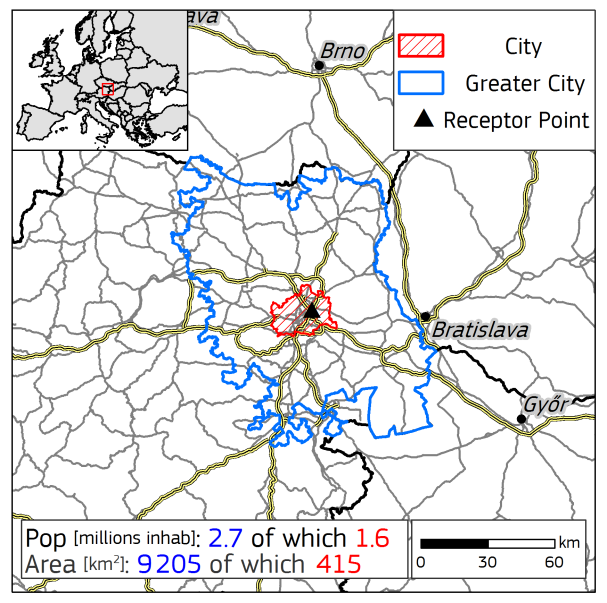
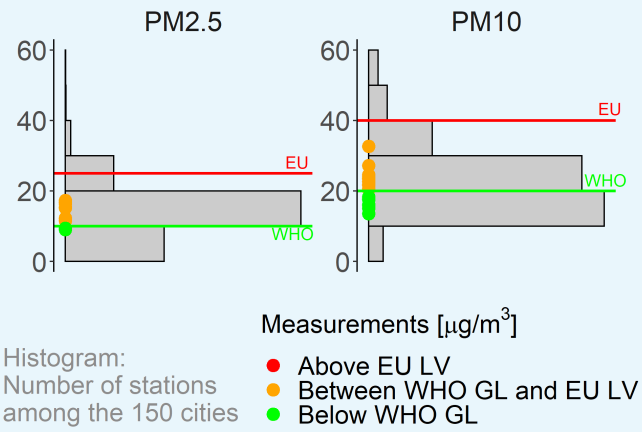
- Greater city

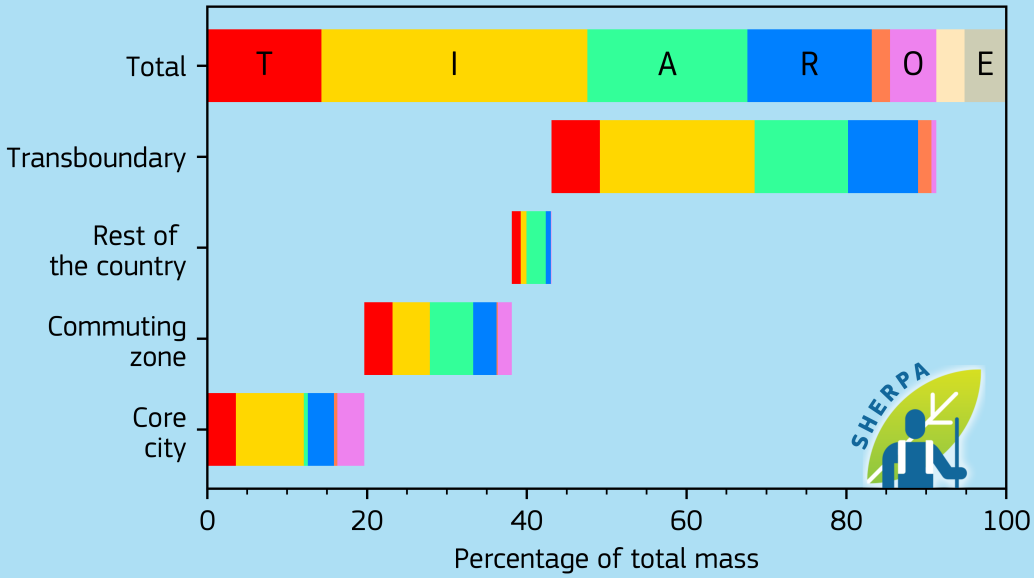
Austria, Vienna



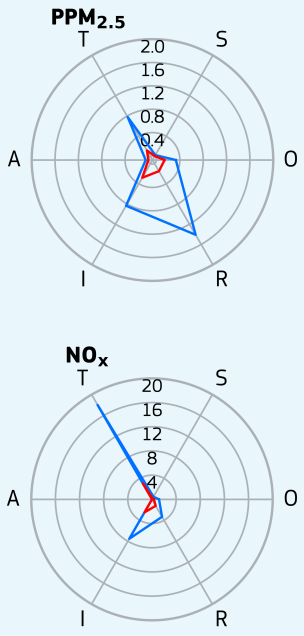
Yearly average urban concentrations (2018)

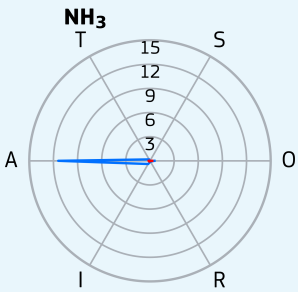


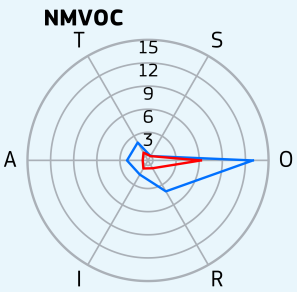
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

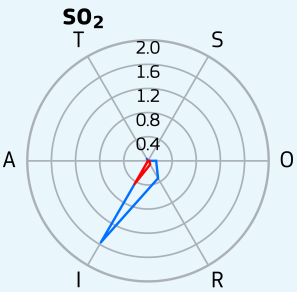


Emissions [kton/year]



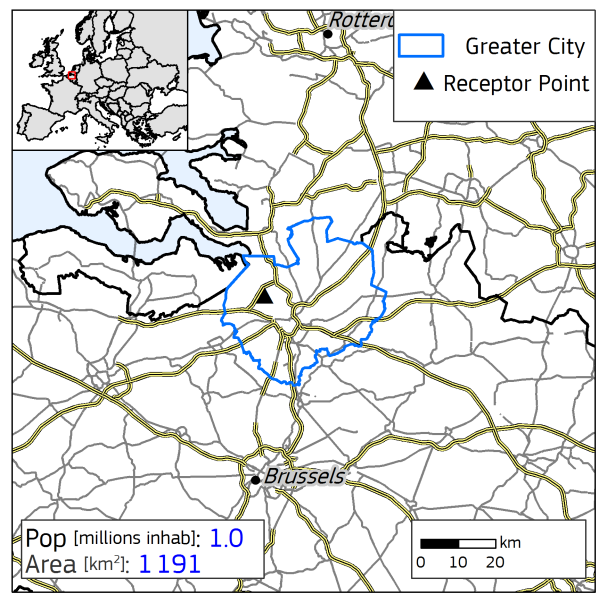




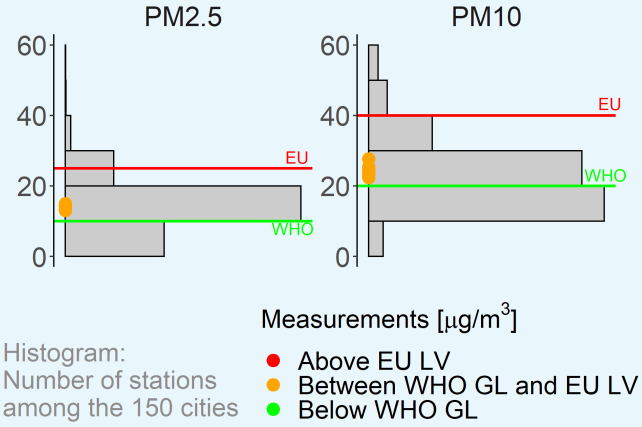


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

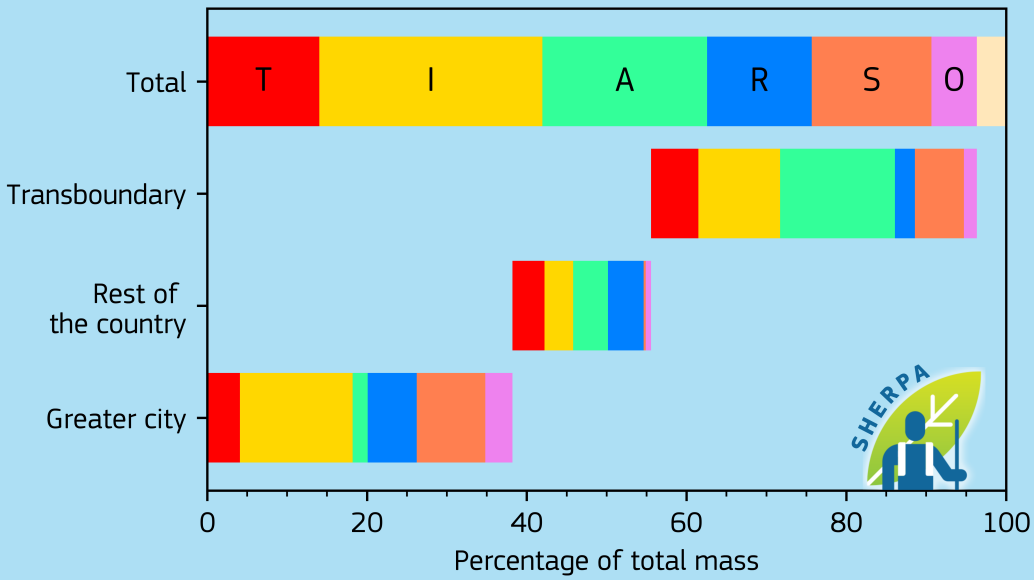
Belgium, Antwerp



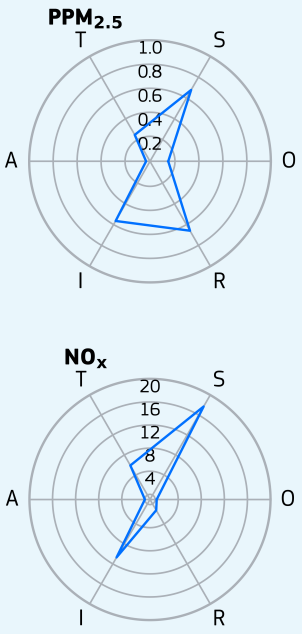
Yearly average urban concentrations (2018)

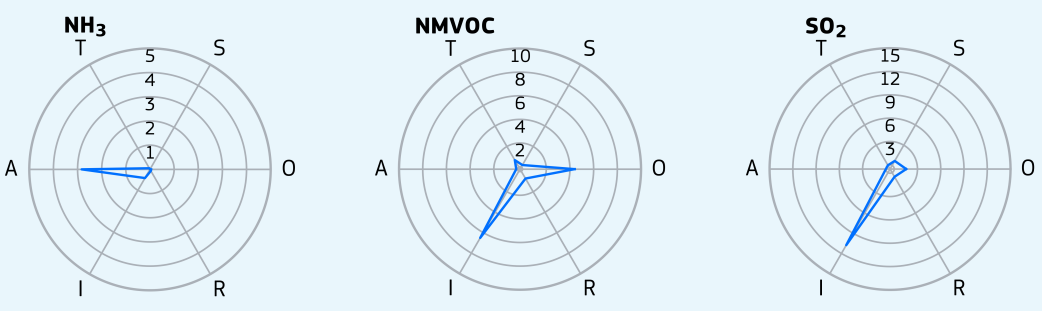


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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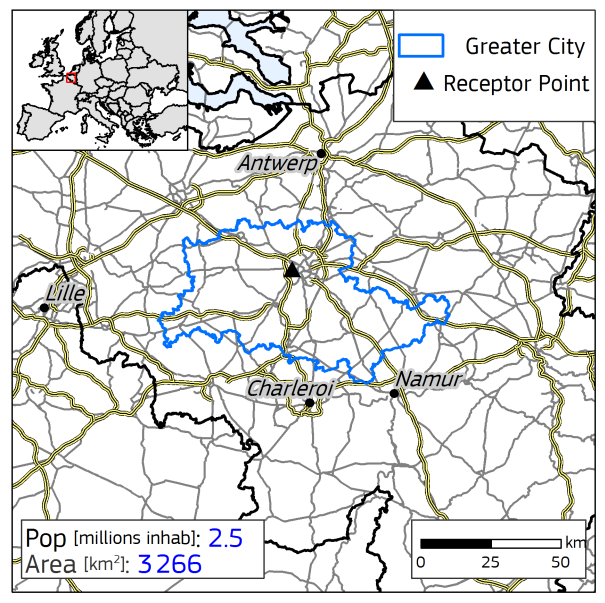
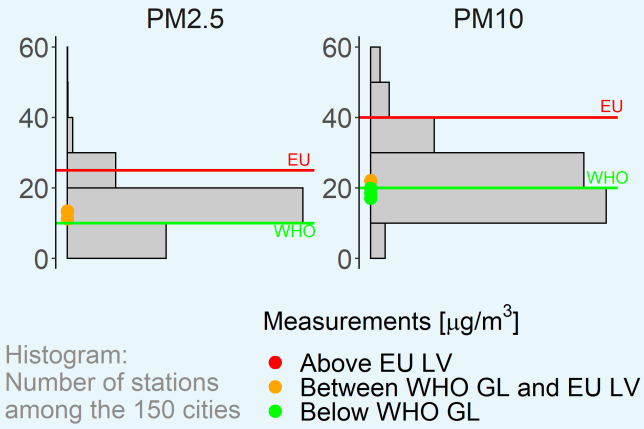
O - Other
N - Natural
Greater city

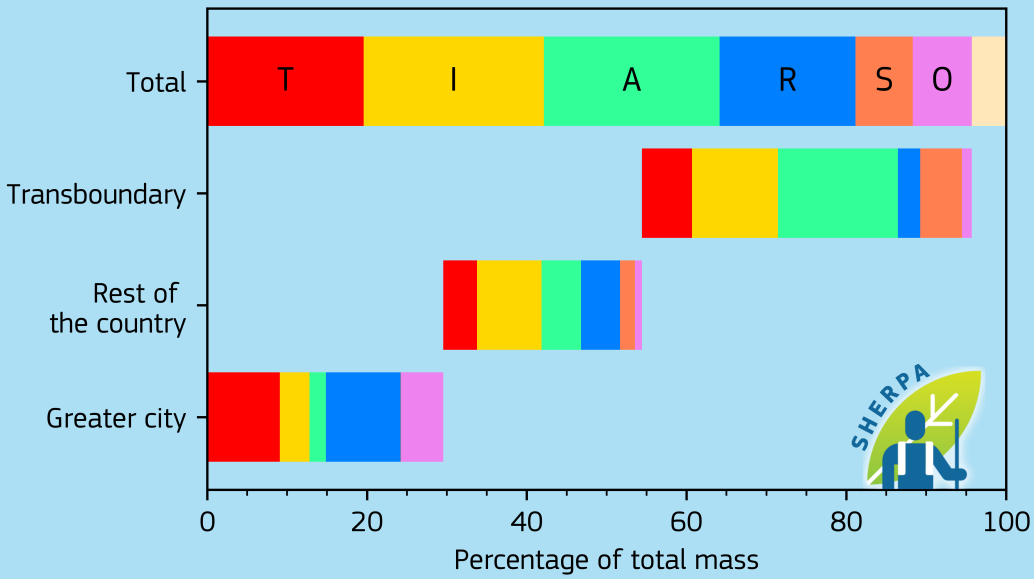
Belgium, Brussels



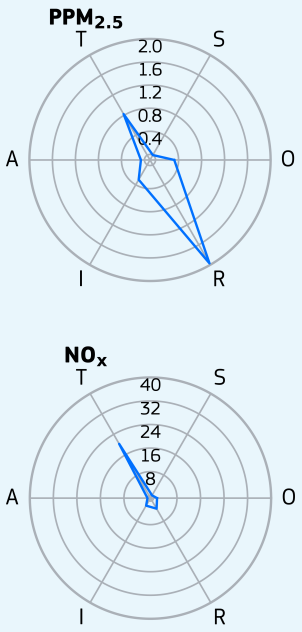
Yearly average urban concentrations (2018)

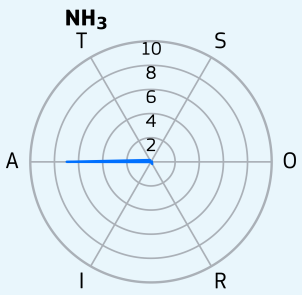


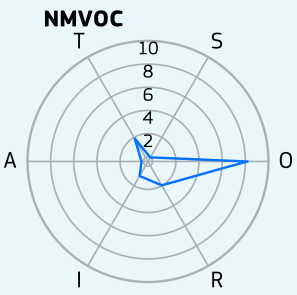
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

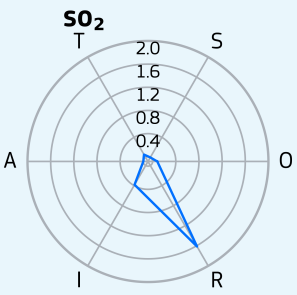


Emissions [kton/year]









T - Transport
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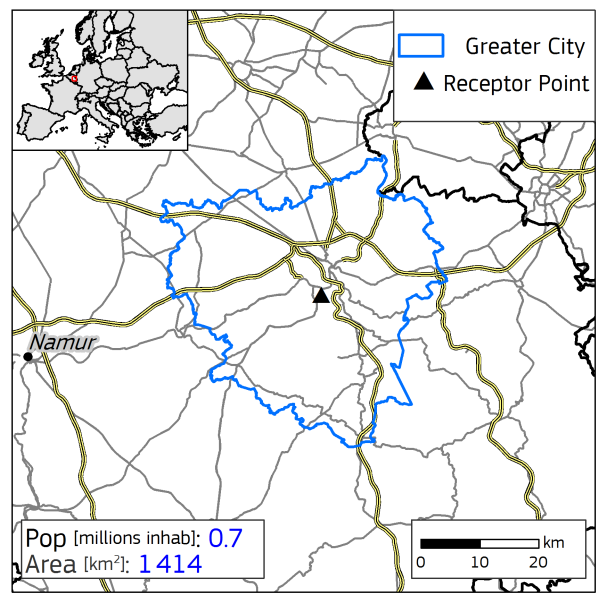
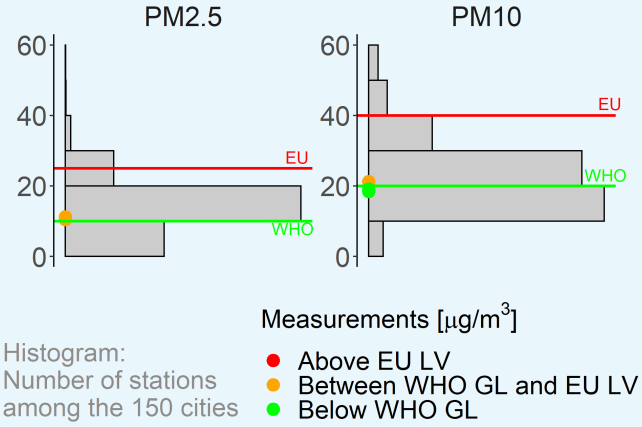
S - Shipping
O - Other
N - Natural
E - External
Greater city

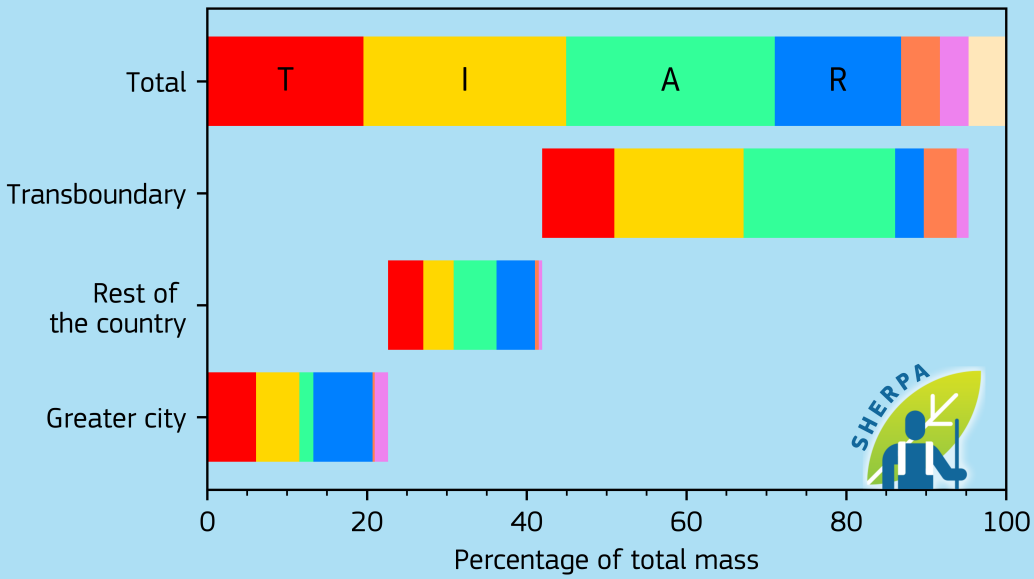
Belgium, Liege



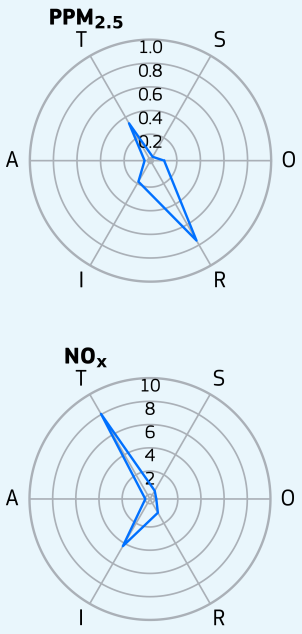
Yearly average urban concentrations (2018)

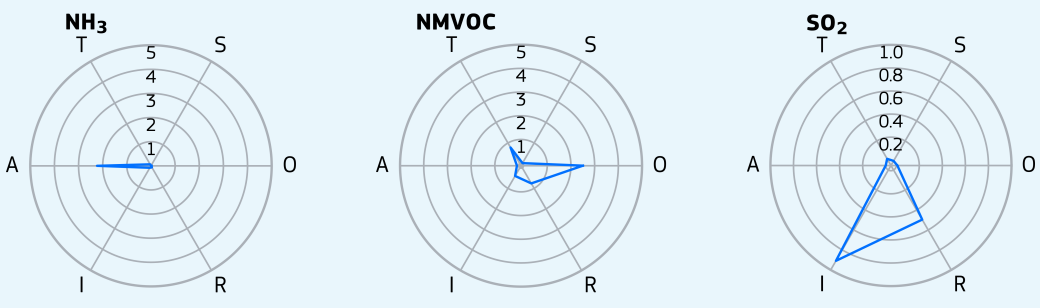


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



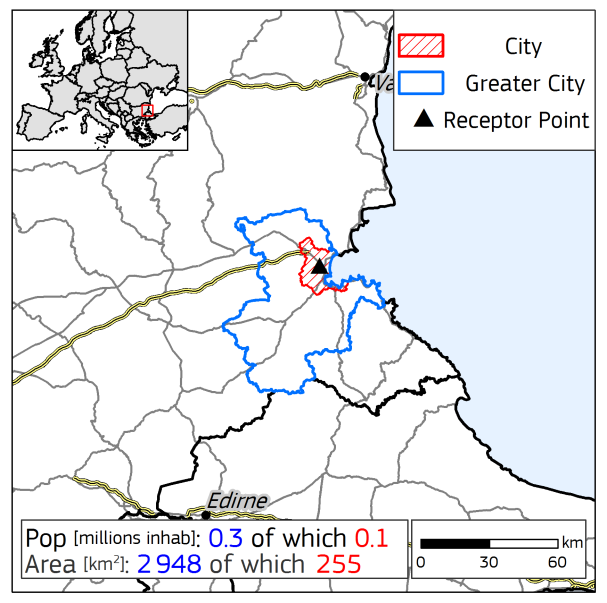
Emissions [kton/year]



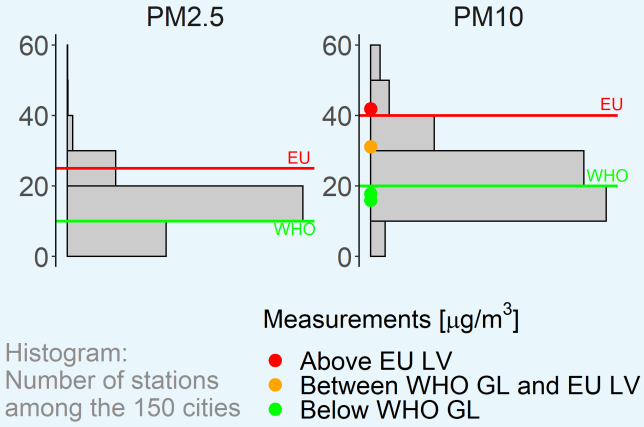




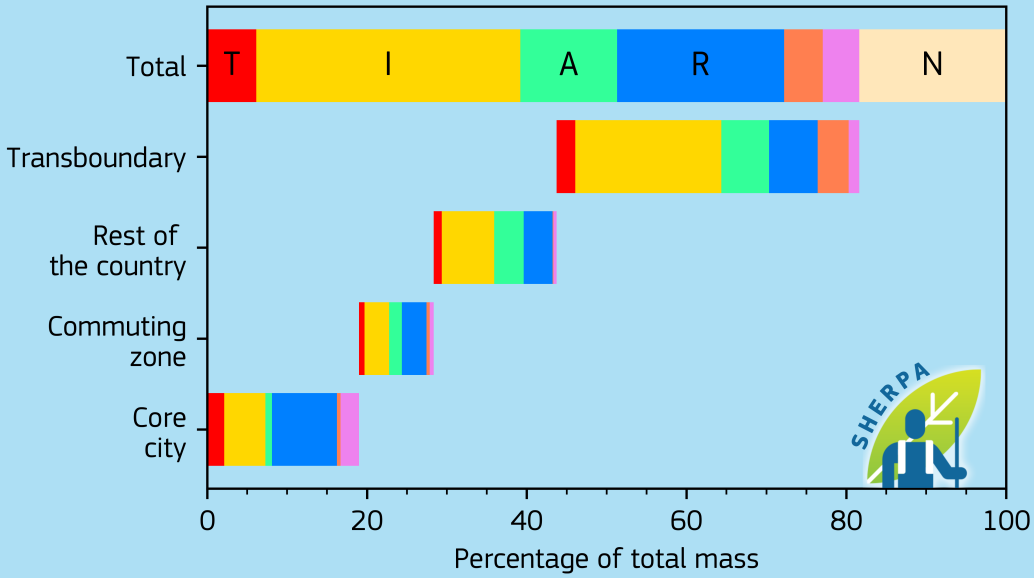
Bulgaria, Burgas



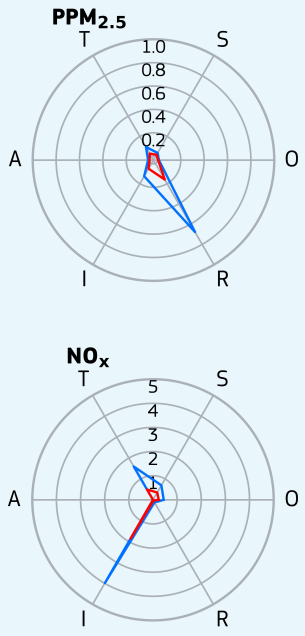
Yearly average urban concentrations (2018)

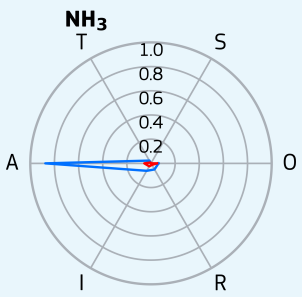


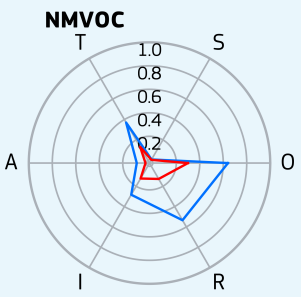
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

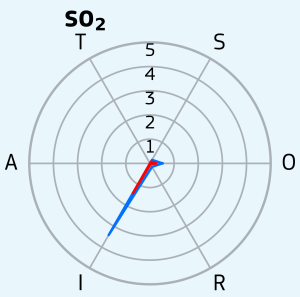


Emissions [kton/year]









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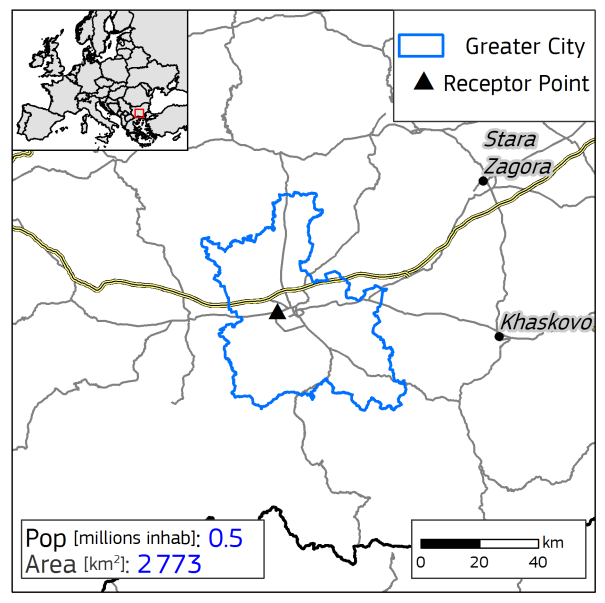
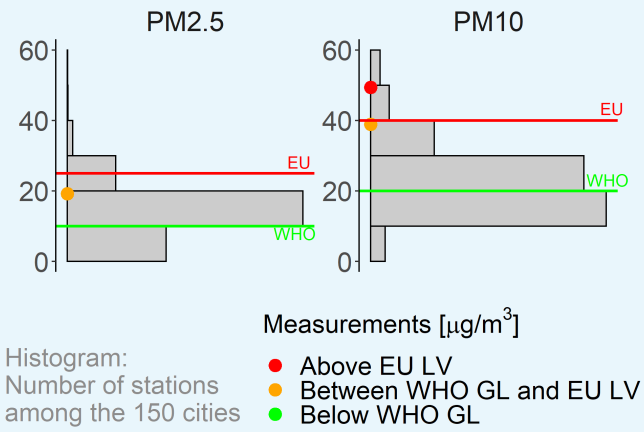
- Greater city
- Core city

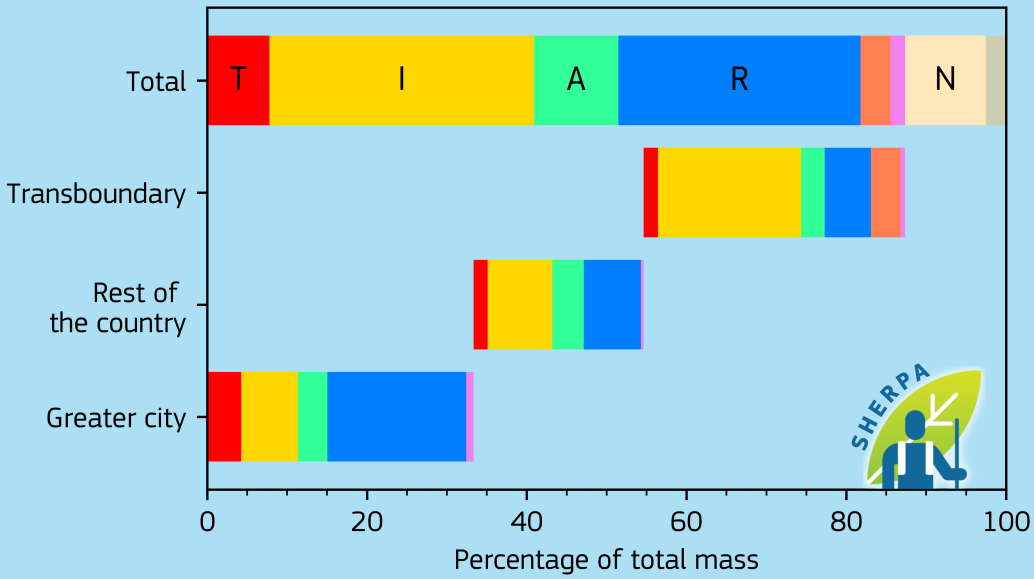
Bulgaria, Plovdiv



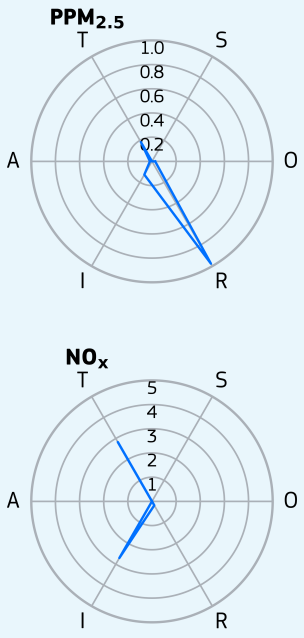
Yearly average urban concentrations (2018)

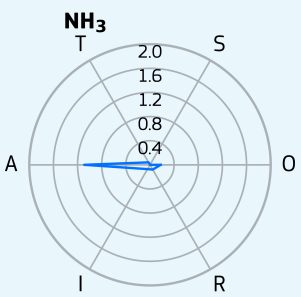


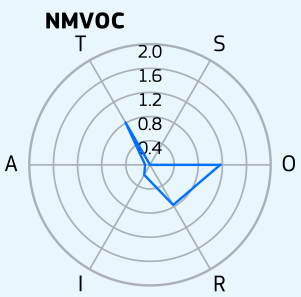
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

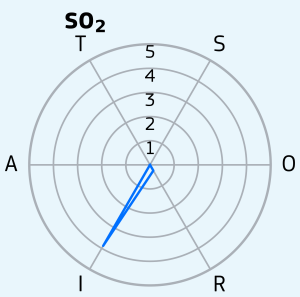


Emissions [kton/year]









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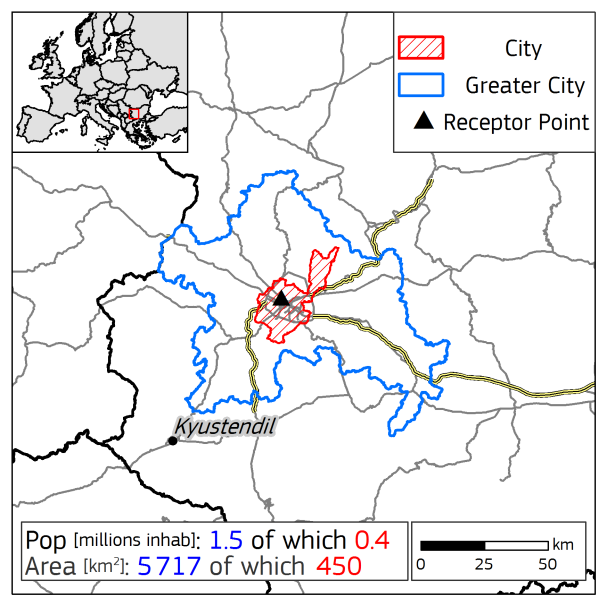
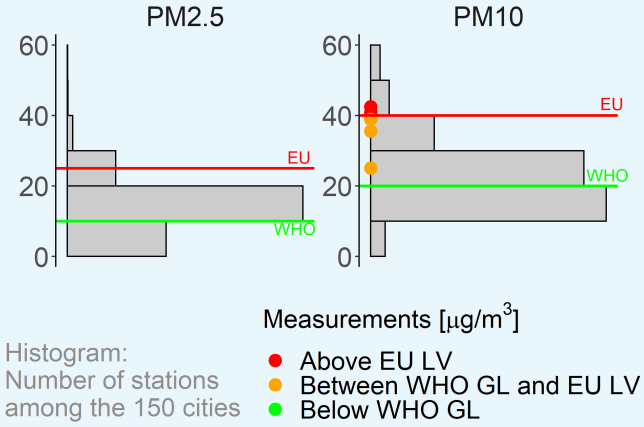
- Greater city

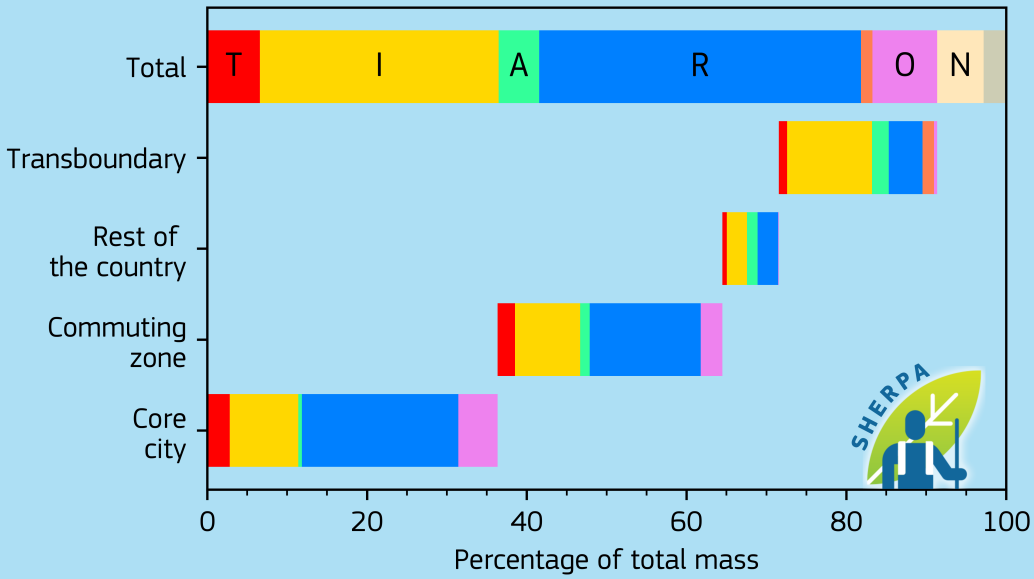
Bulgaria, Sofia



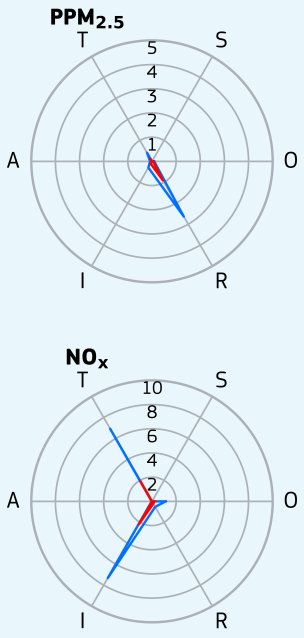
Yearly average urban concentrations (2018)

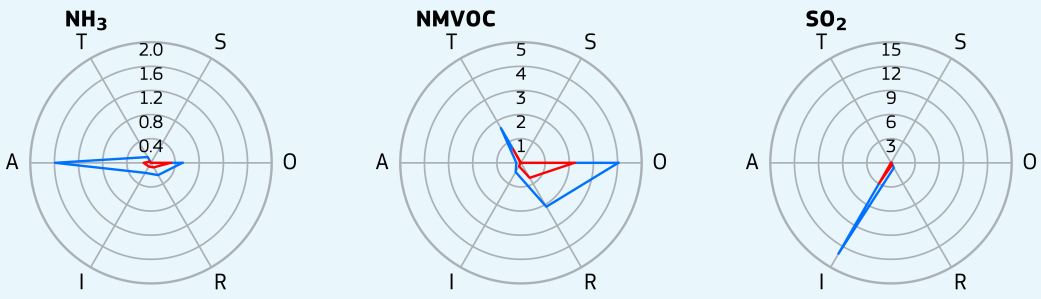


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



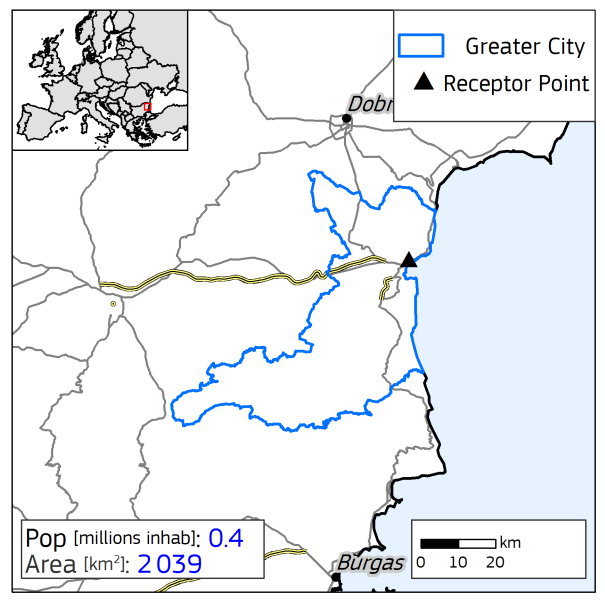
Emissions [kton/year]



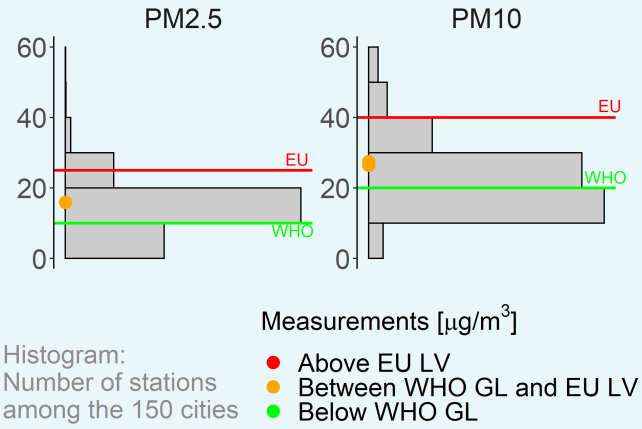


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

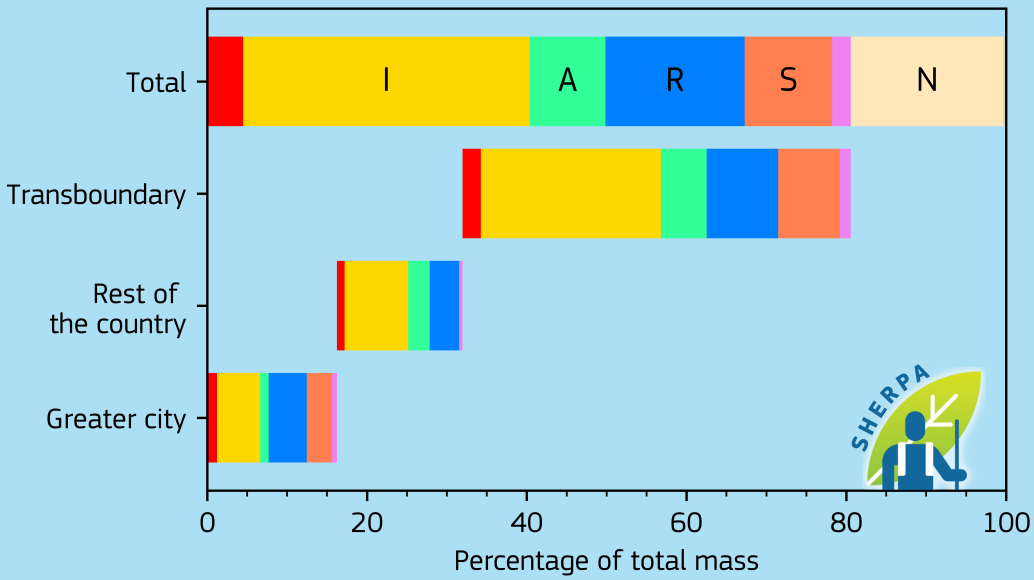
Bulgaria, Varna



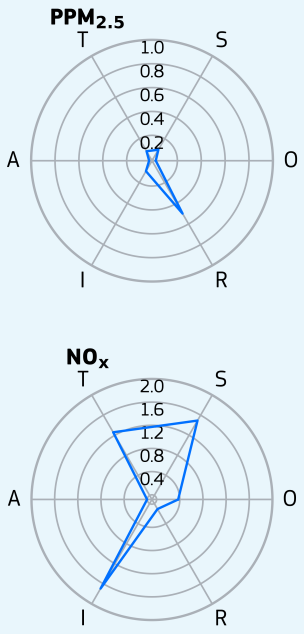
Yearly average urban concentrations (2018)

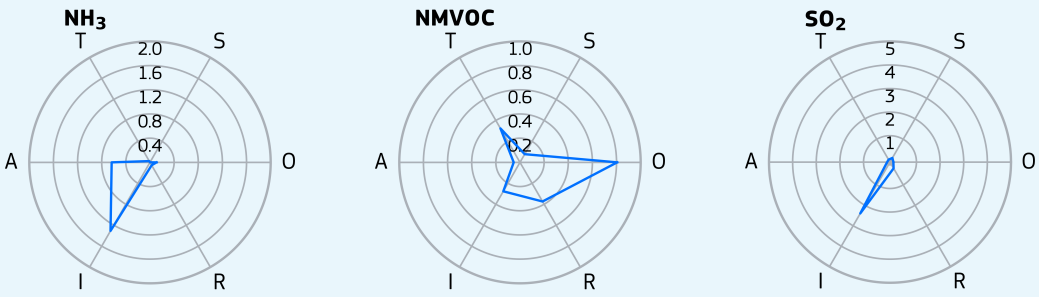


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



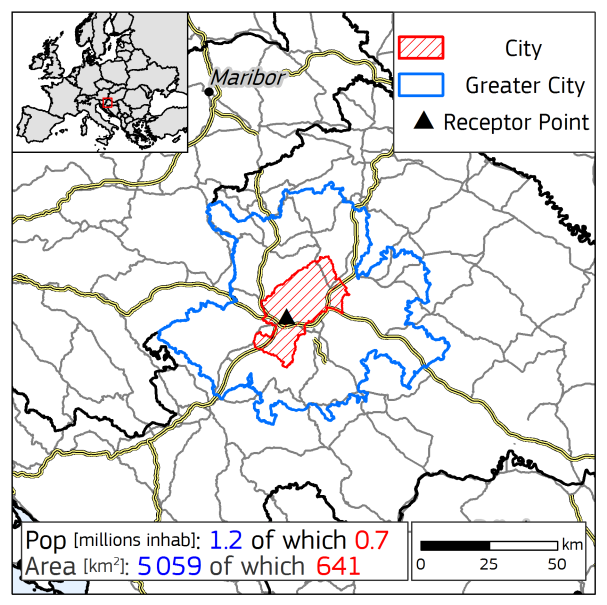
Emissions [kton/year]



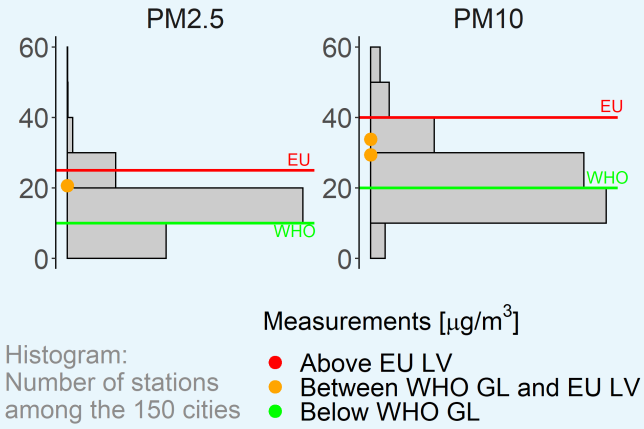


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

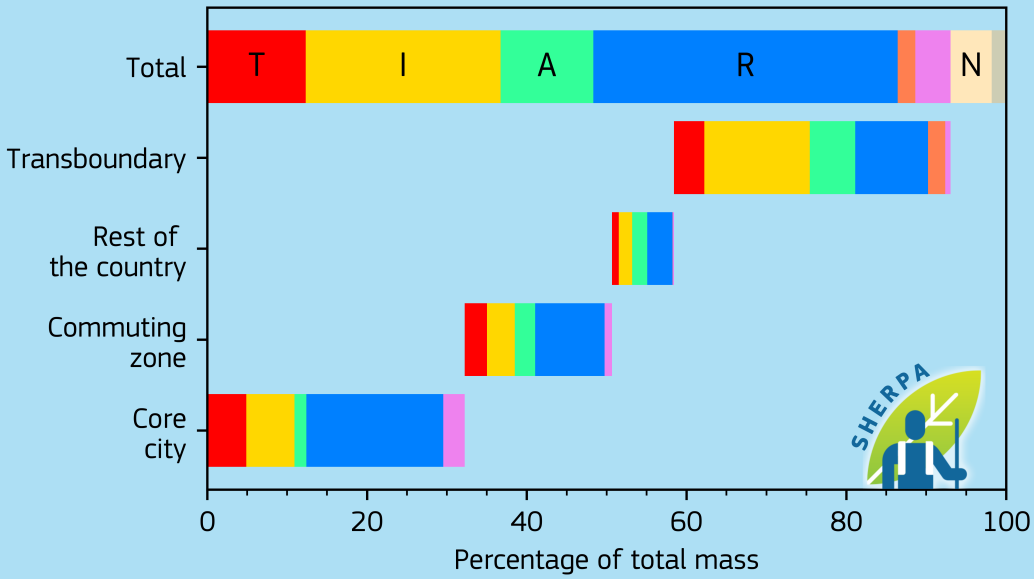
Croatia, Zagreb



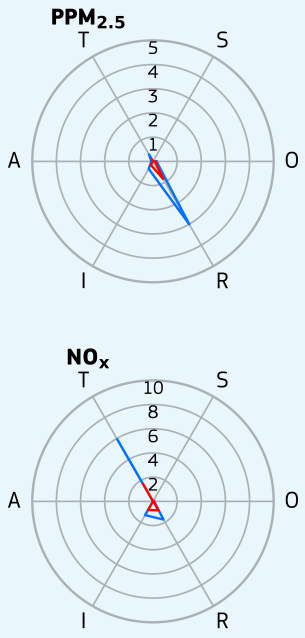
Yearly average urban concentrations (2018)

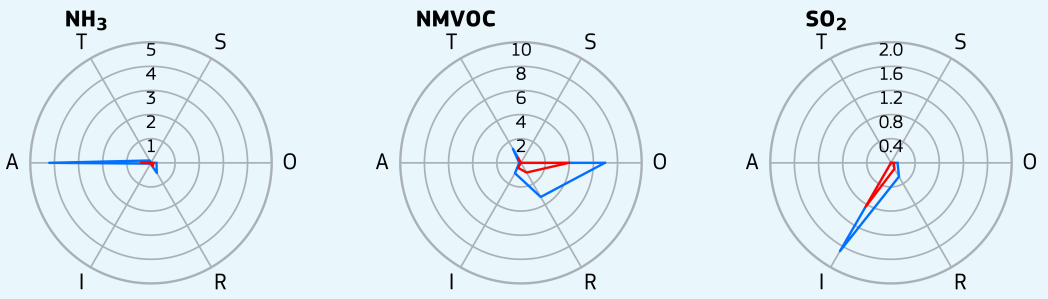


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



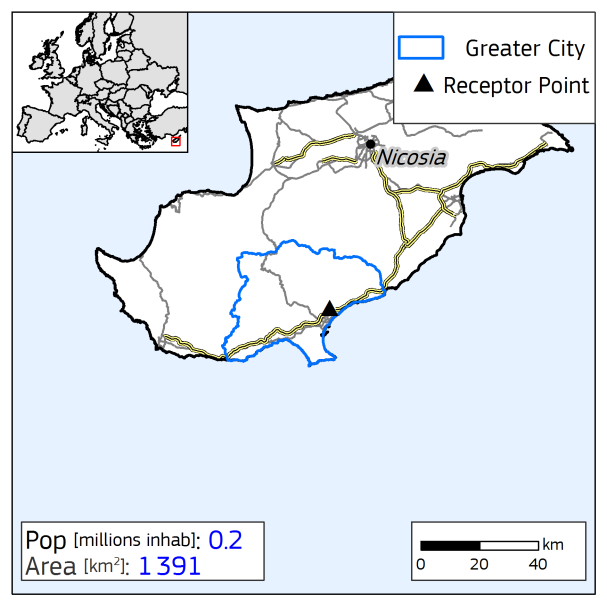
Emissions [kton/year]



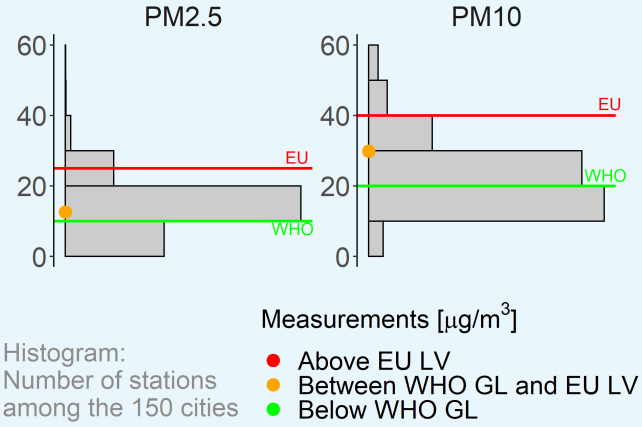


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

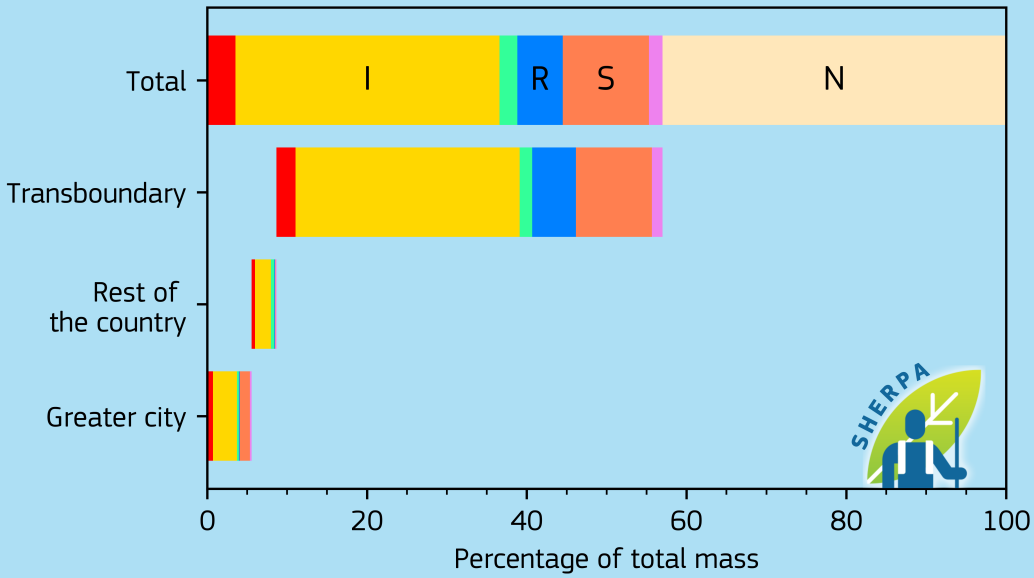
Cyprus, Limassol



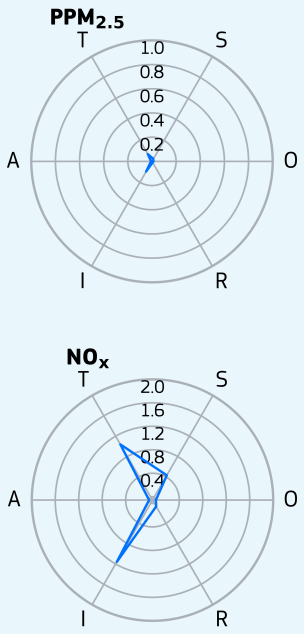
Yearly average urban concentrations (2018)

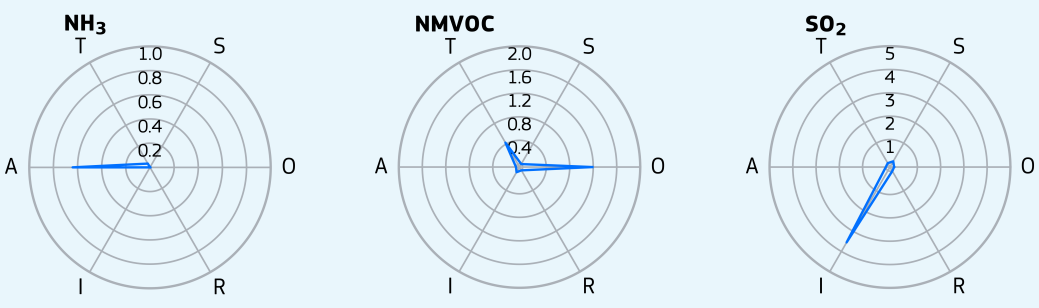


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]



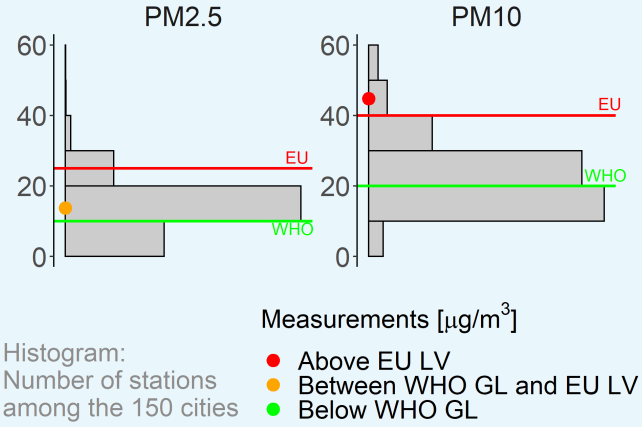


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

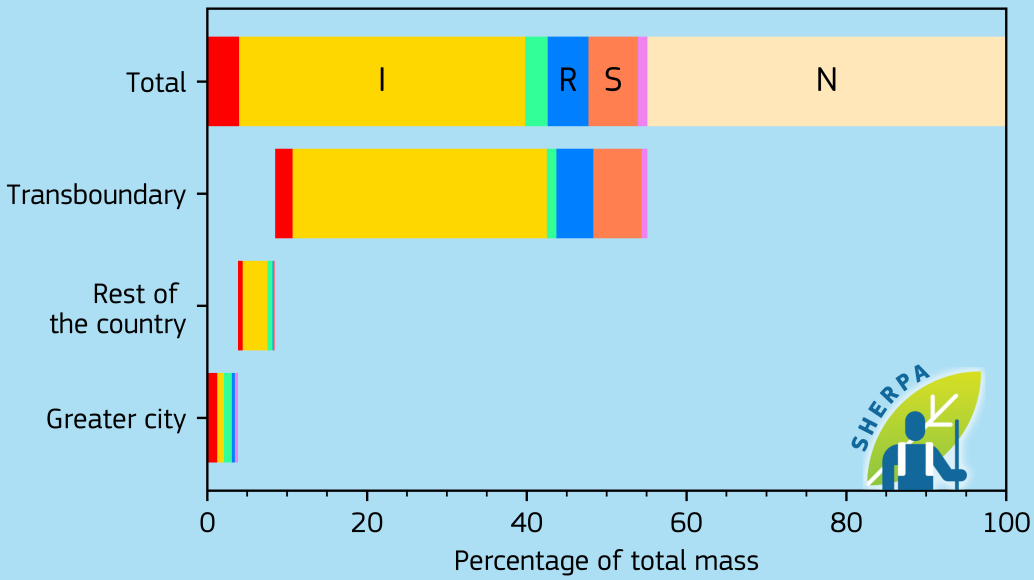
Cyprus, Nicosia



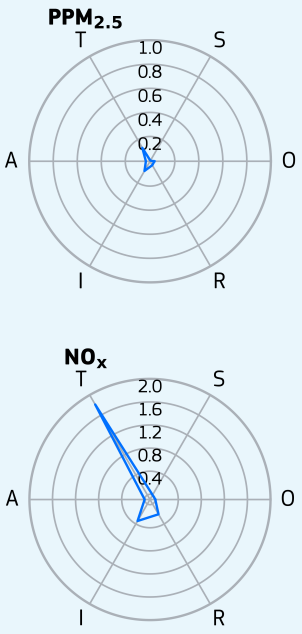
Yearly average urban concentrations (2018)

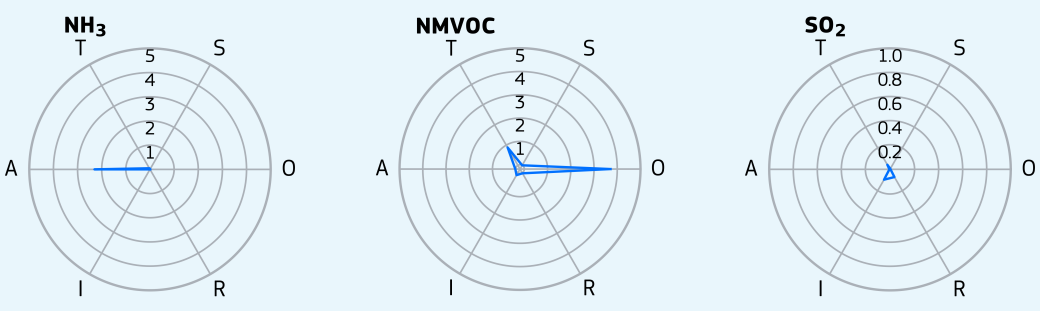


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



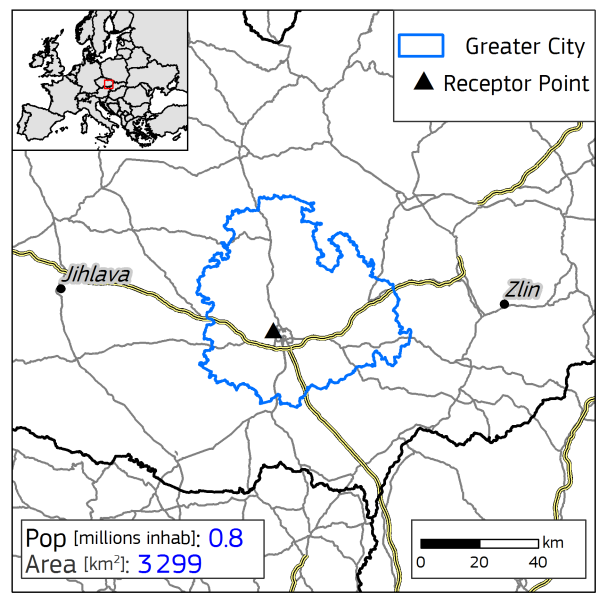
Emissions [kton/year]



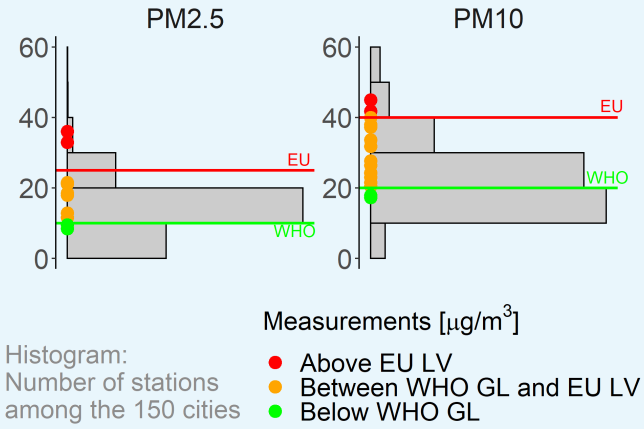


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

Czech Republic, Brno

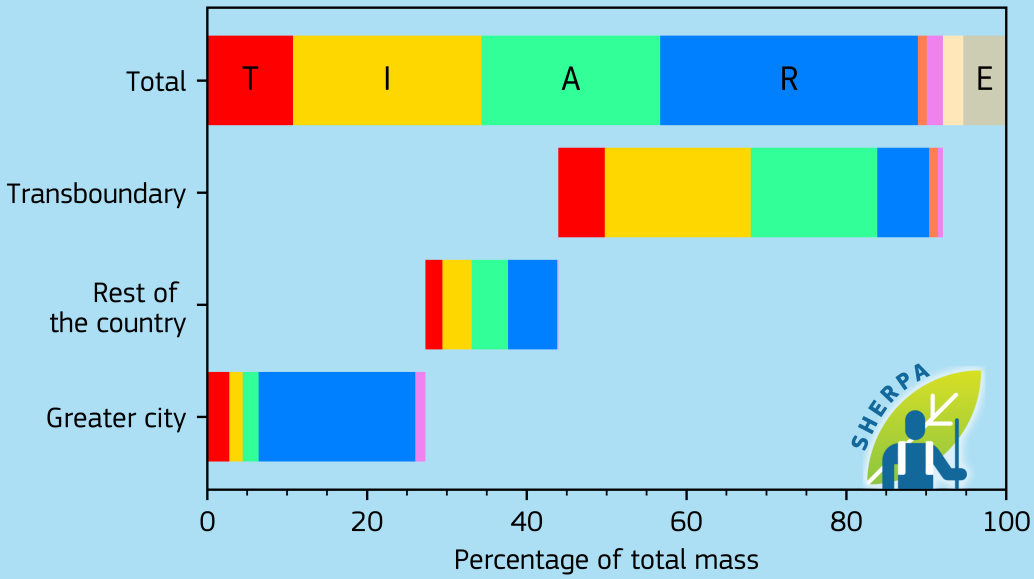


Yearly average urban concentrations (2018)

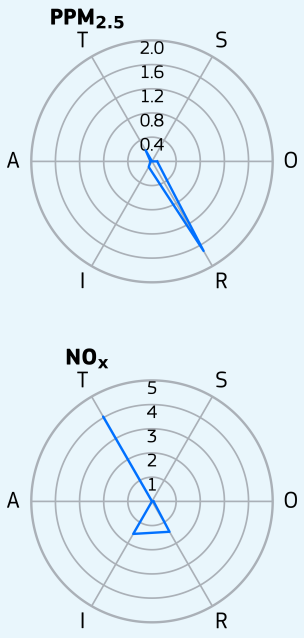


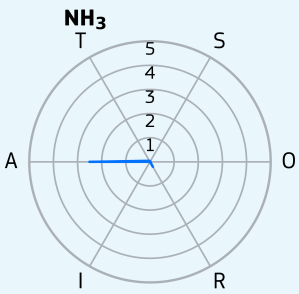
Histogram:
Number of stations
among the 150 cities

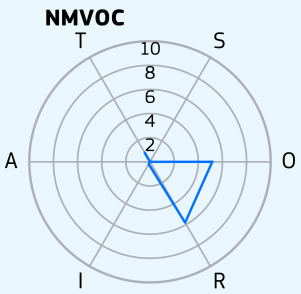
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

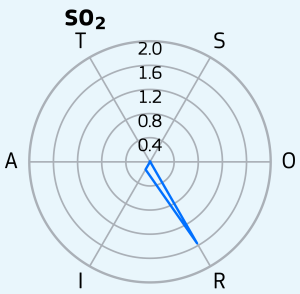


Emissions [kton/year]



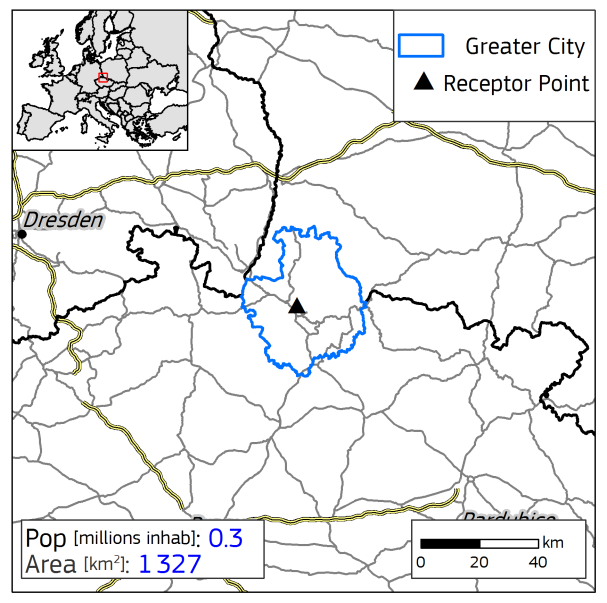




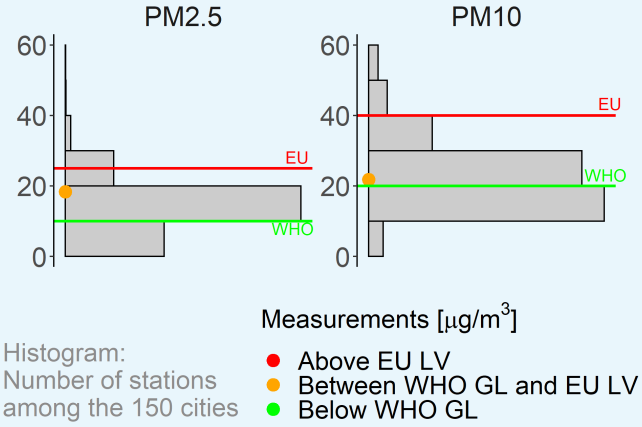


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

Czech Republic, Liberec

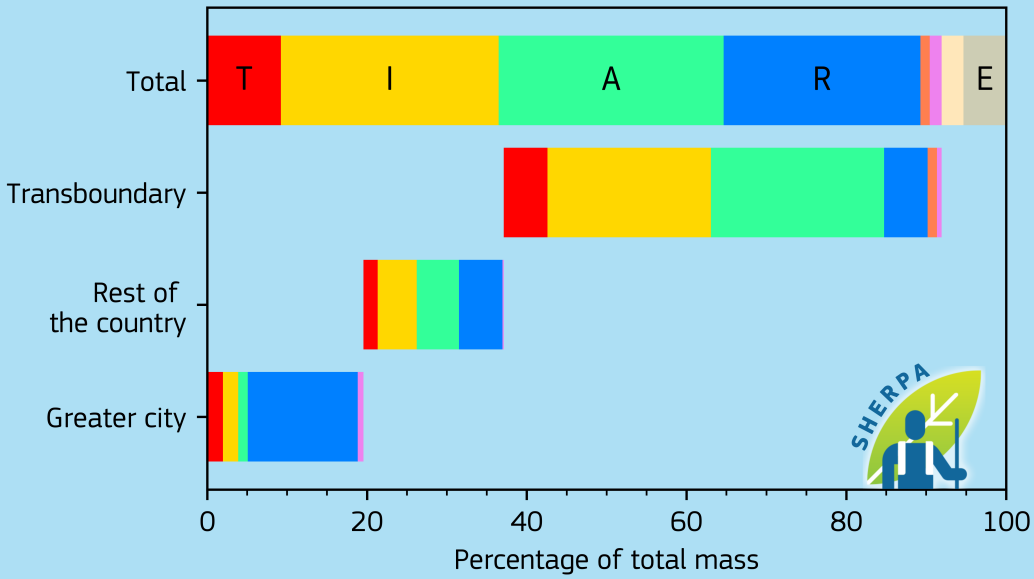


Yearly average urban concentrations (2018)

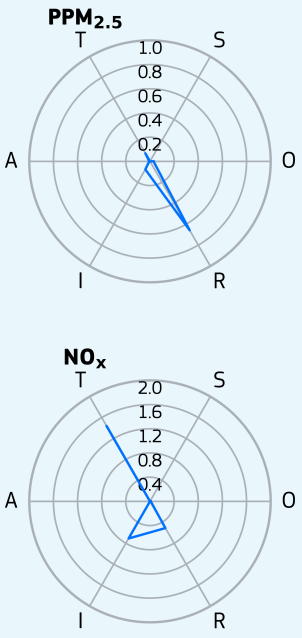


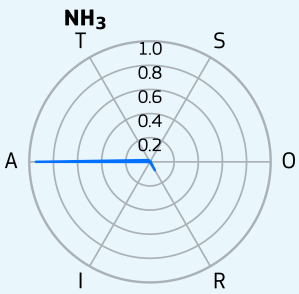
Histogram:
Number of stations
among the 150 cities

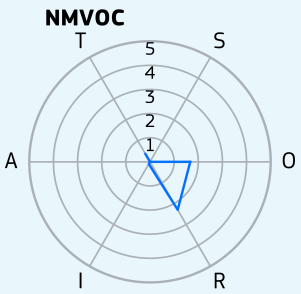
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

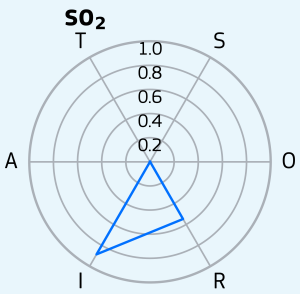


Emissions [kton/year]



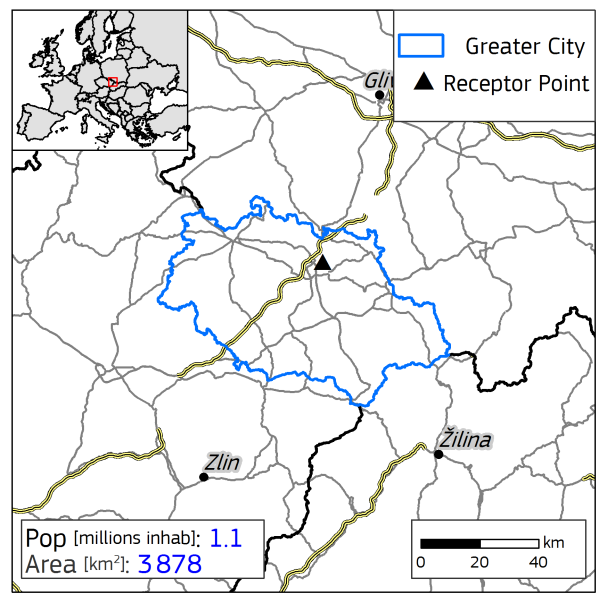




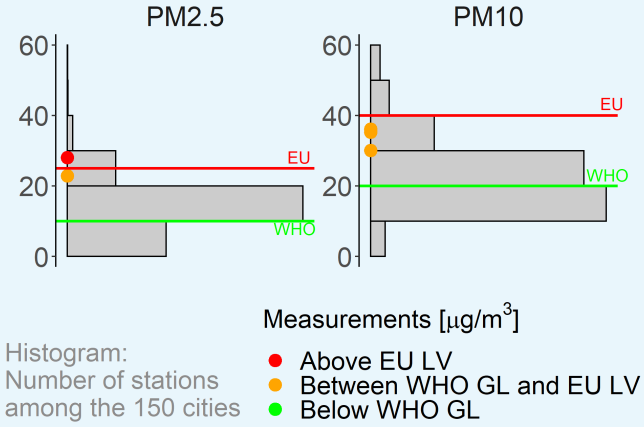


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

Czech Republic, Ostrava

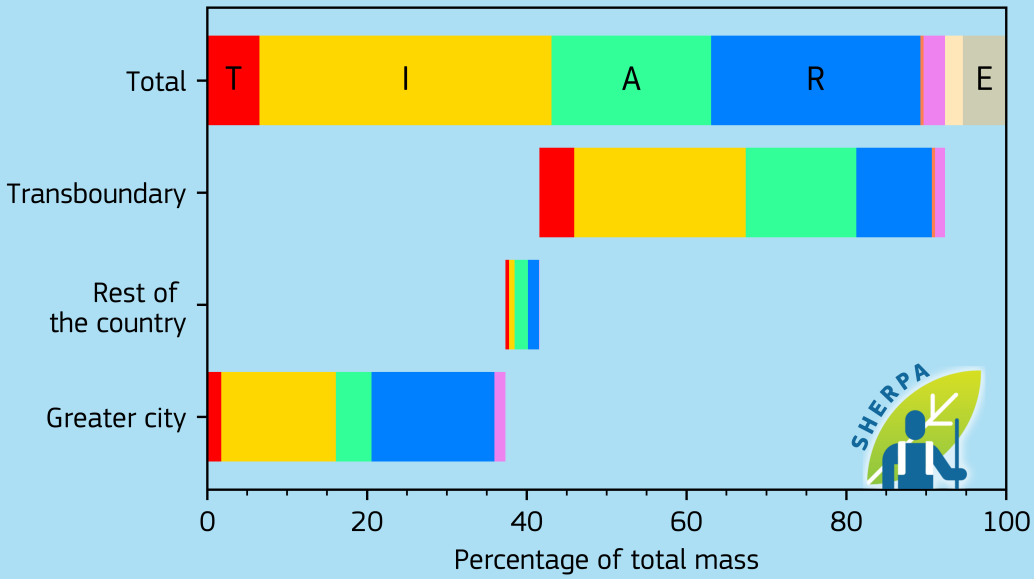


Yearly average urban concentrations (2018)

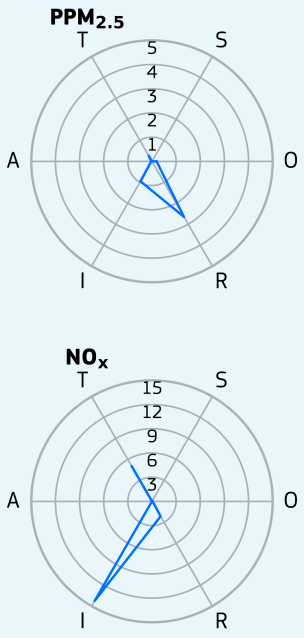


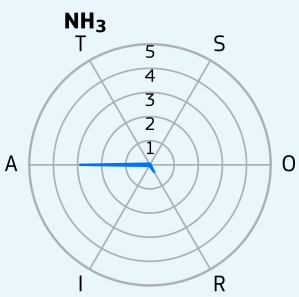
Histogram:
Number of stations
among the 150 cities

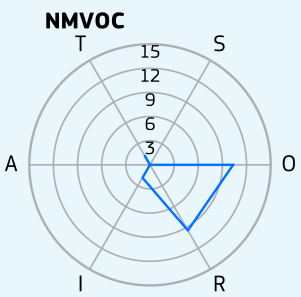
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

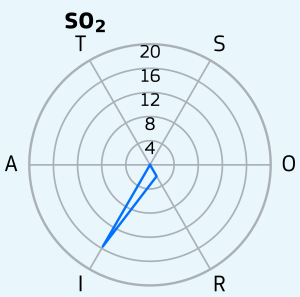


Emissions [kton/year]









- T - Transport
- I - Industry
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- N - Natural
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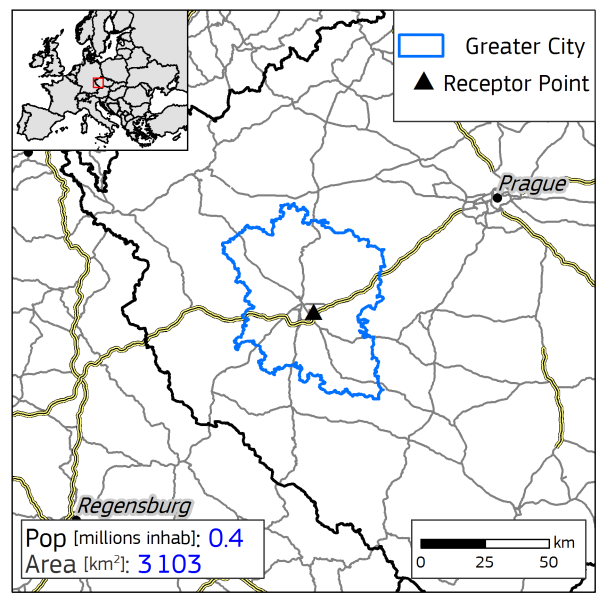
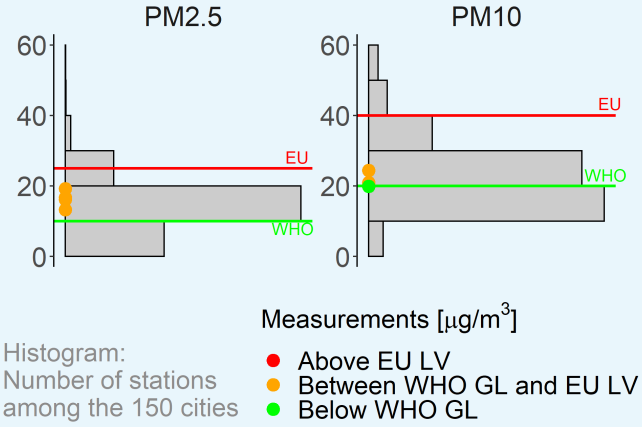
- Greater city

Czech Republic, Pilsen

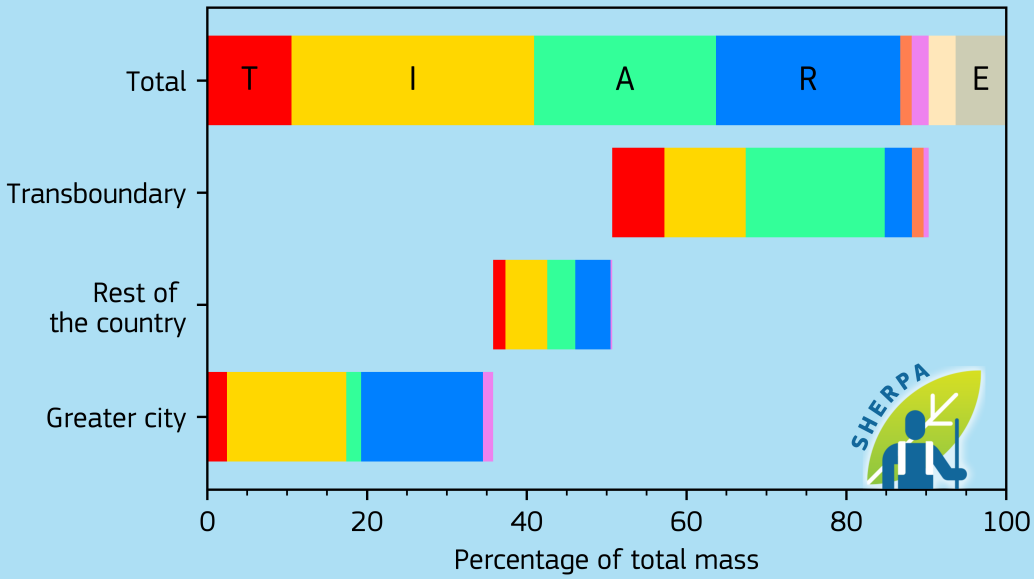


Yearly average urban concentrations (2018)

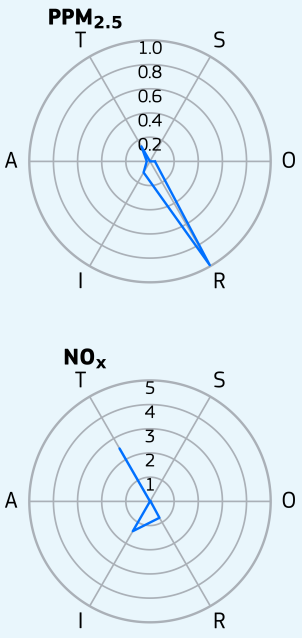


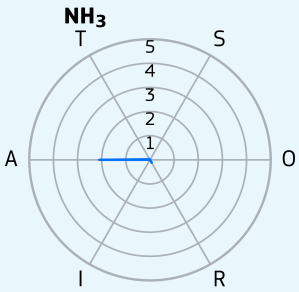
Histogram:
Number of stations
among the 150 cities

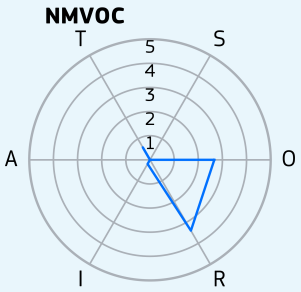
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

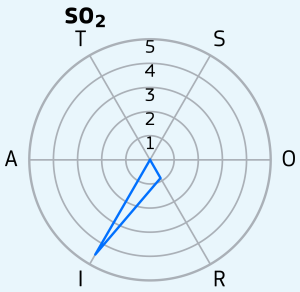


Emissions [kton/year]









- T - Transport
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- A - Agriculture
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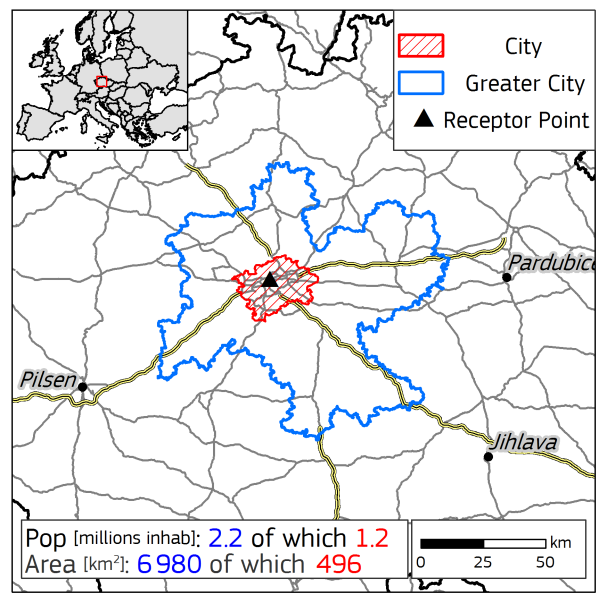
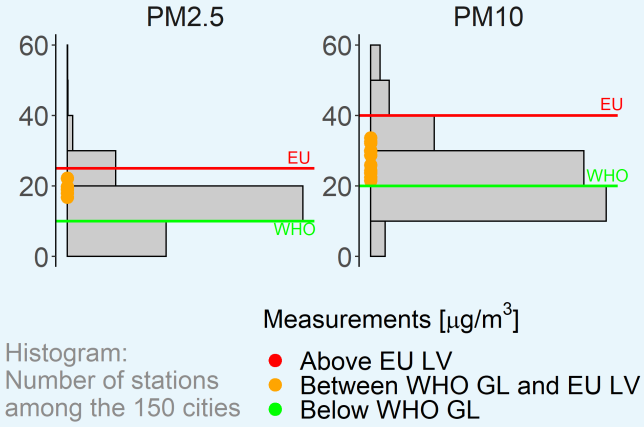
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

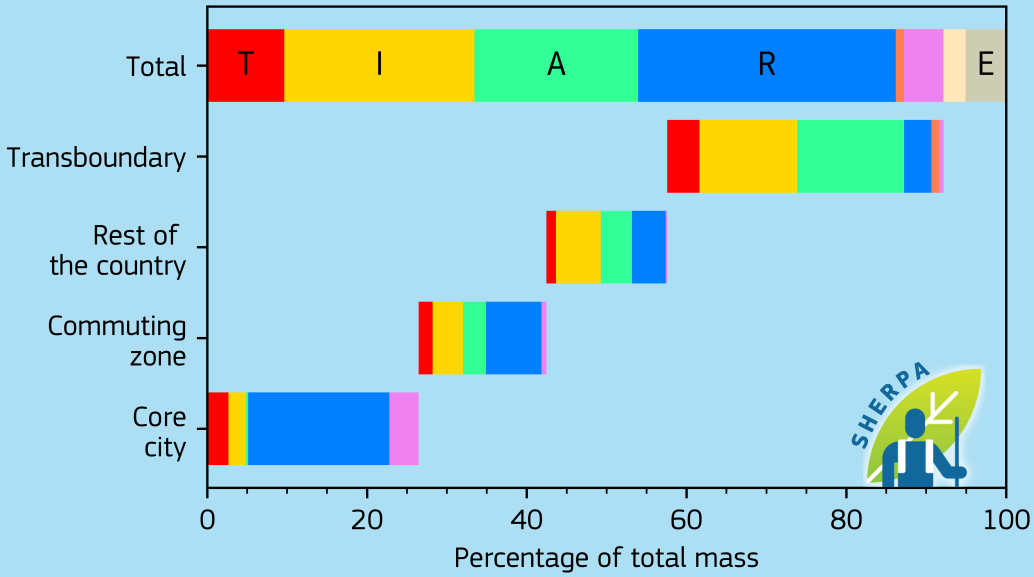
Czech Republic, Prague



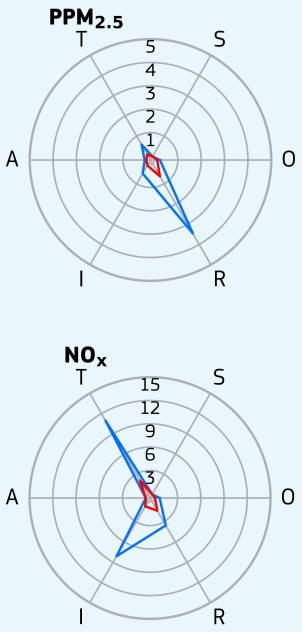
Yearly average urban concentrations (2018)

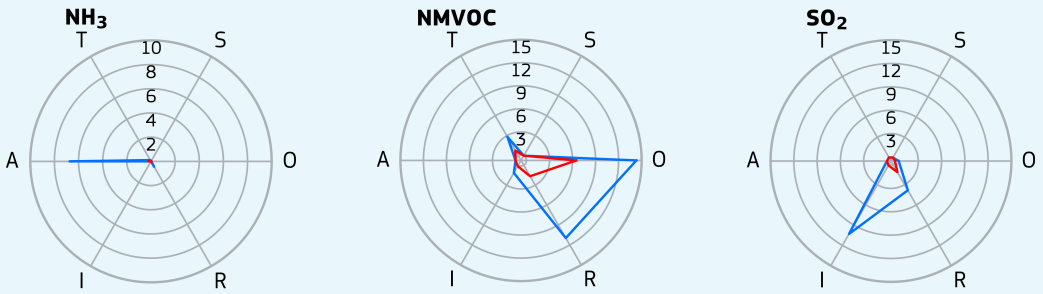


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



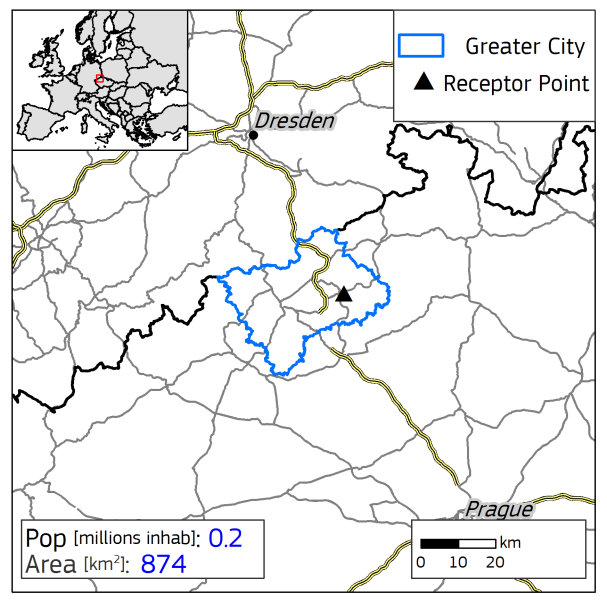
Emissions [kton/year]



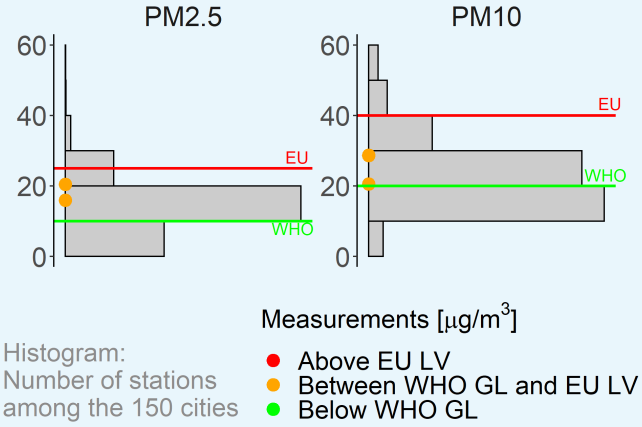




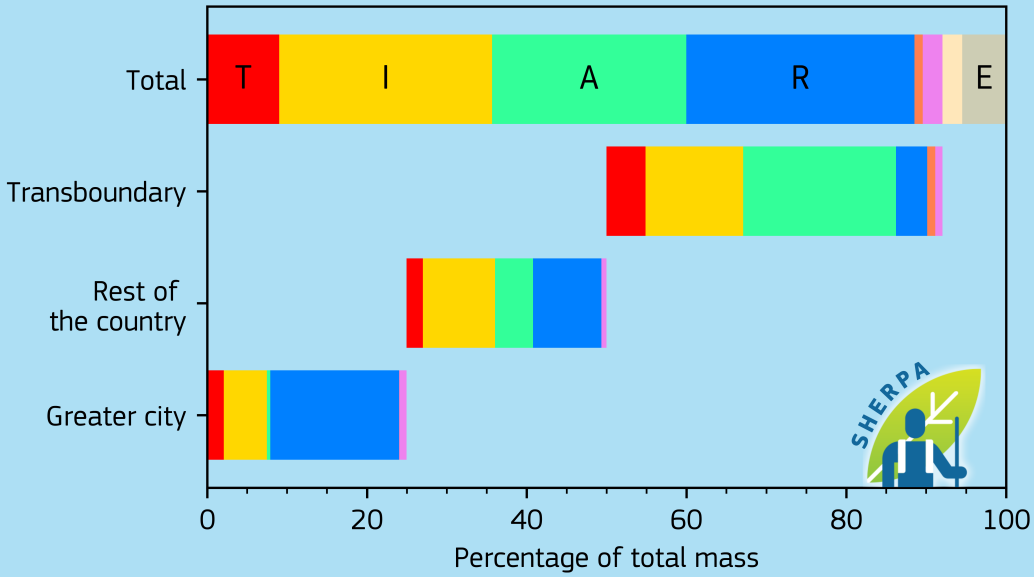
Czech Republic, Ústí nad Labem



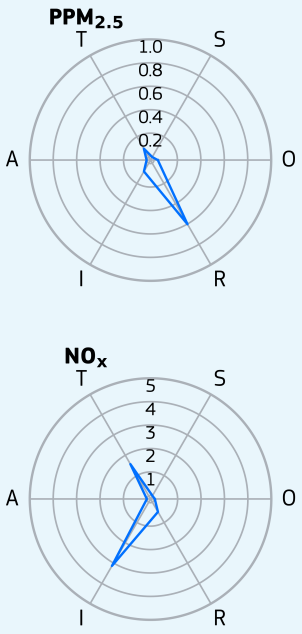
Yearly average urban concentrations (2018)

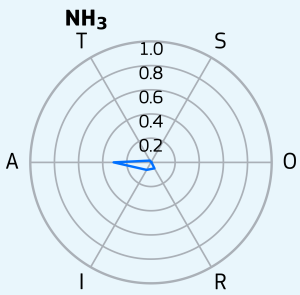


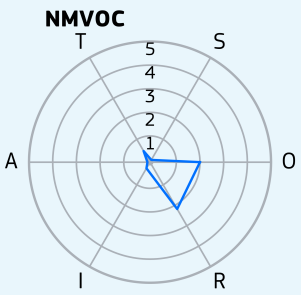
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

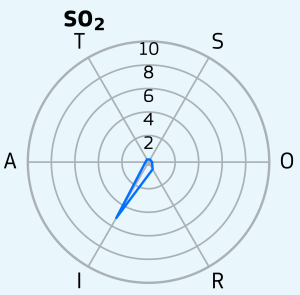


Emissions [kton/year]



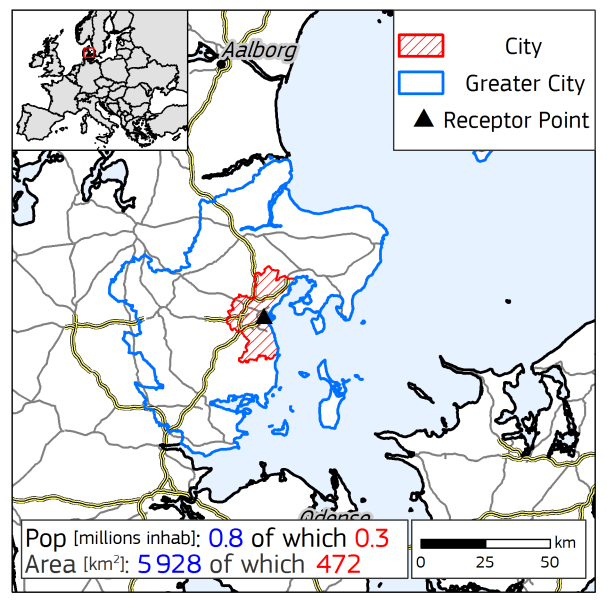




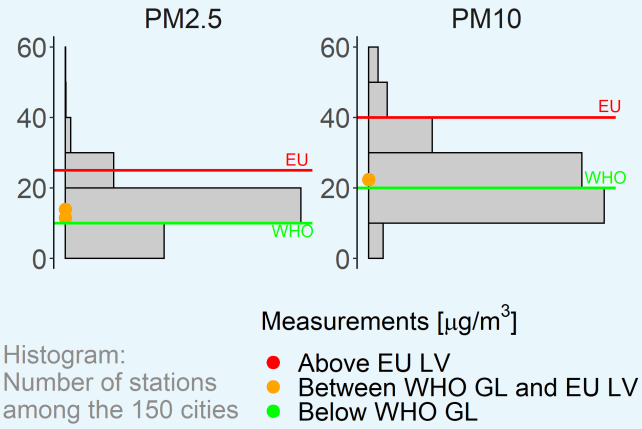


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

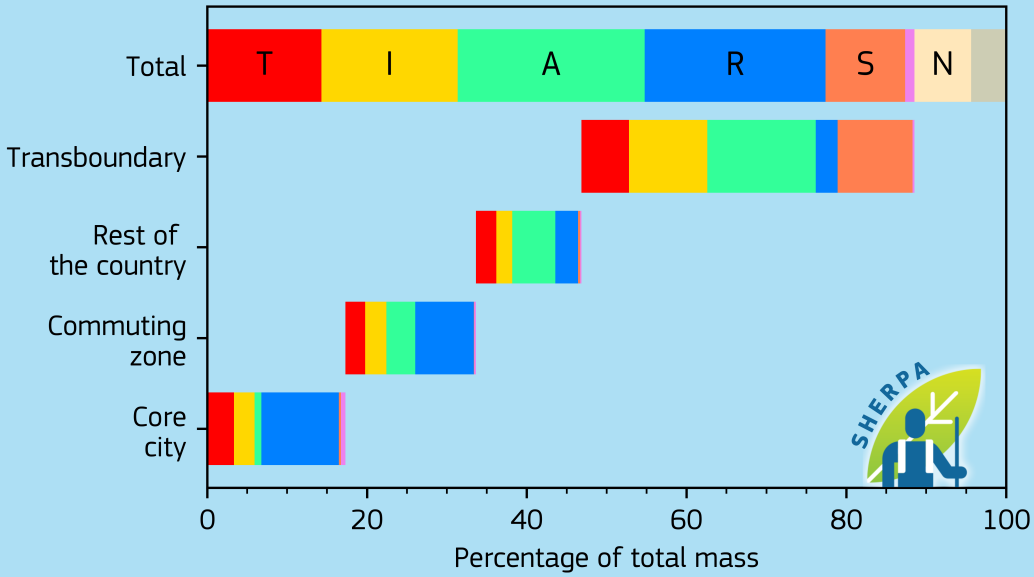
Denmark, Aarhus



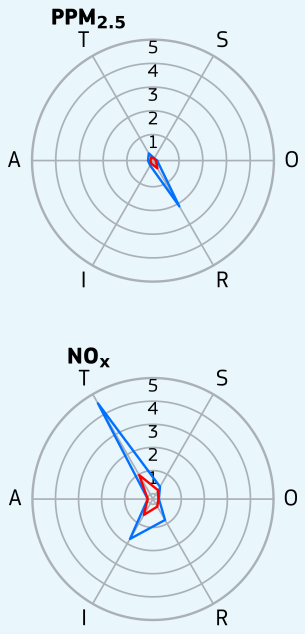
Yearly average urban concentrations (2018)

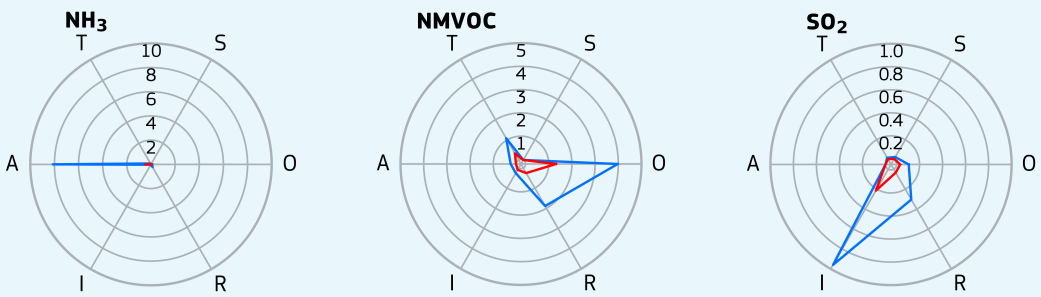


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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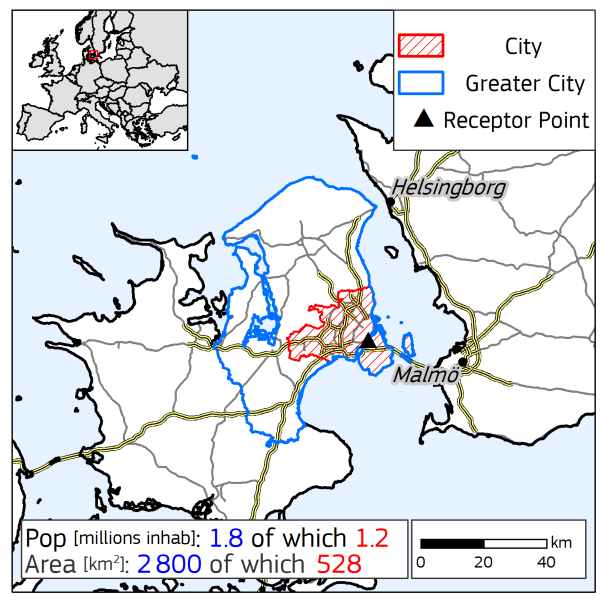
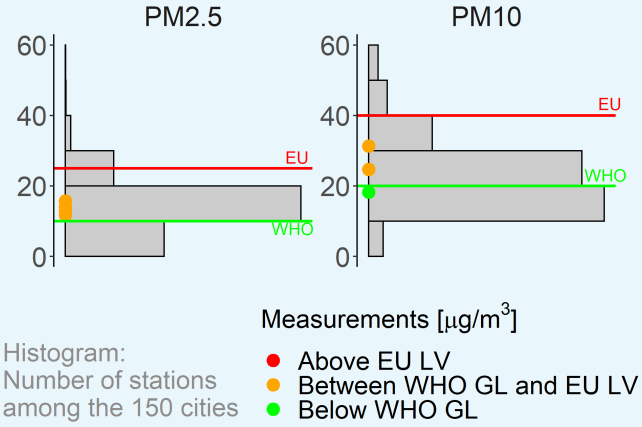
- Greater city
- Core city

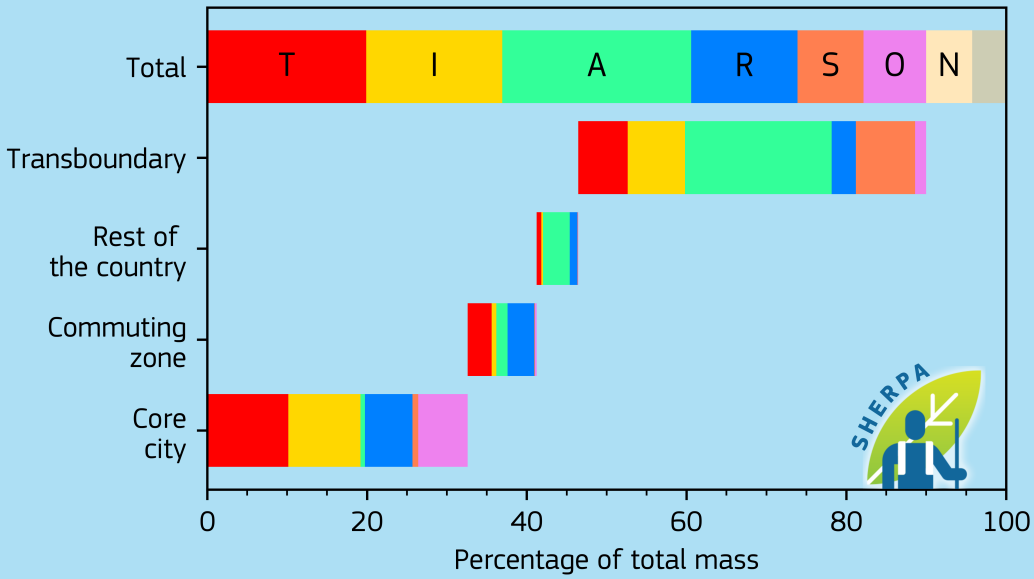
Denmark, Copenhagen



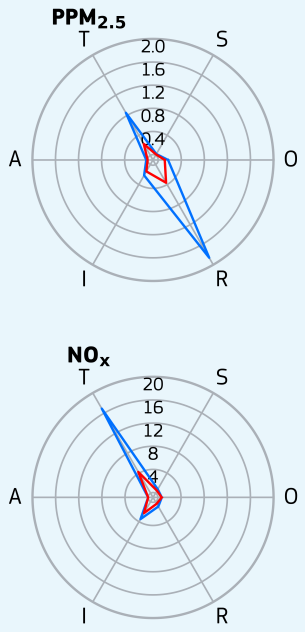
Yearly average urban concentrations (2018)

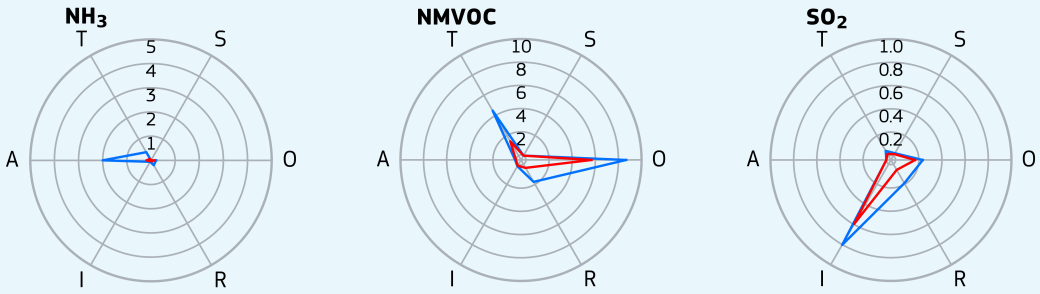


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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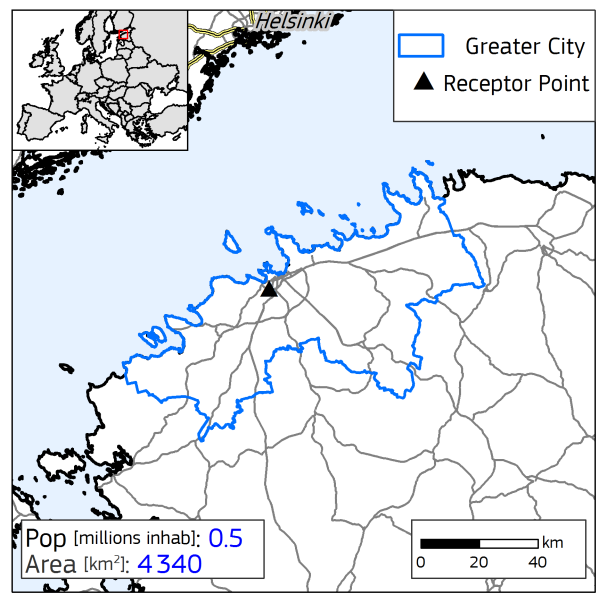
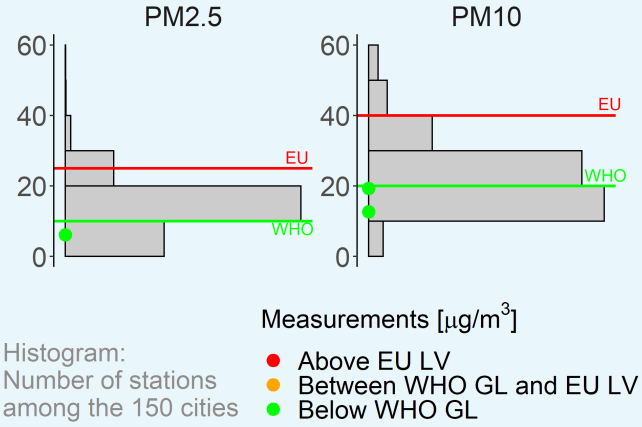
- Core city

Estonia, Tallinn

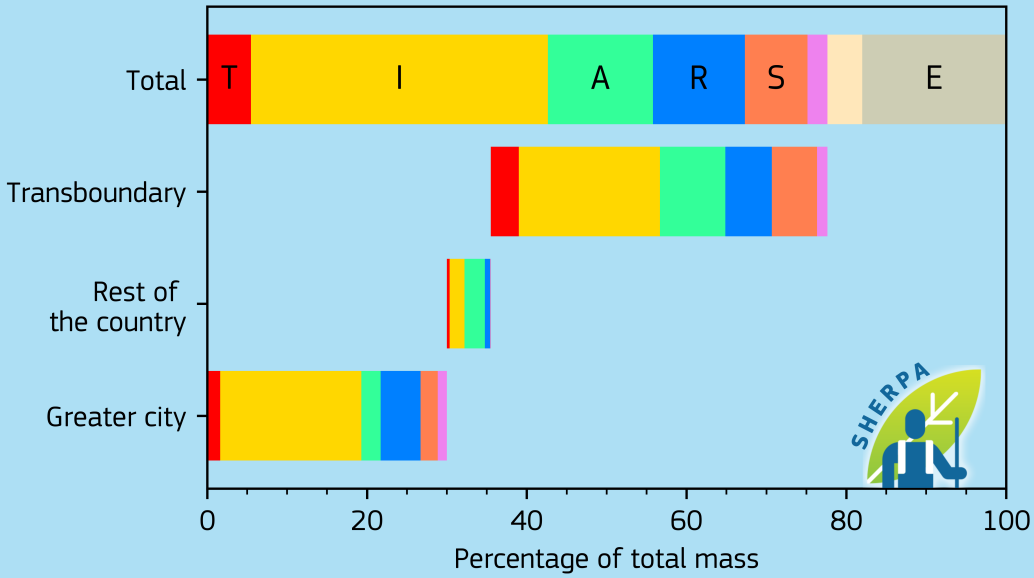


Yearly average urban concentrations (2018)

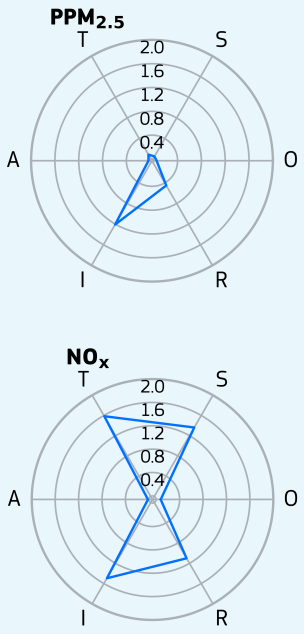


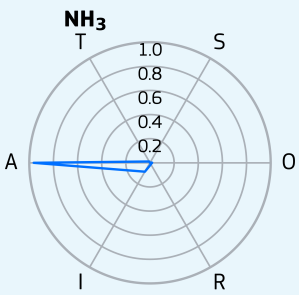
Histogram:
Number of stations
among the 150 cities

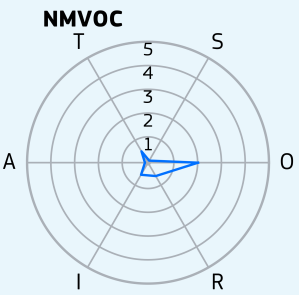
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

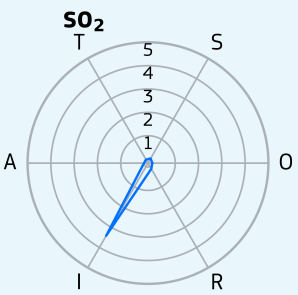


Emissions [kton/year]









- T - Transport
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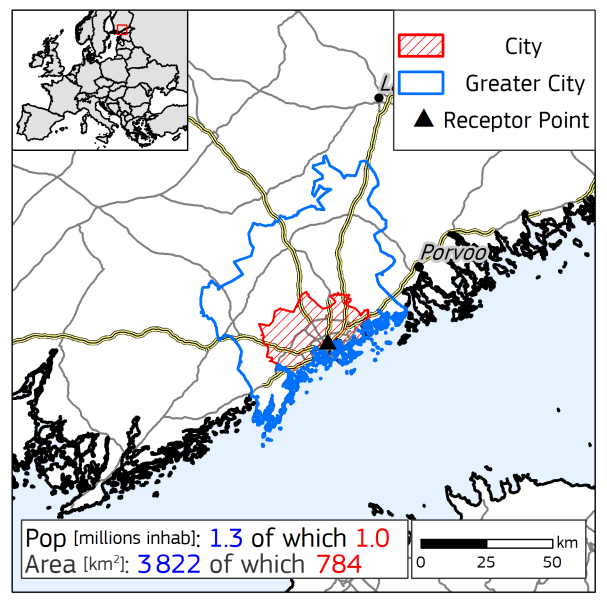
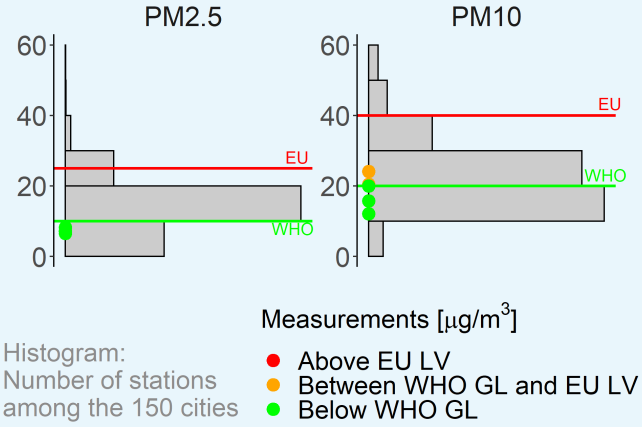
- N - Natural
- E - External
- Greater city

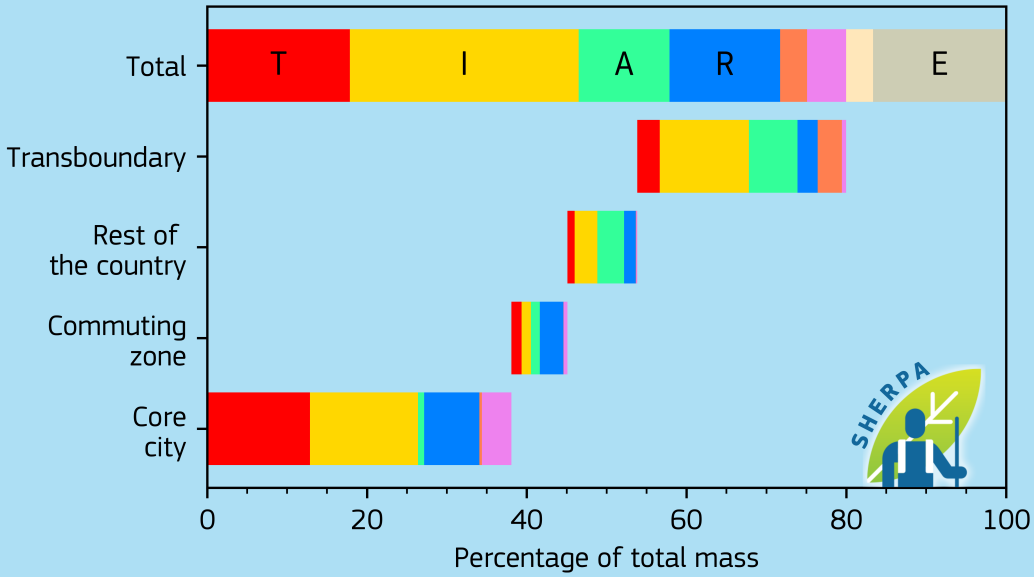
Finland, Helsinki



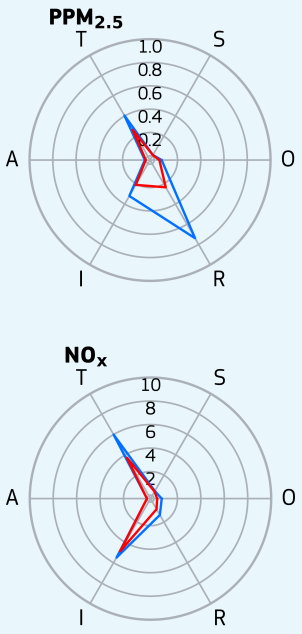
Yearly average urban concentrations (2018)

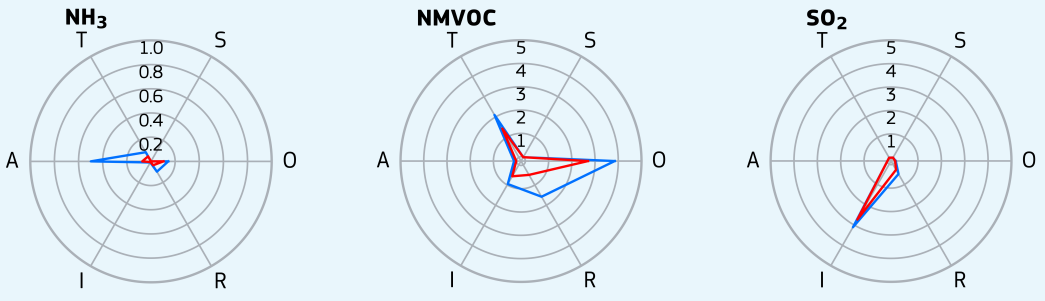


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



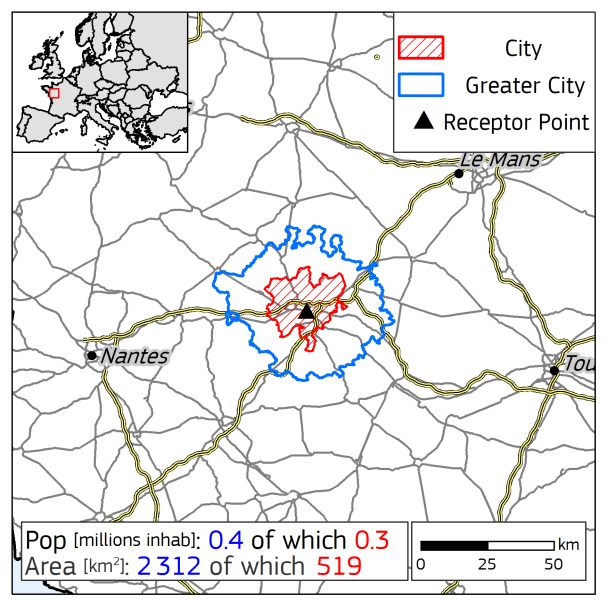
Emissions [kton/year]



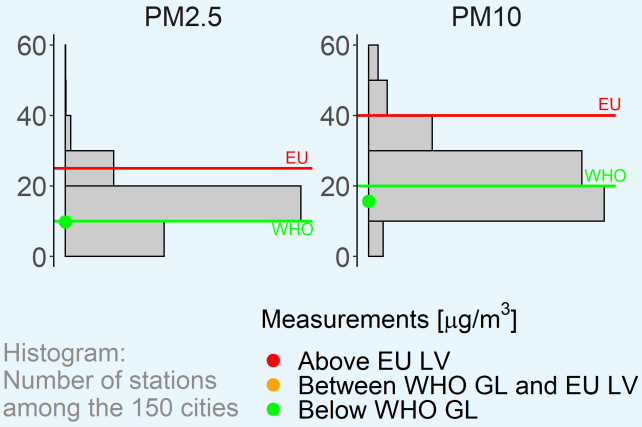


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

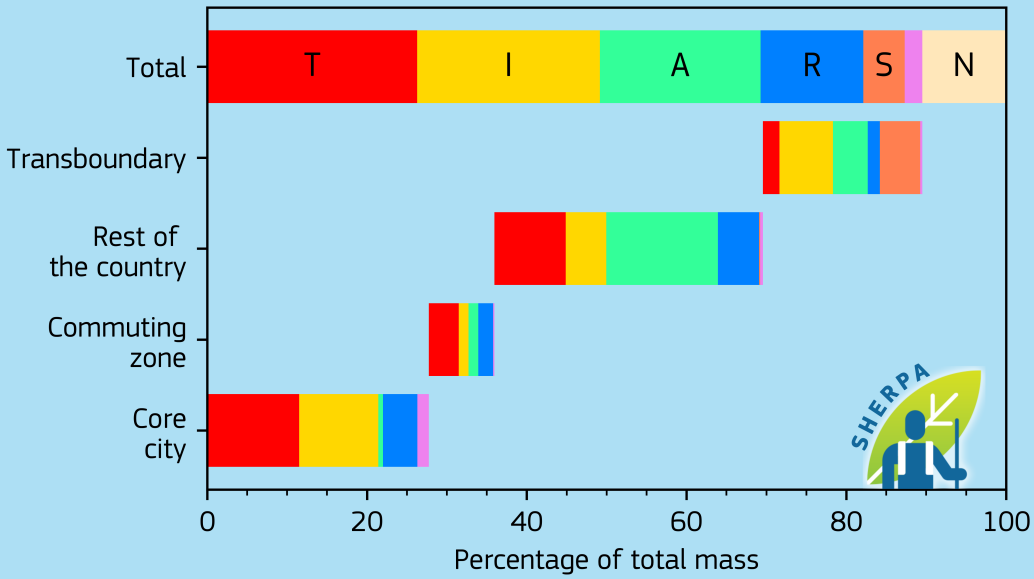
France, Angers



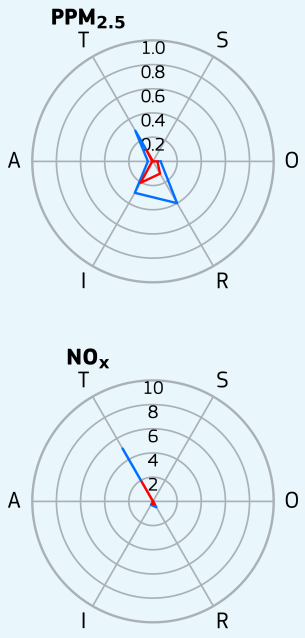
Yearly average urban concentrations (2018)

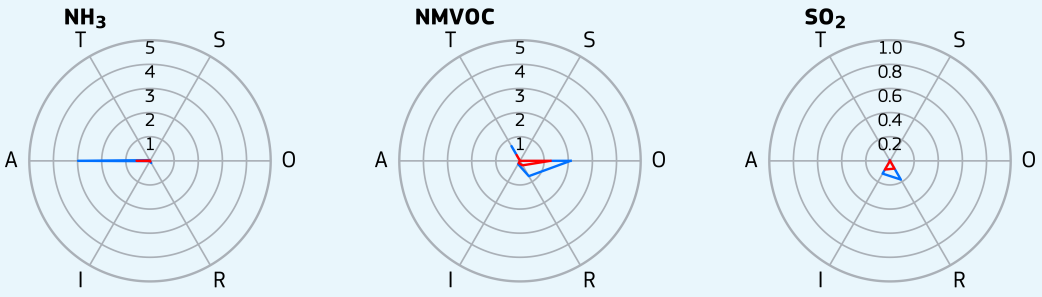


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
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R - Residential
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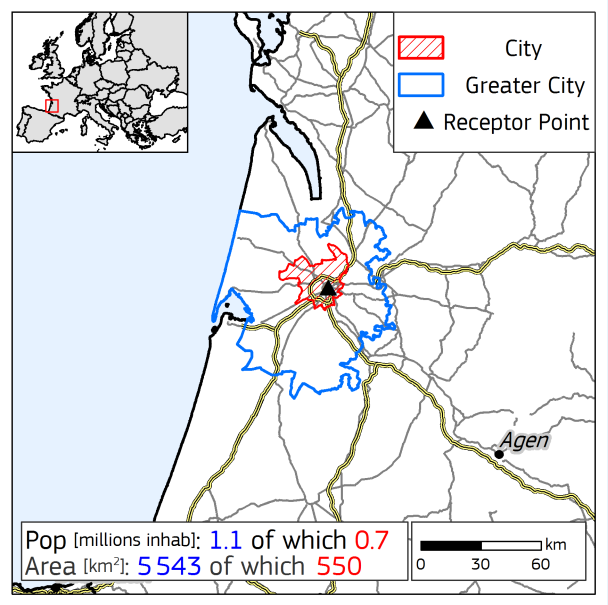
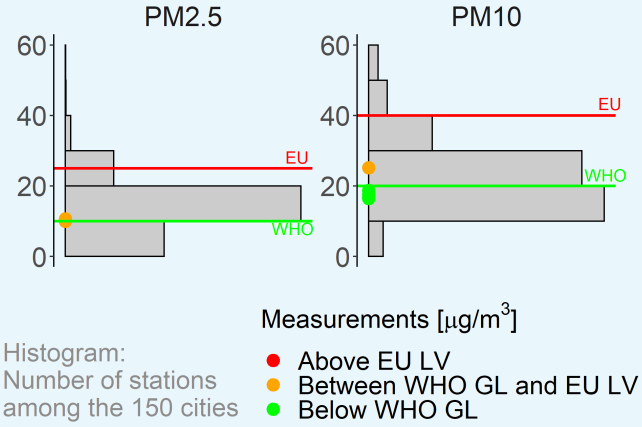
O - Other
N - Natural
E - External
Greater city
Core city

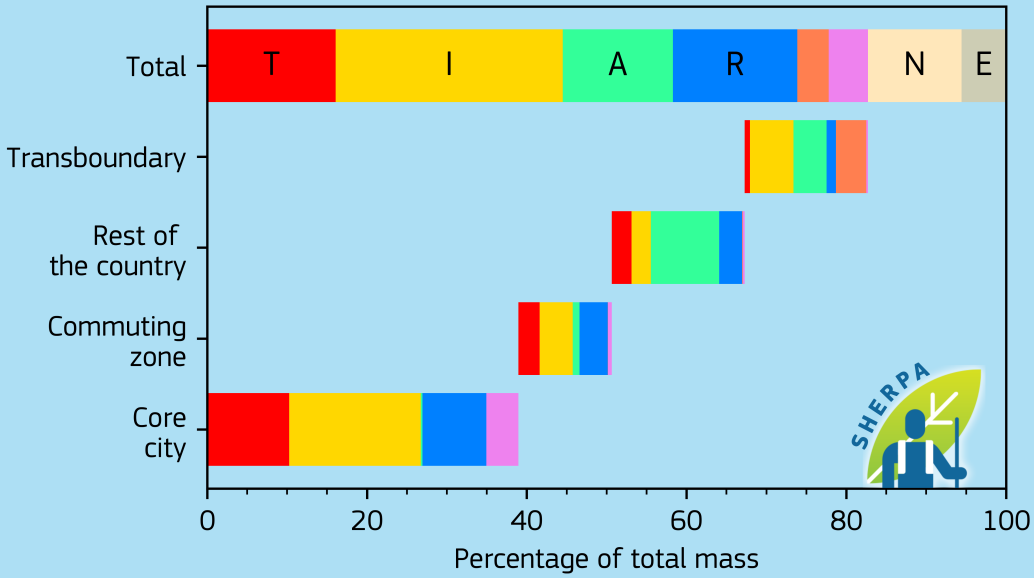
France, Bordeaux



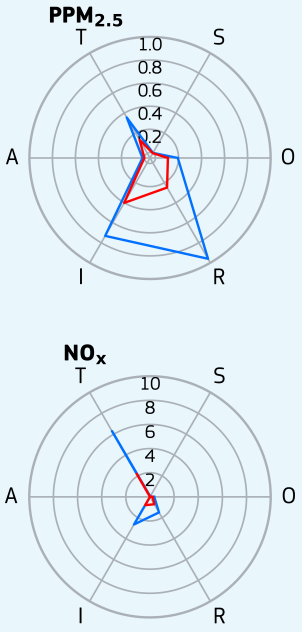
Yearly average urban concentrations (2018)

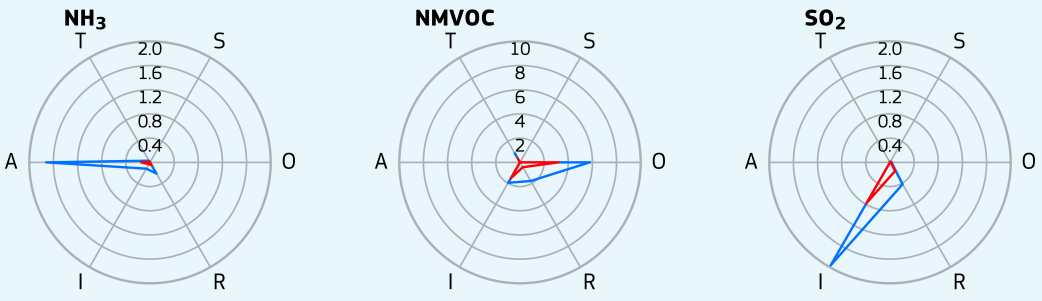


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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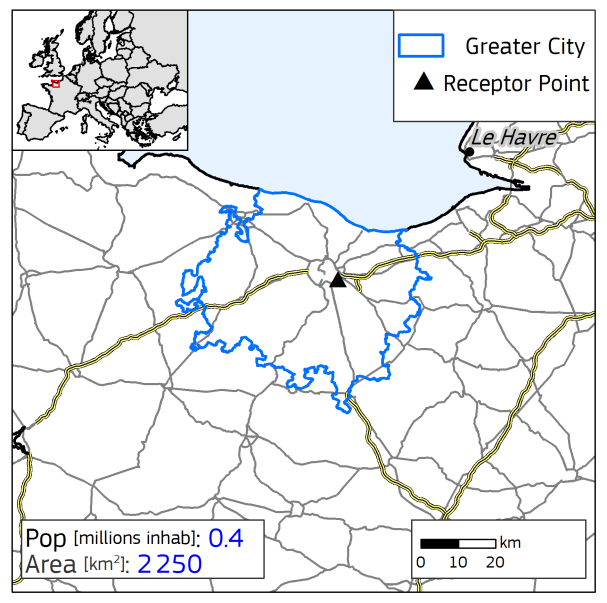
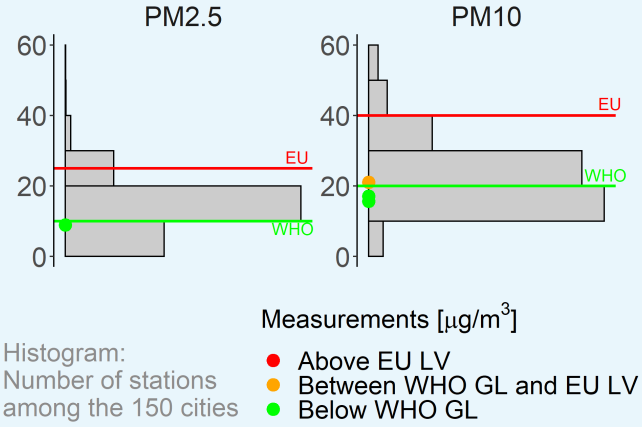
Greater city
Core city

France, Caen



Yearly average urban concentrations (2018)



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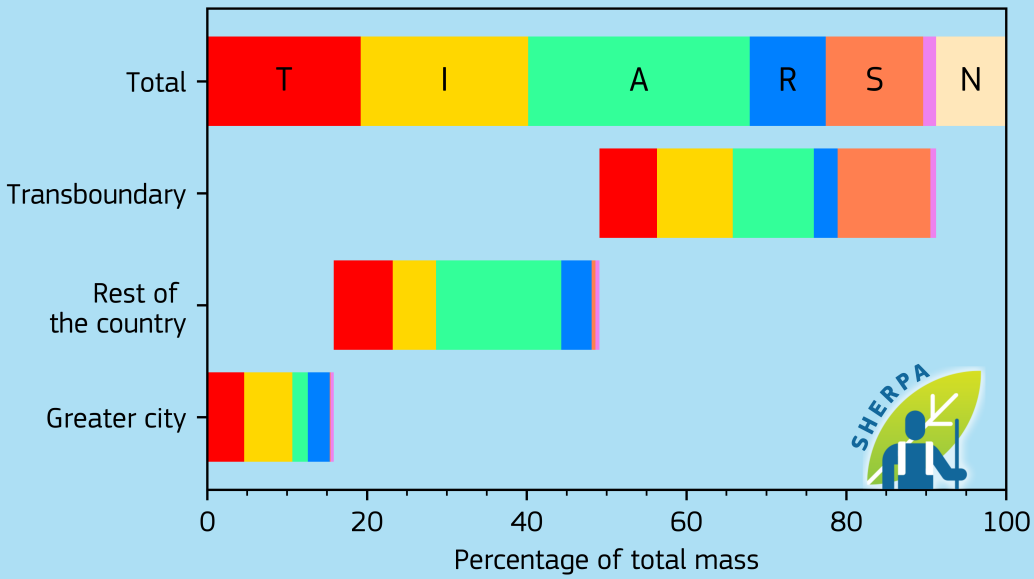
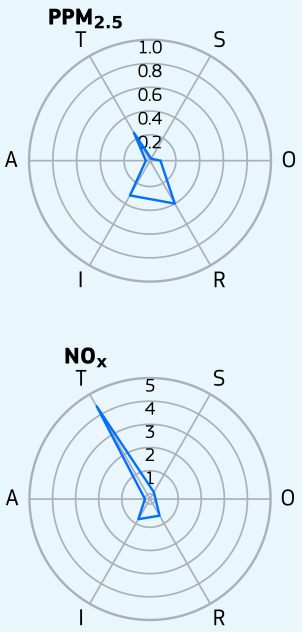
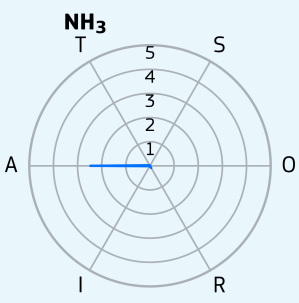
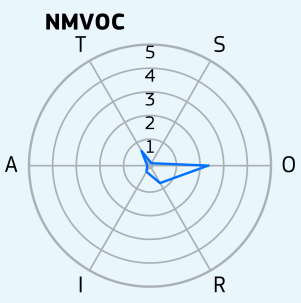
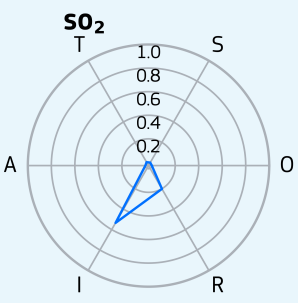


Emissions [kton/year]









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O - Other
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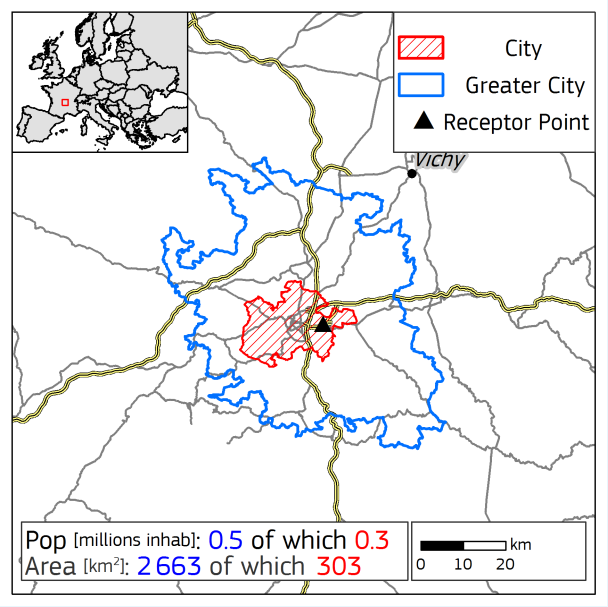
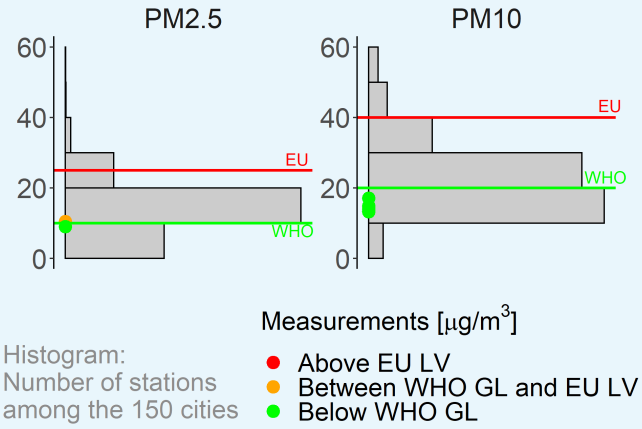
Greater city

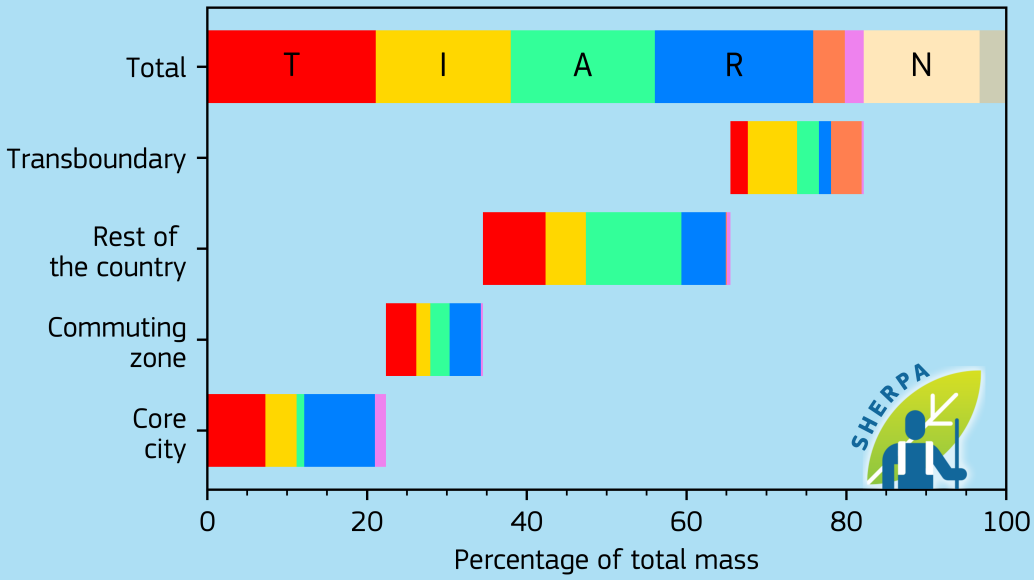
France, Clermont-Ferrand



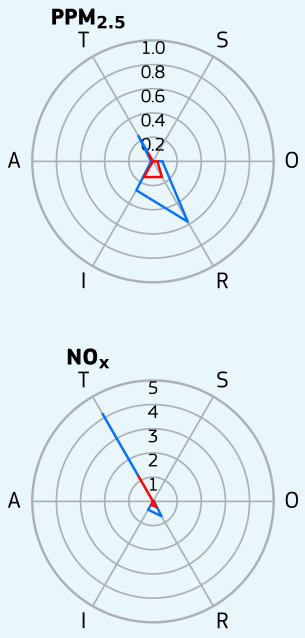
Yearly average urban concentrations (2018)

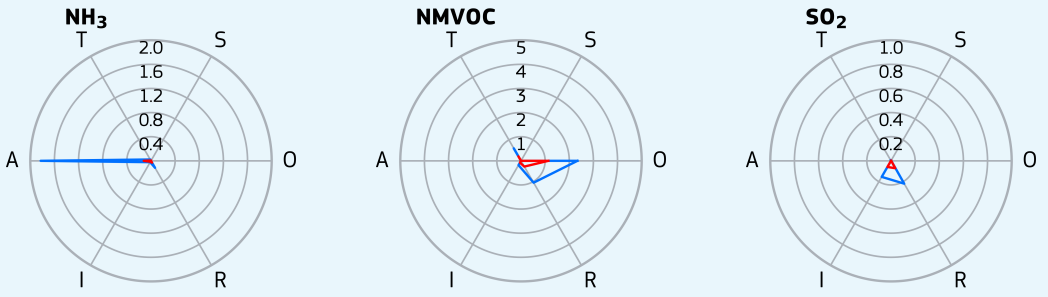


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



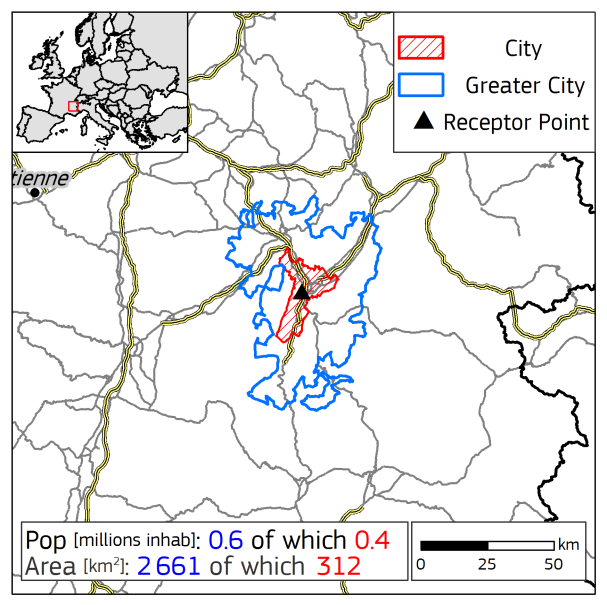
Emissions [kton/year]



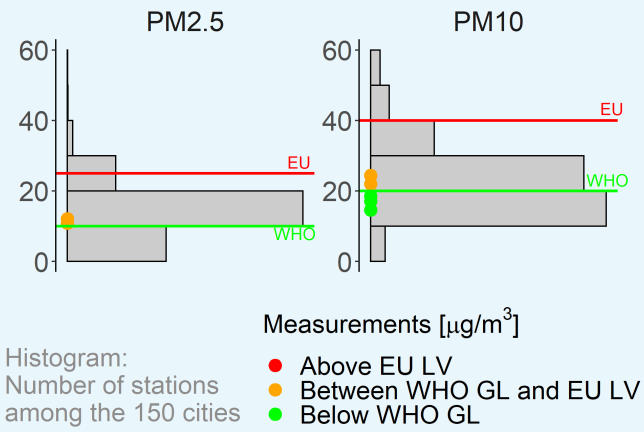


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

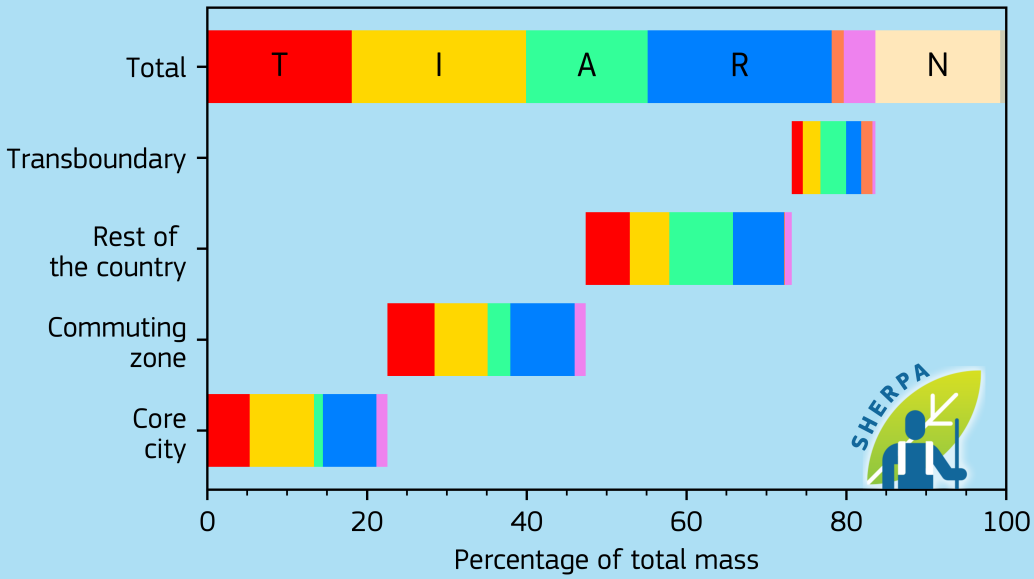
France, Grenoble



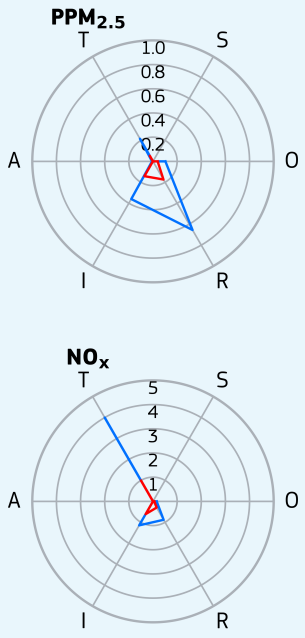
Yearly average urban concentrations (2018)

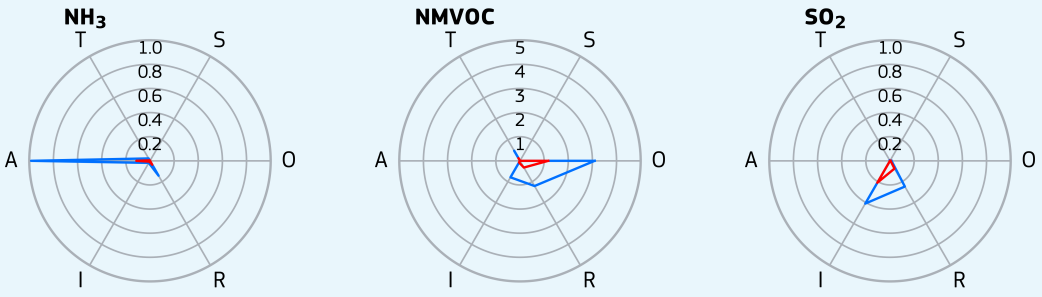


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



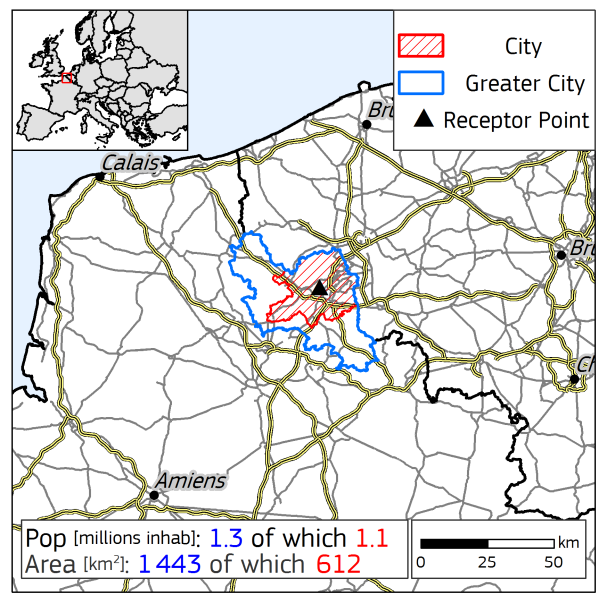
Emissions [kton/year]



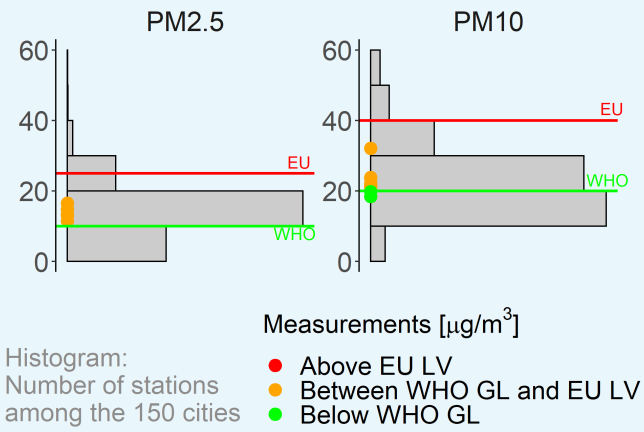


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

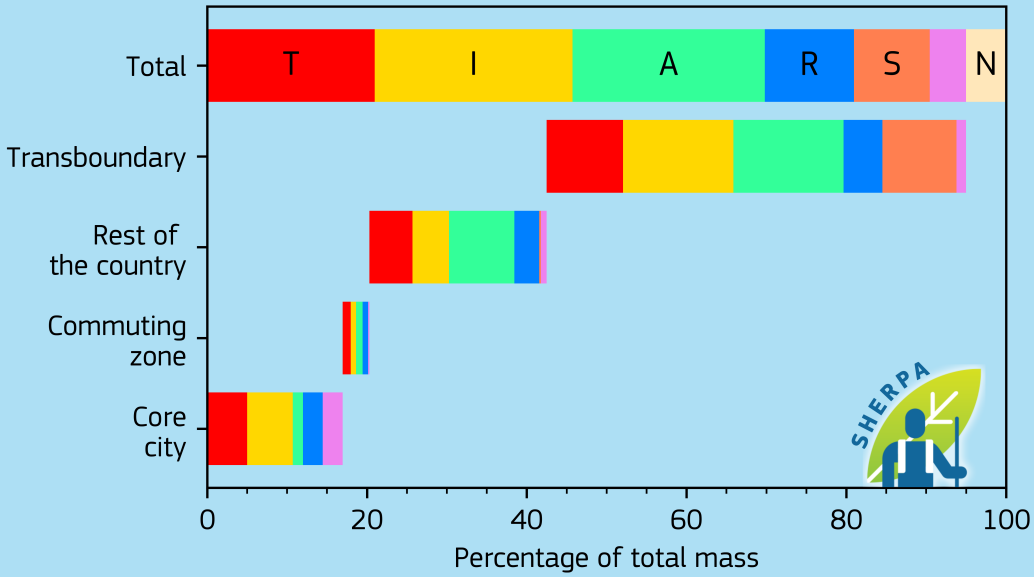
France, Lille



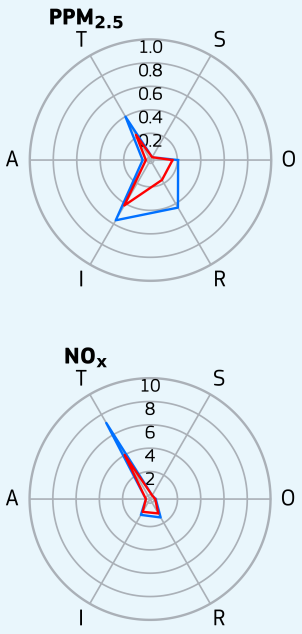
Yearly average urban concentrations (2018)

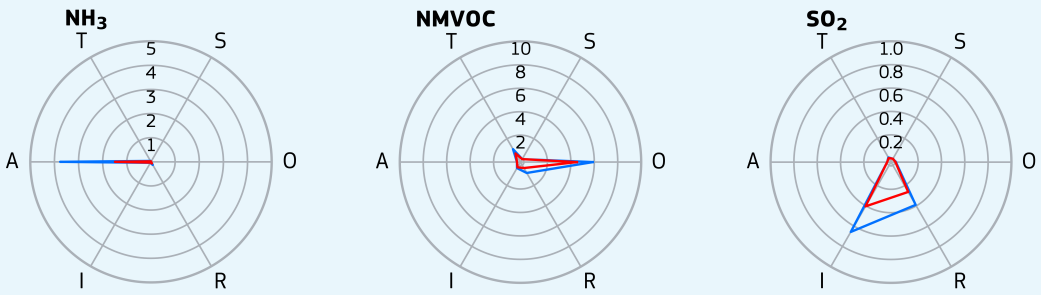


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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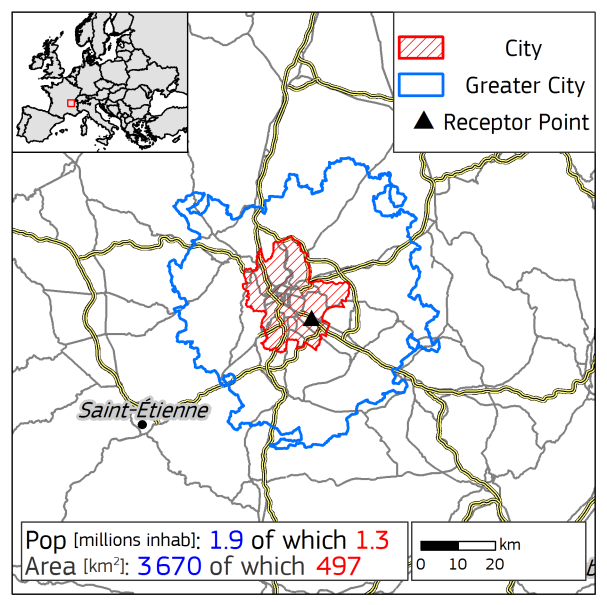
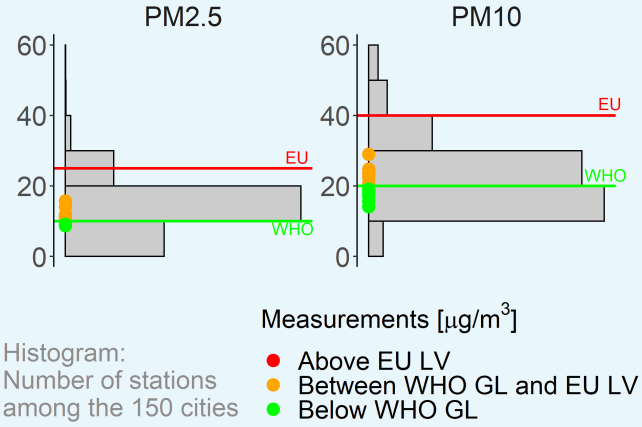
- S - Shipping
- O - Other
- N - Natural
- Greater city
- Core city

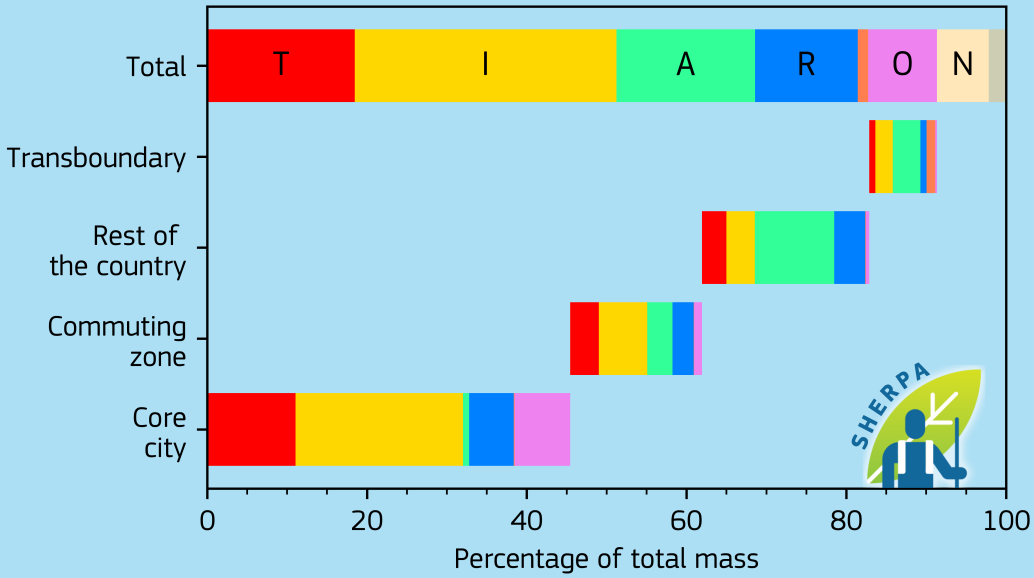
France, Lyon



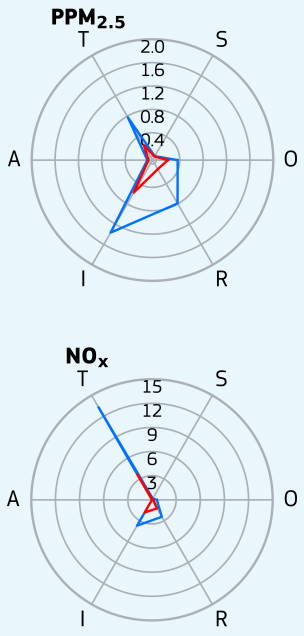
Yearly average urban concentrations (2018)

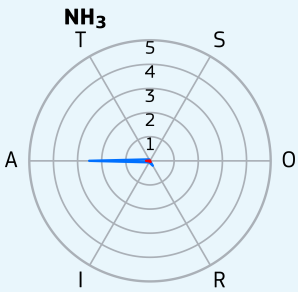


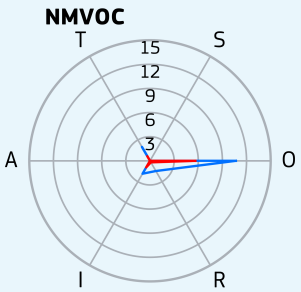
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

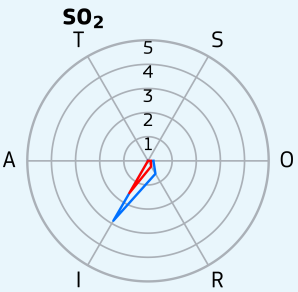


Emissions [kton/year]



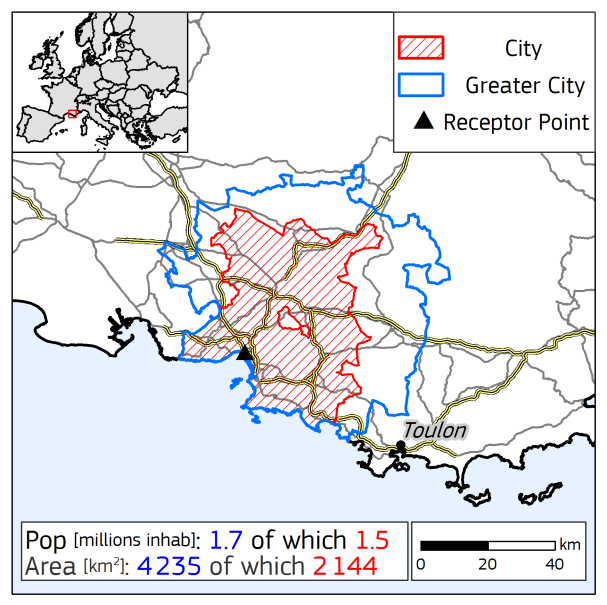




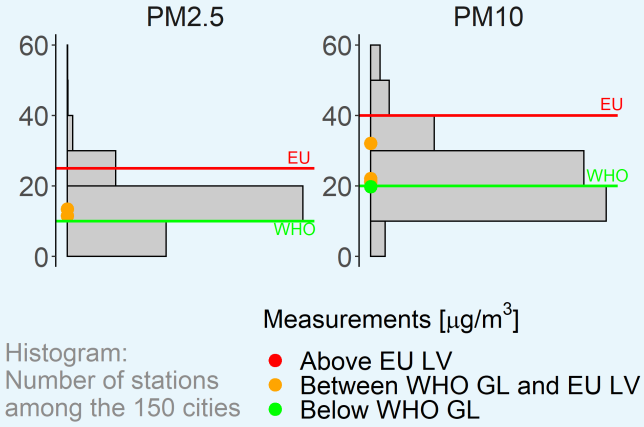


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

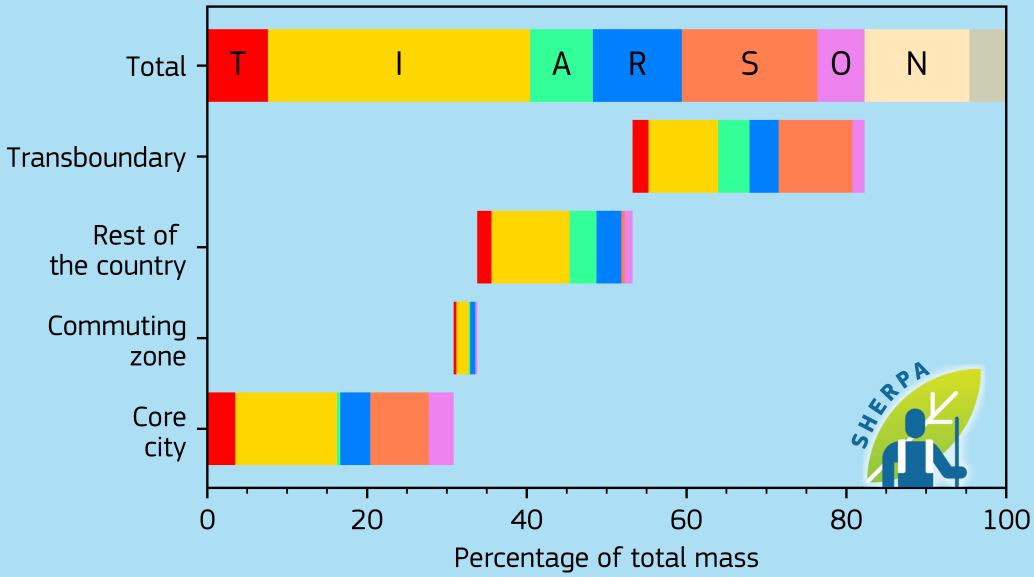
France, Marseille



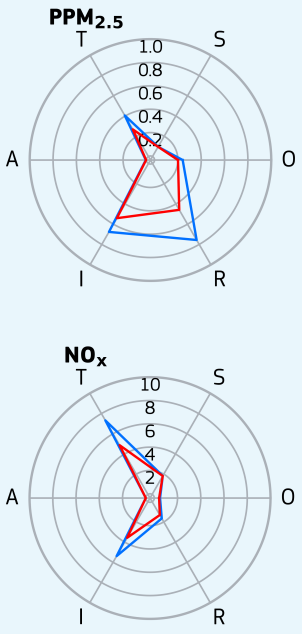
Yearly average urban concentrations (2018)

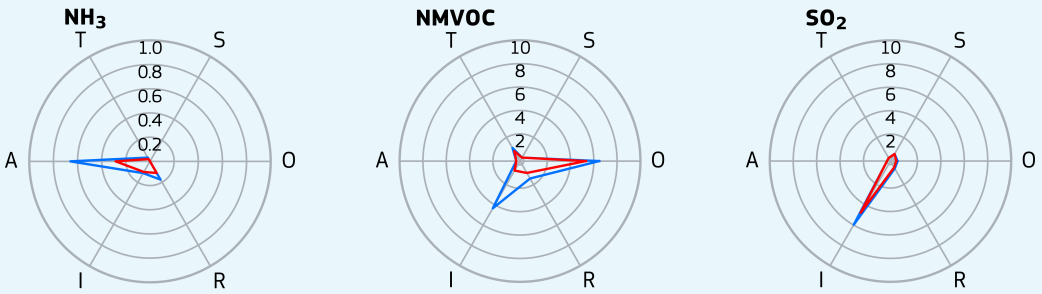


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



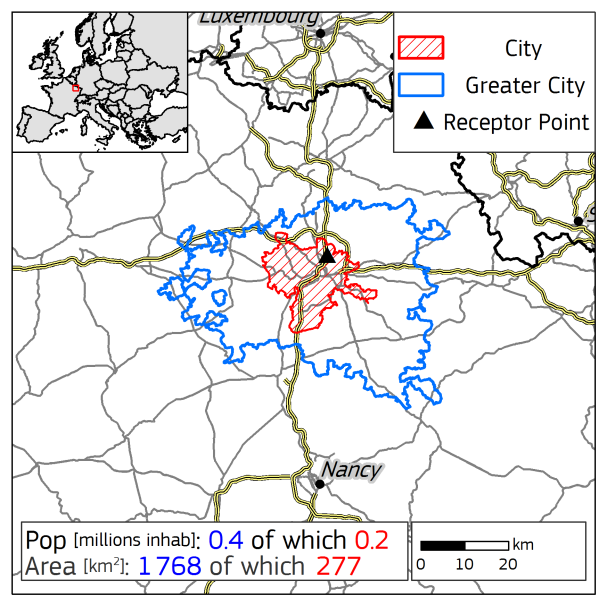
Emissions [kton/year]



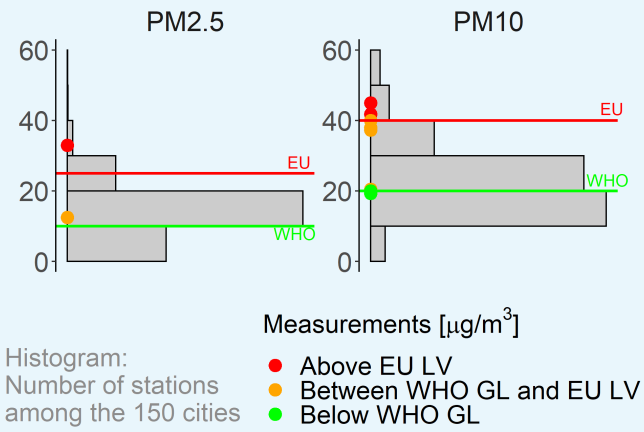


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

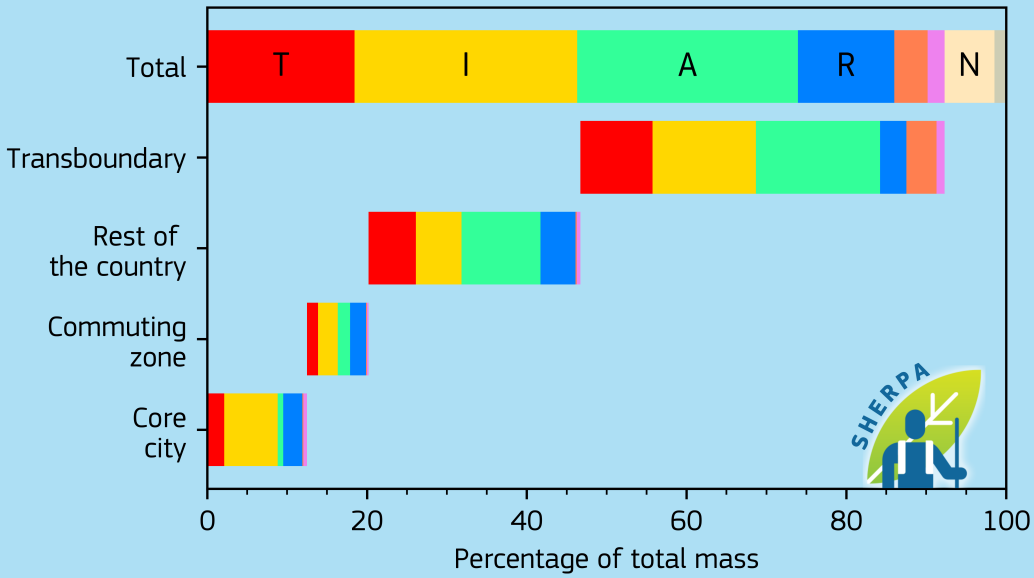
France, Metz



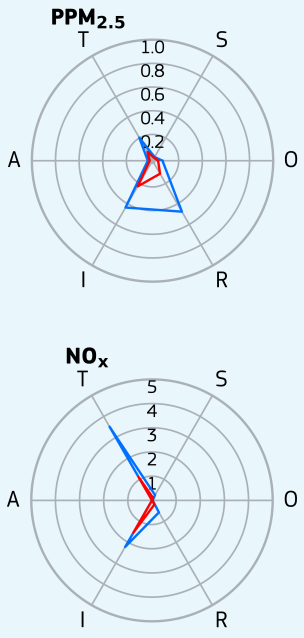
Yearly average urban concentrations (2018)

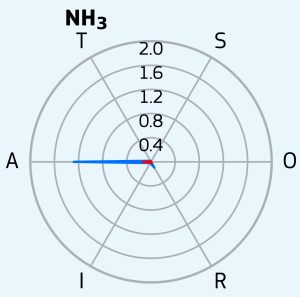


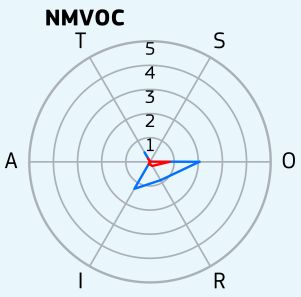
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

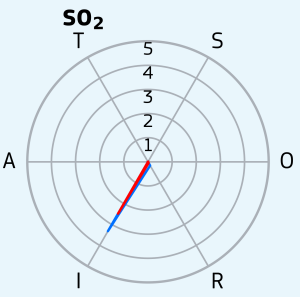


Emissions [kton/year]



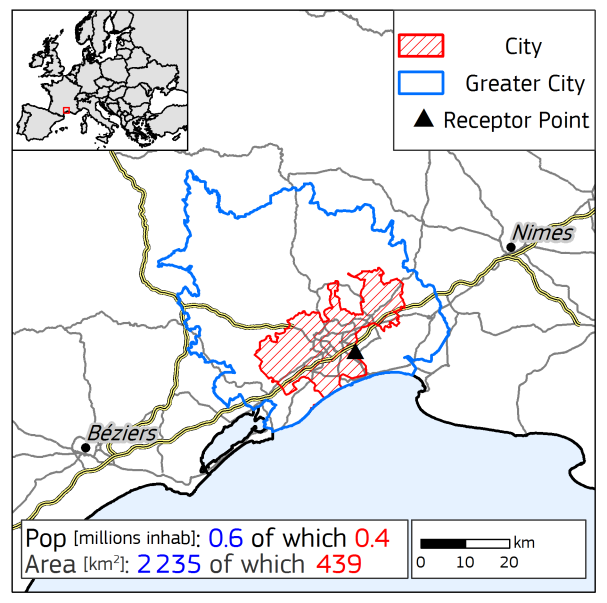




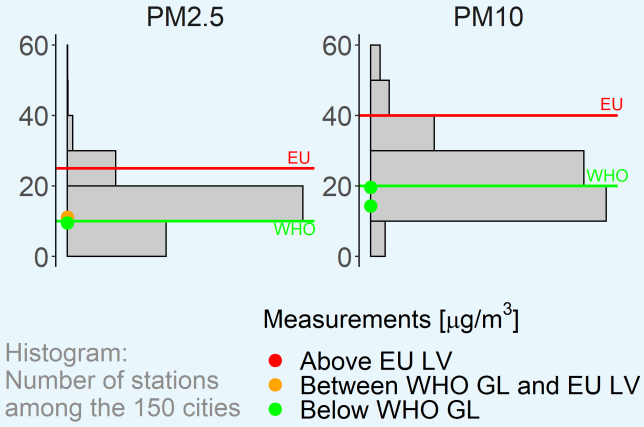


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

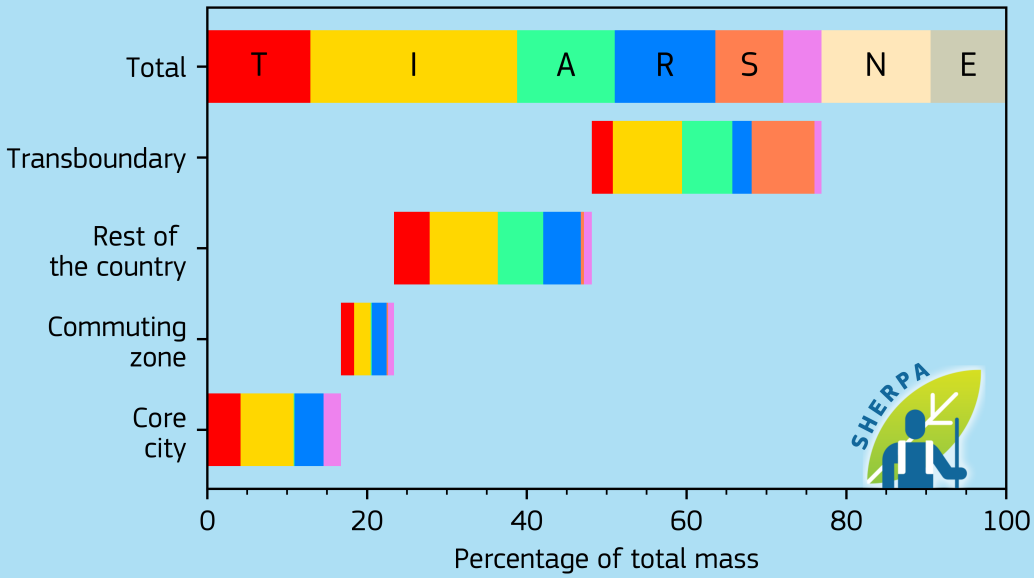
France, Montpellier



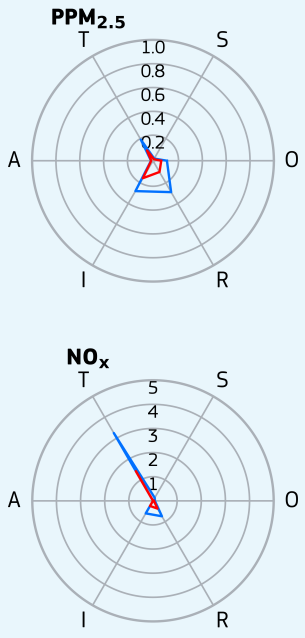
Yearly average urban concentrations (2018)

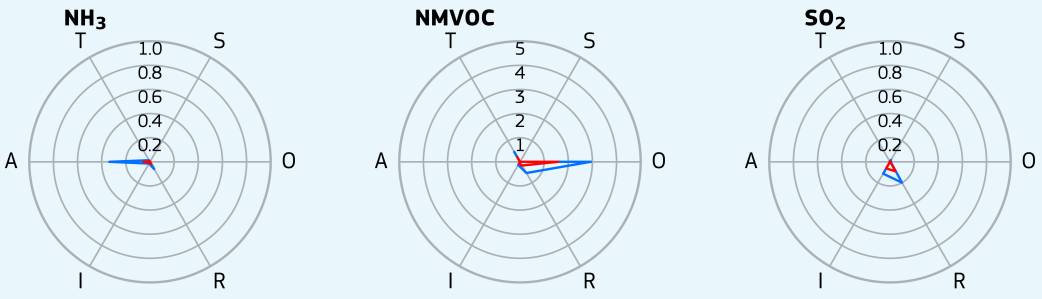


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
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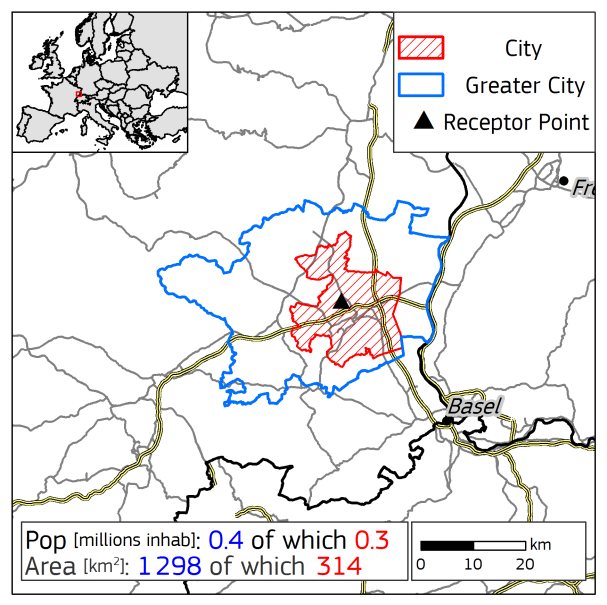
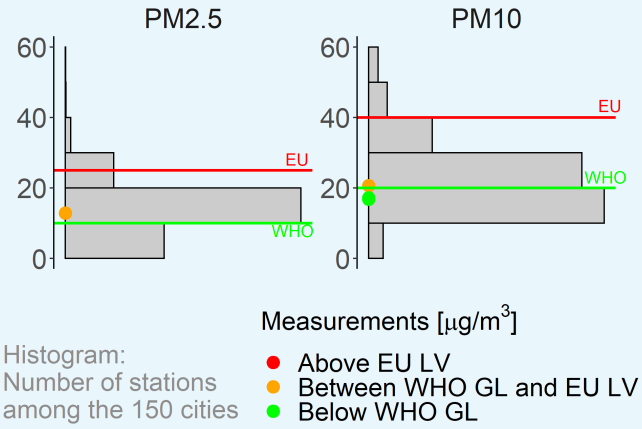
O - Other
N - Natural
E - External
Greater city
Core city

France, Mulhouse

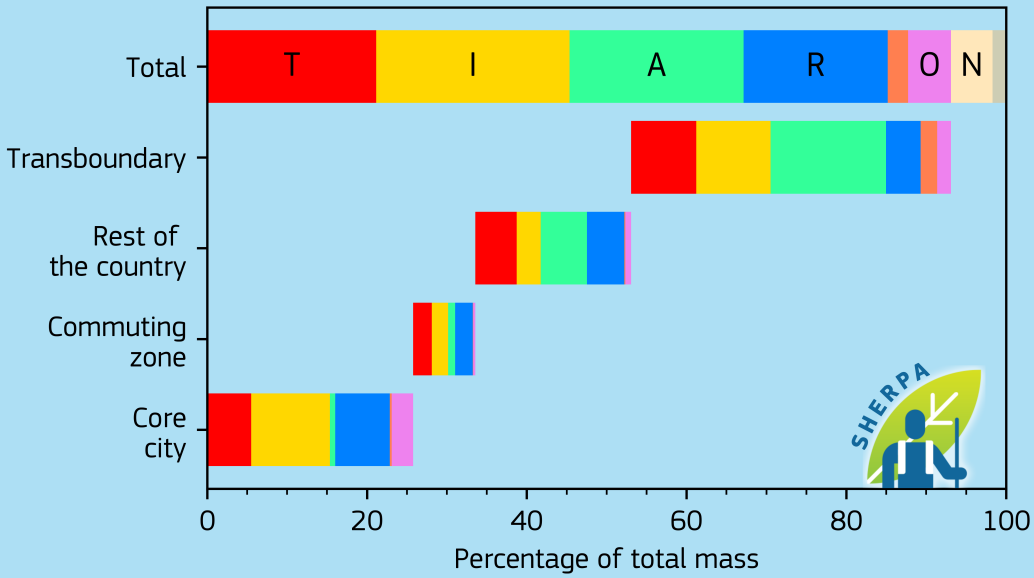


Yearly average urban concentrations (2018)

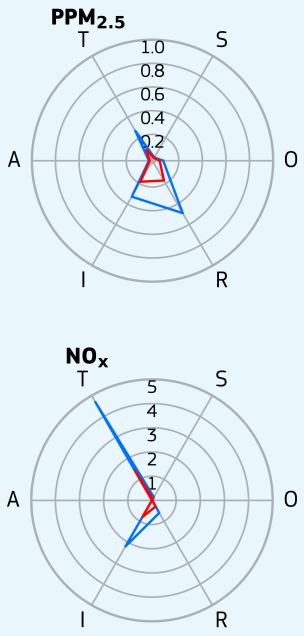


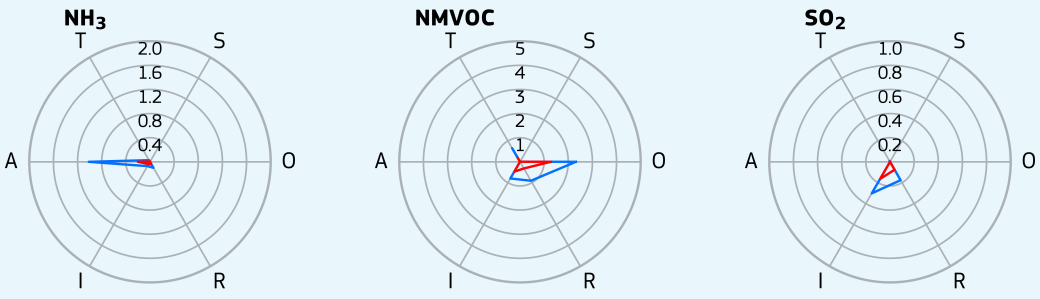
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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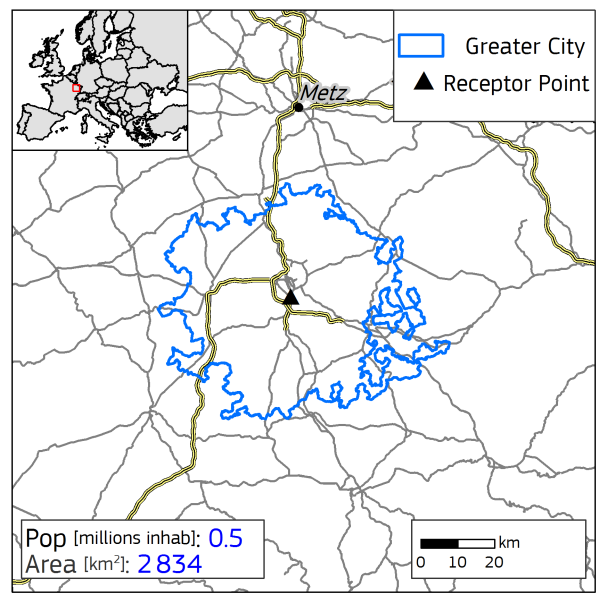
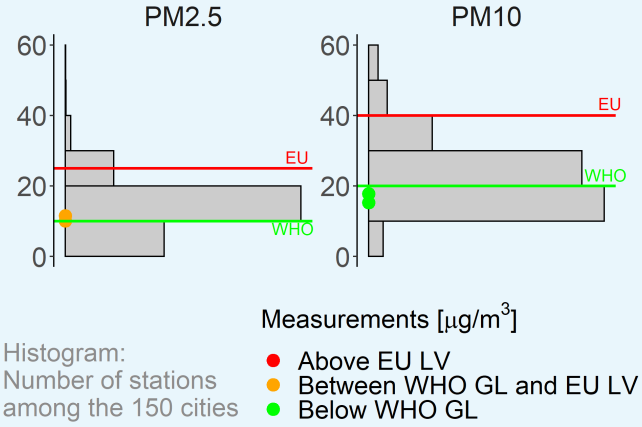
France, Nancy



Yearly average urban concentrations (2018)



Histogram:
Number of stations
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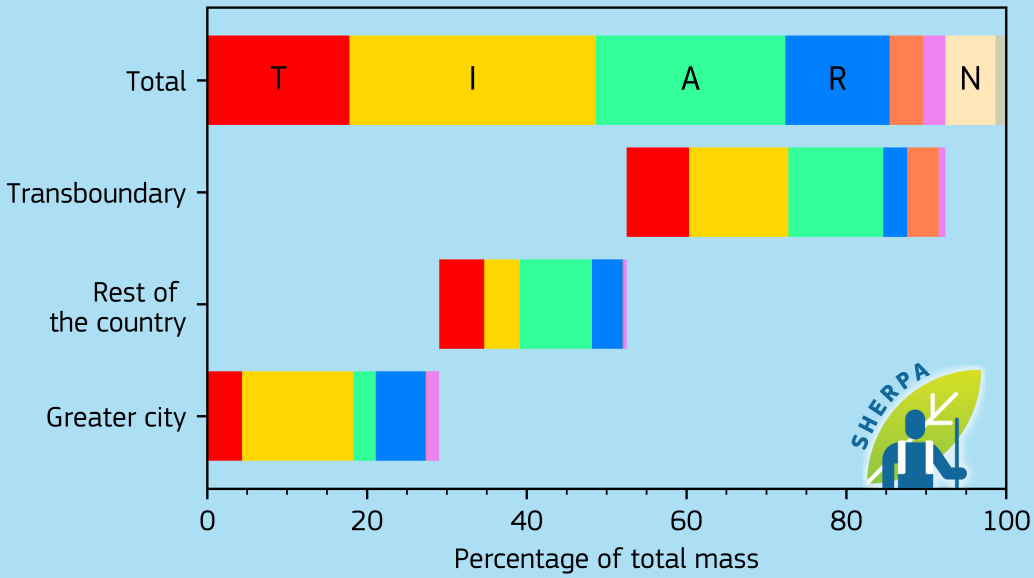
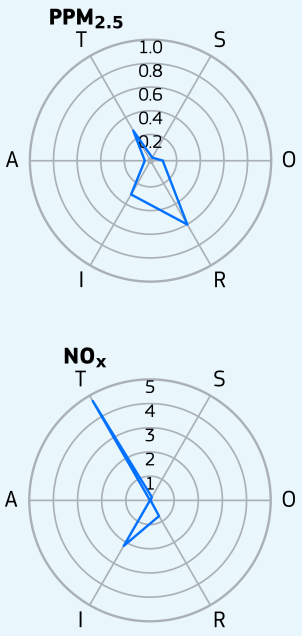
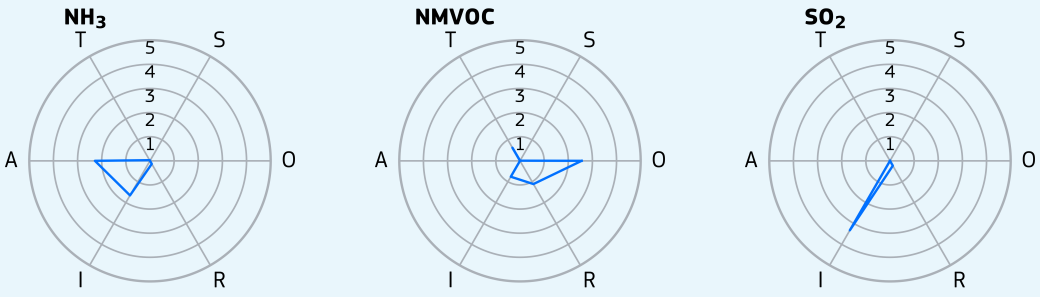


Emissions [kton/year]





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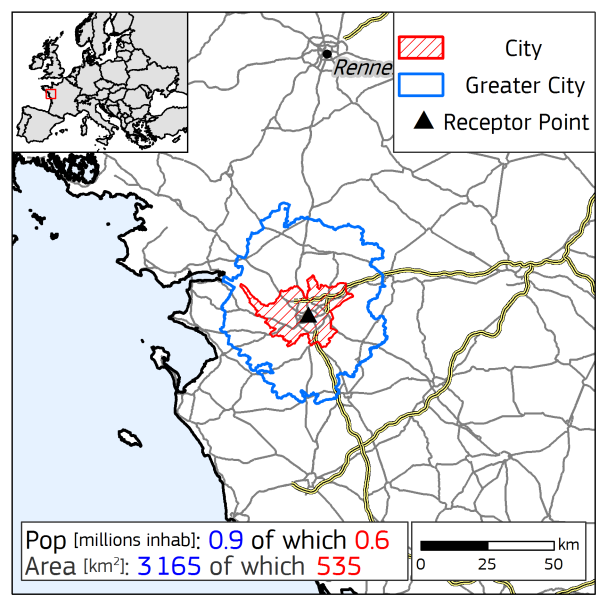
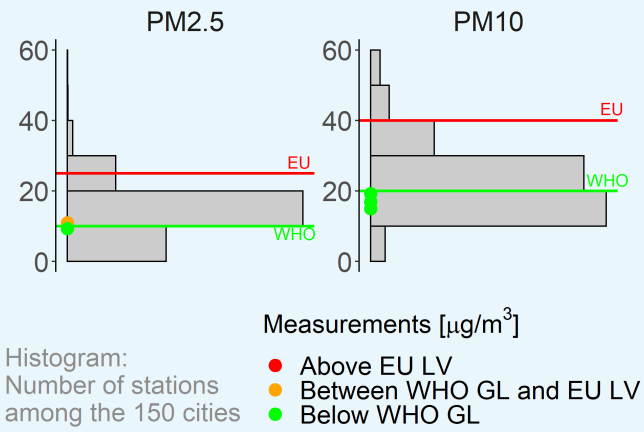
- Greater city

France, Nantes

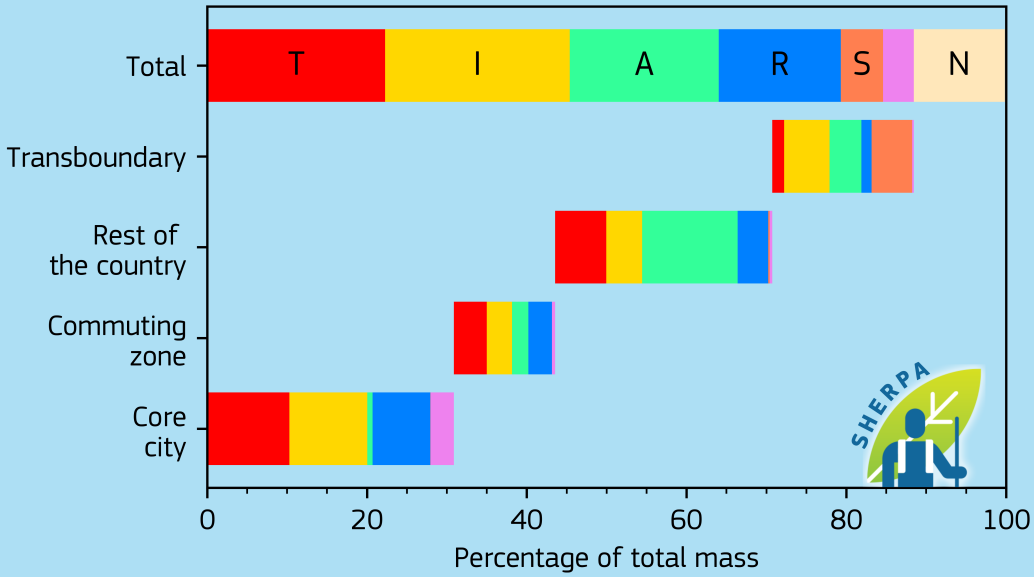


Yearly average urban concentrations (2018)

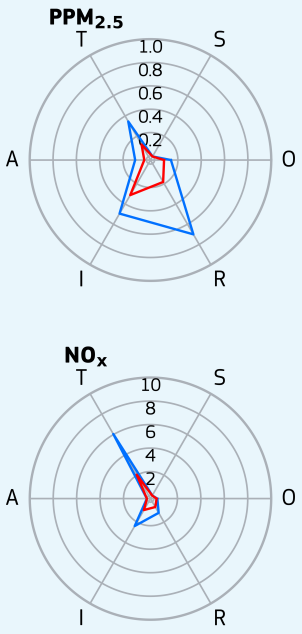


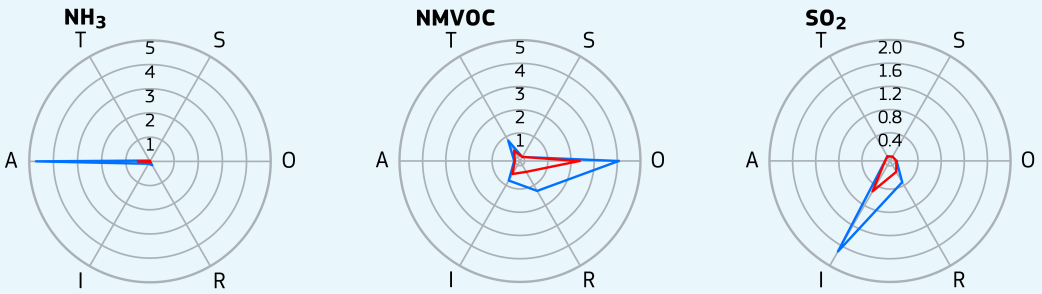
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



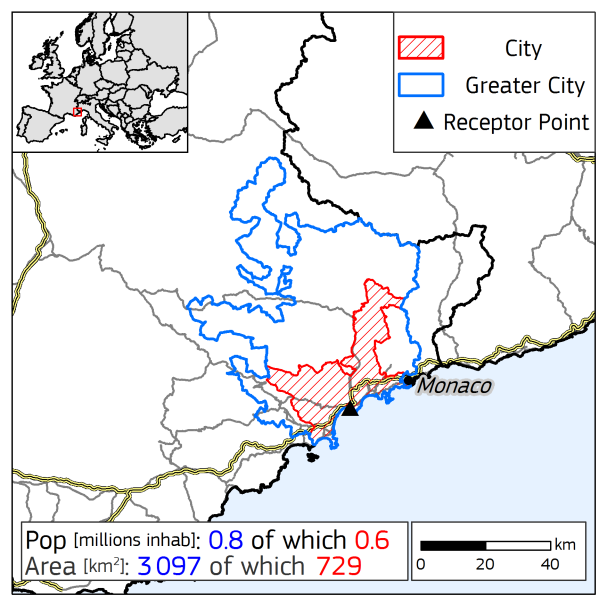
Emissions [kton/year]



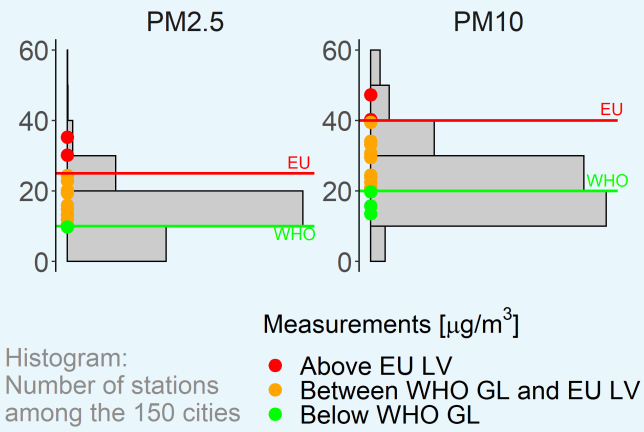


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

France, Nice

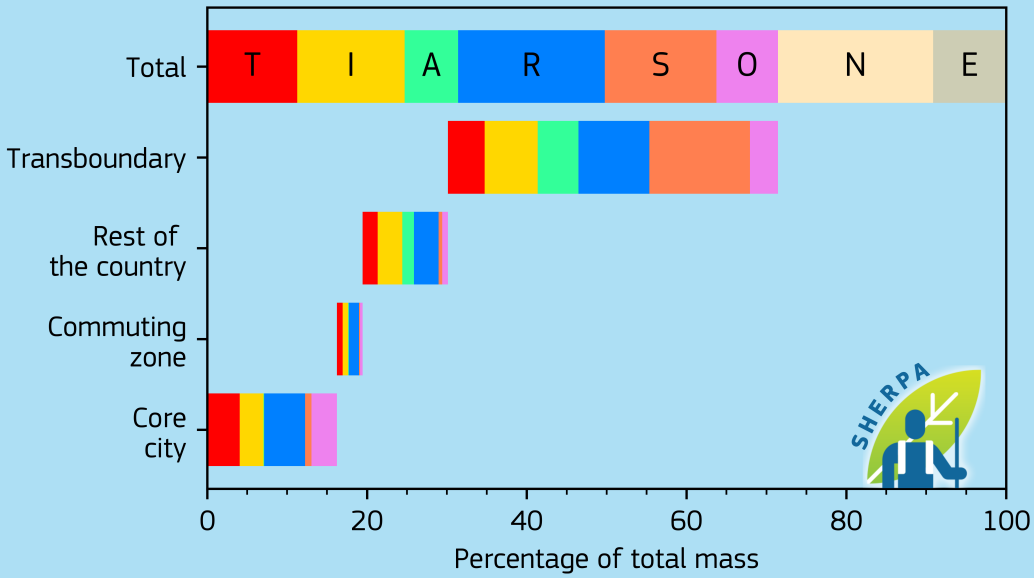


Yearly average urban concentrations (2018)

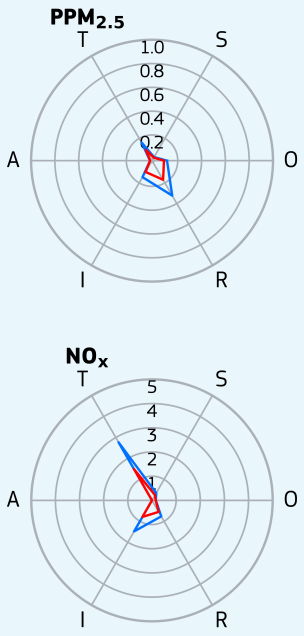


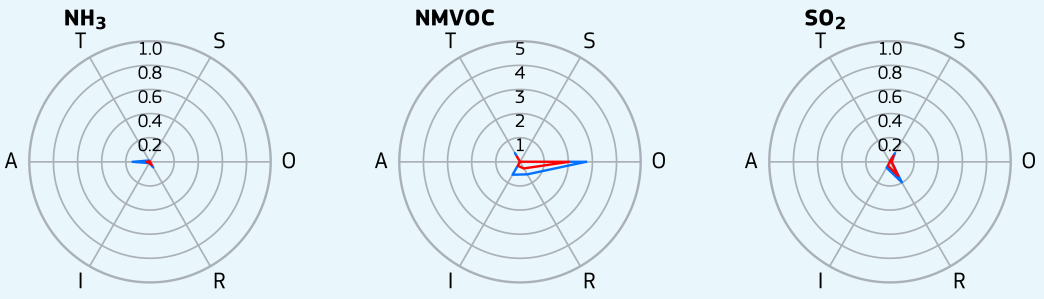
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



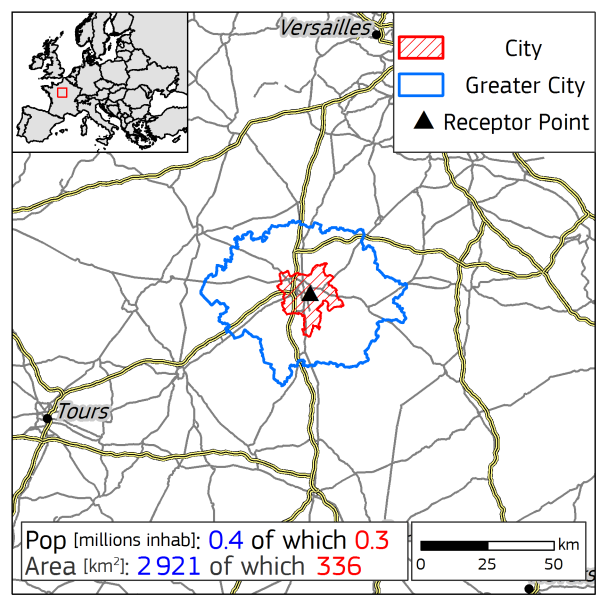
Emissions [kton/year]



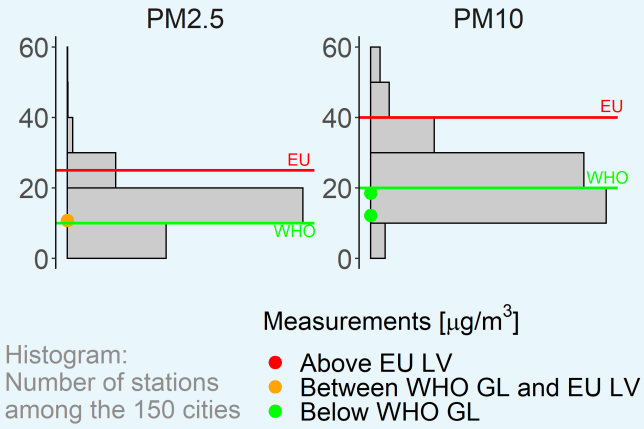


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

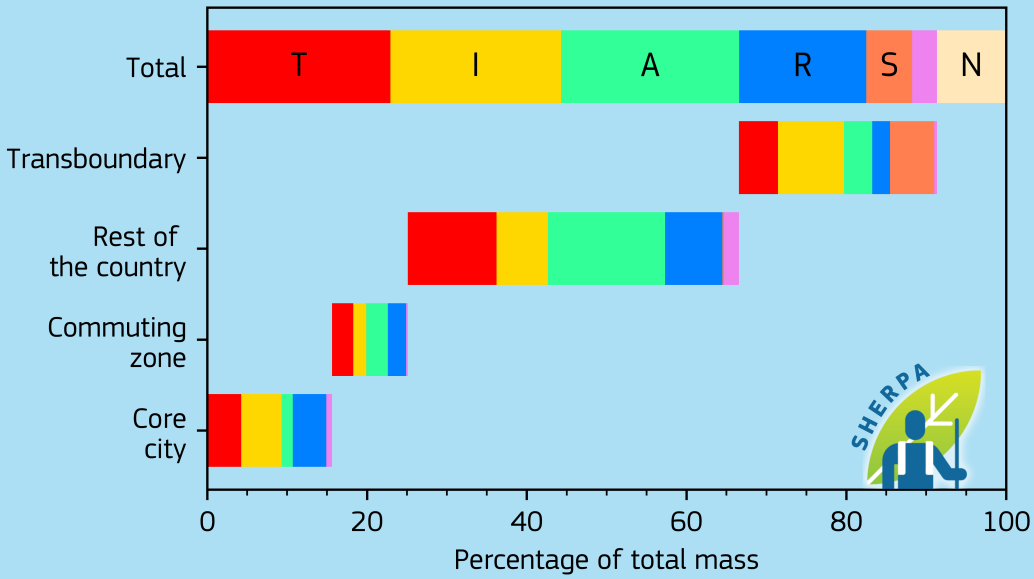
France, Orleans



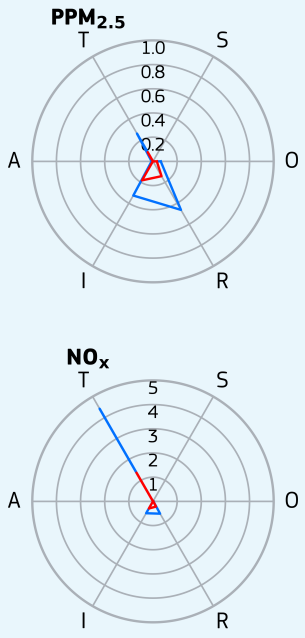
Yearly average urban concentrations (2018)

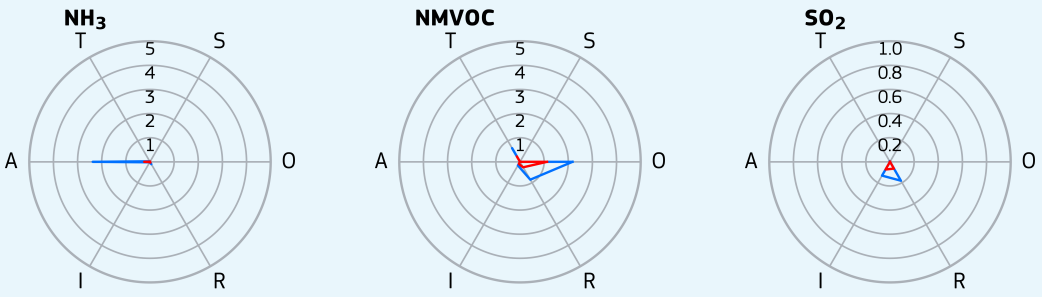


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



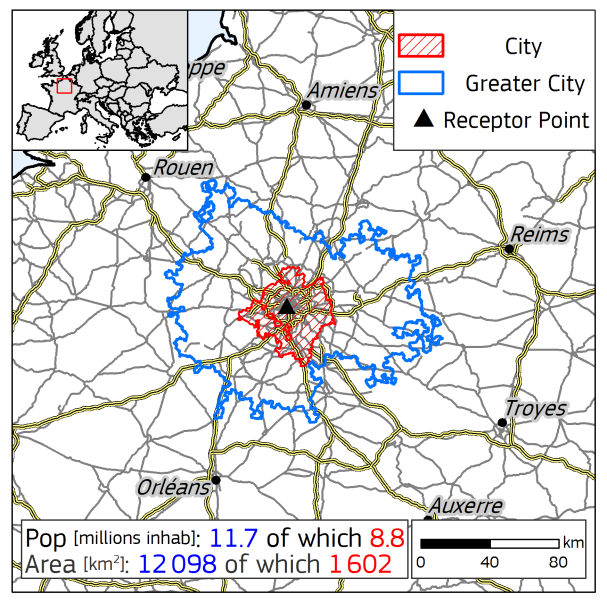
Emissions [kton/year]



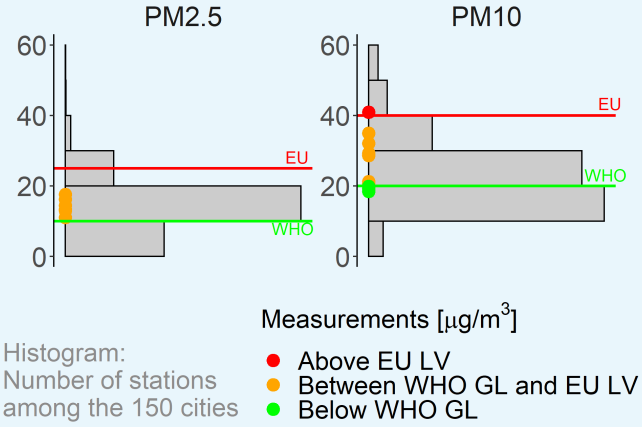


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city
Core city

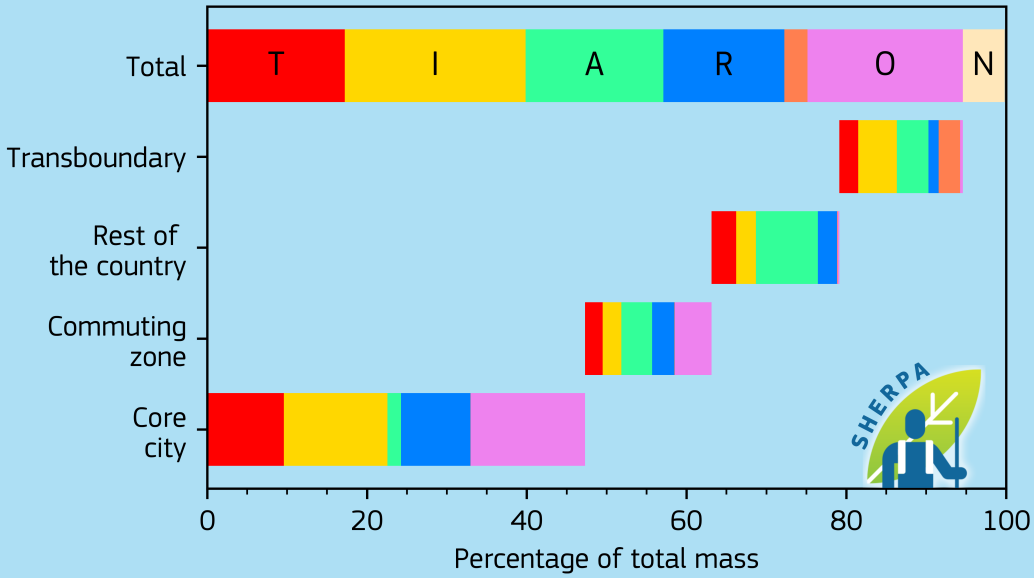
France, Paris



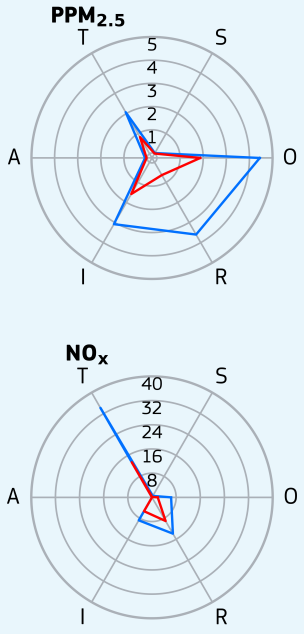
Yearly average urban concentrations (2018)

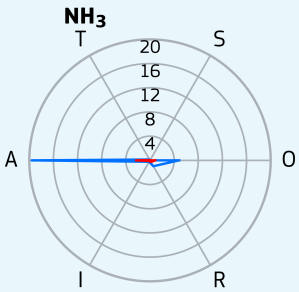


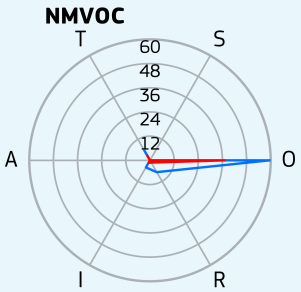
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]



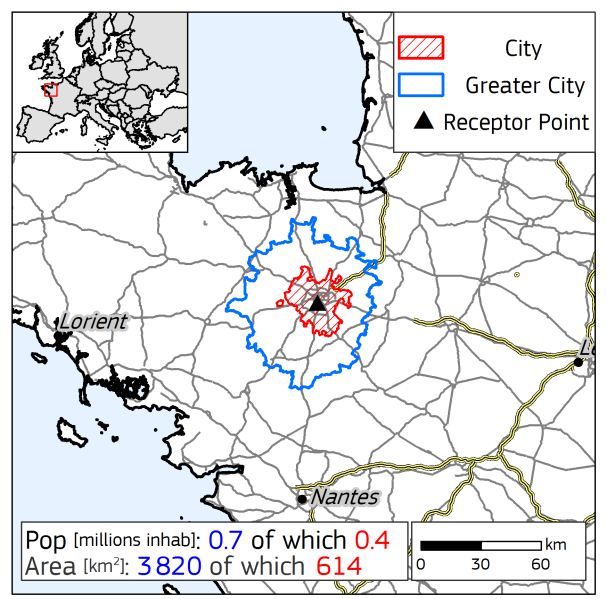




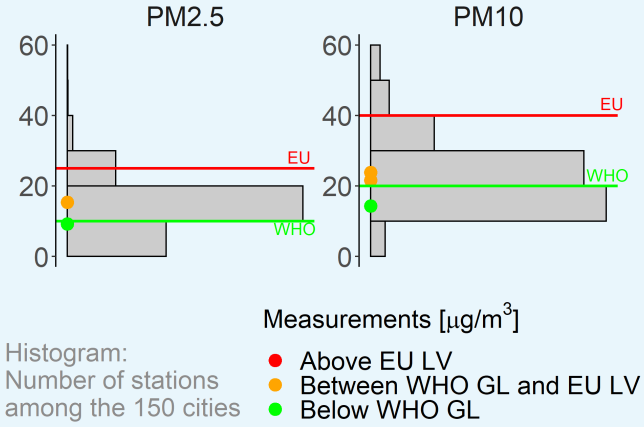


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

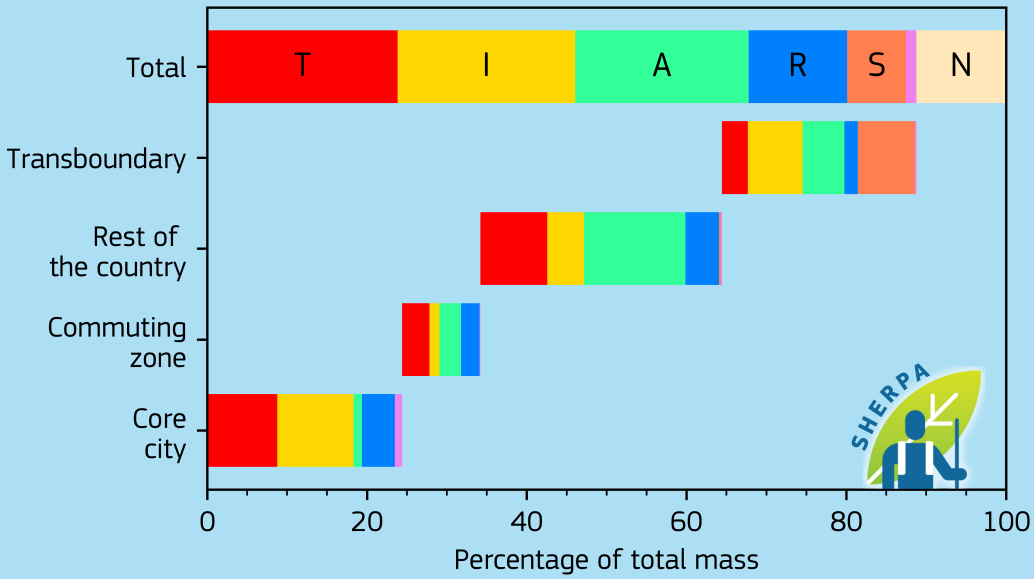
France, Rennes



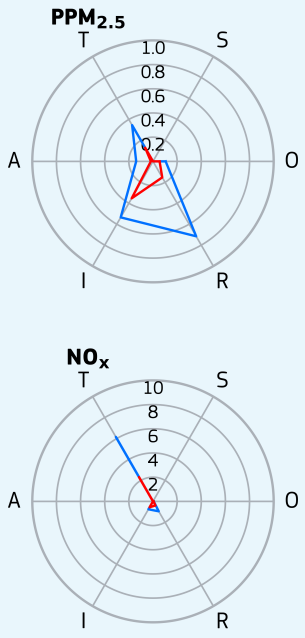
Yearly average urban concentrations (2018)

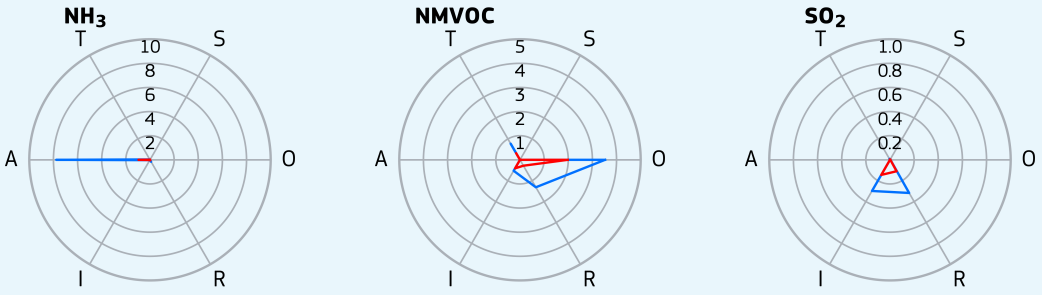


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



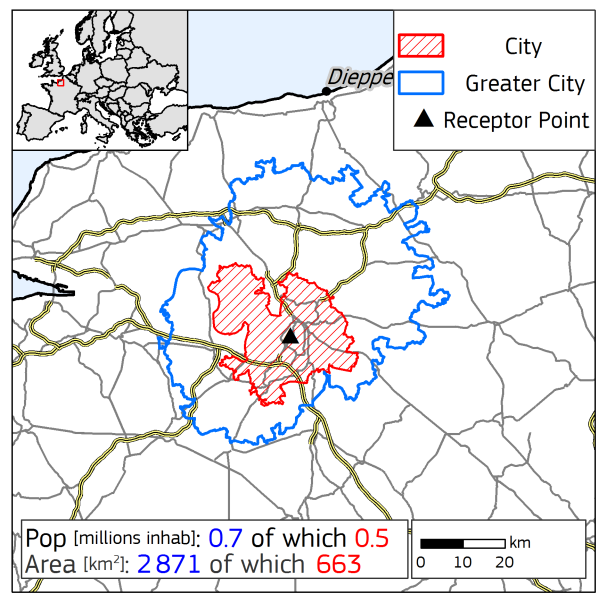
Emissions [kton/year]



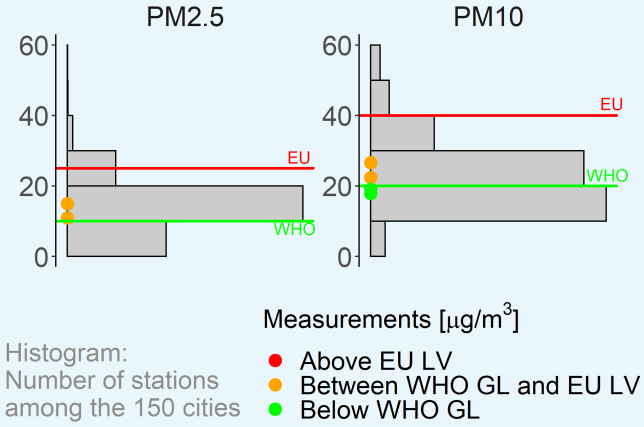


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city
Core city

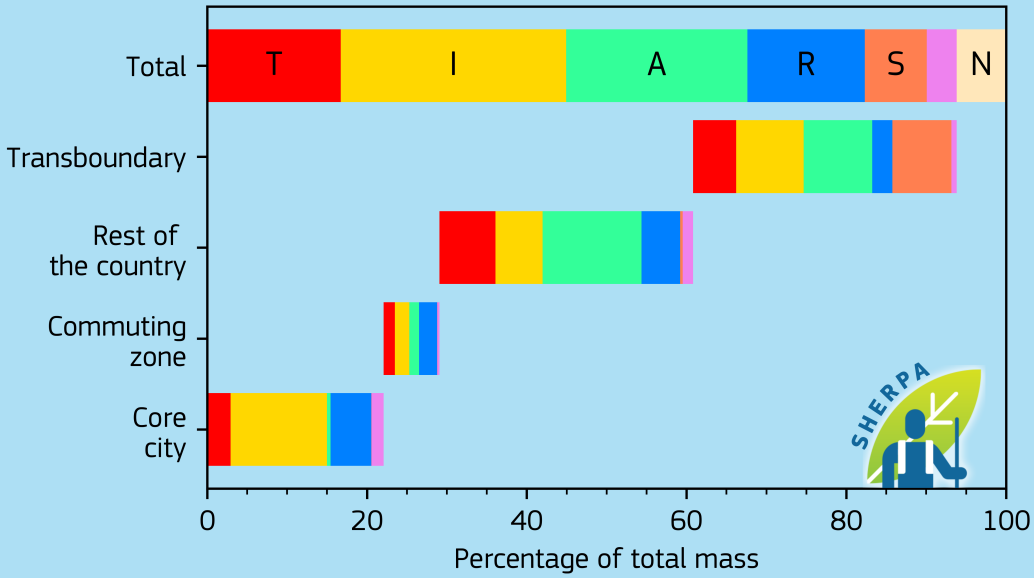
France, Rouen



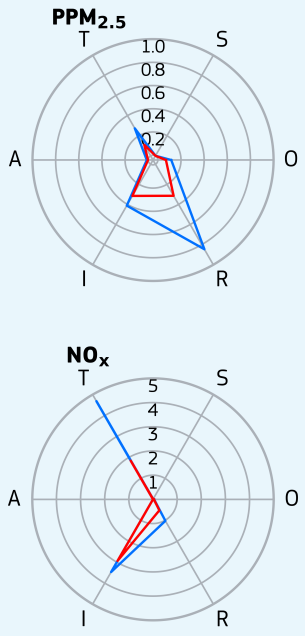
Yearly average urban concentrations (2018)

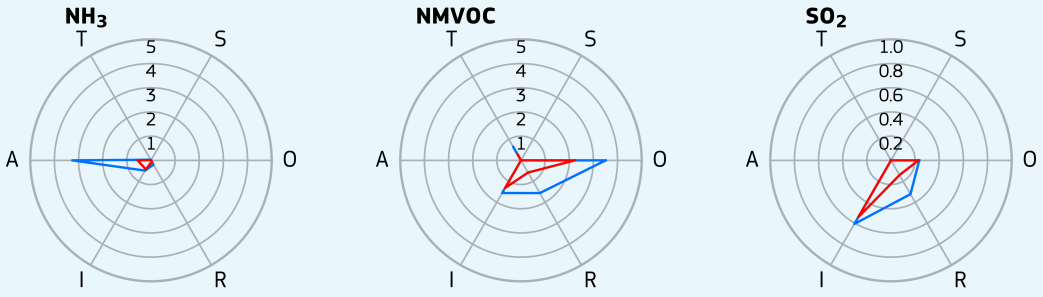


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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I - Industry
A - Agriculture
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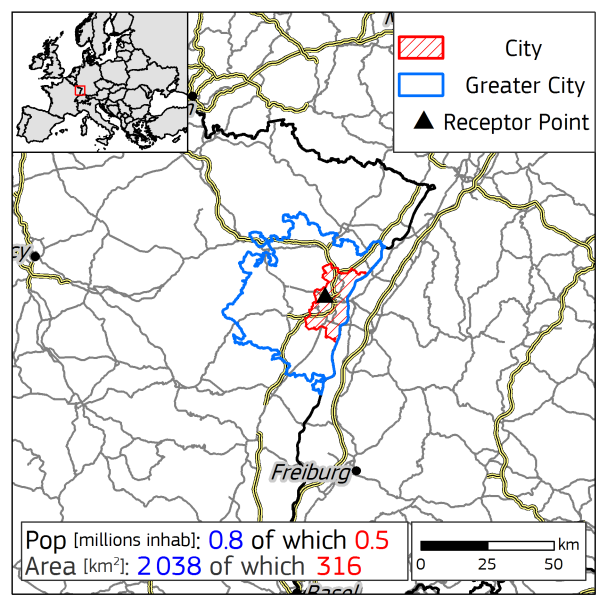
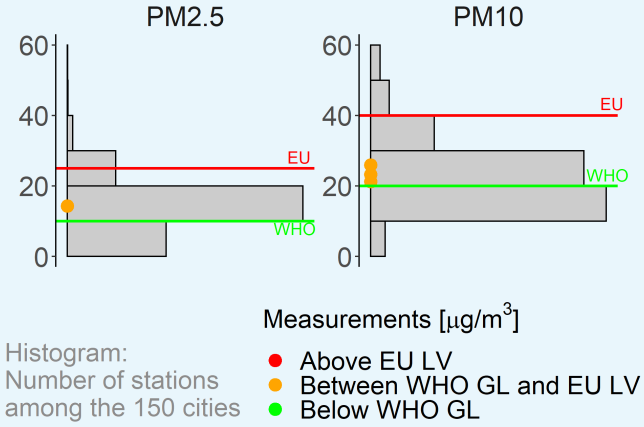
Greater city
Core city

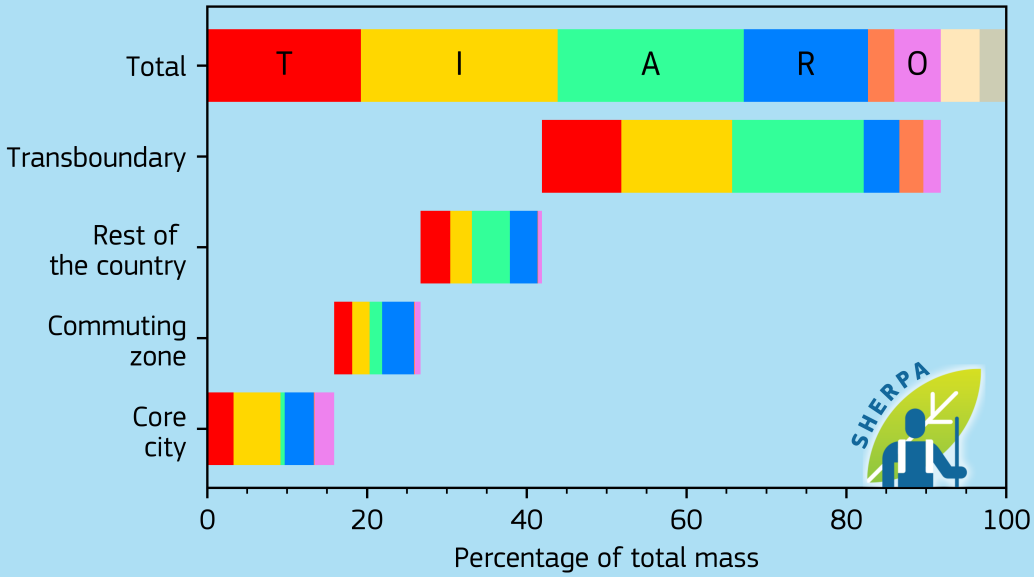
France, Strasbourg



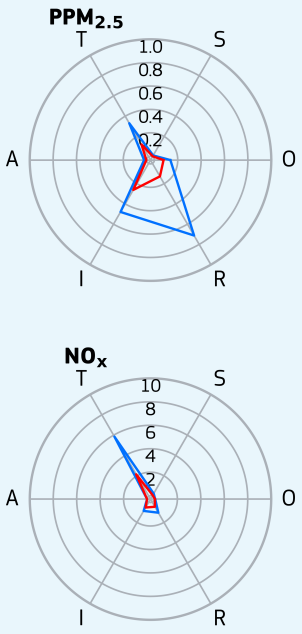
Yearly average urban concentrations (2018)

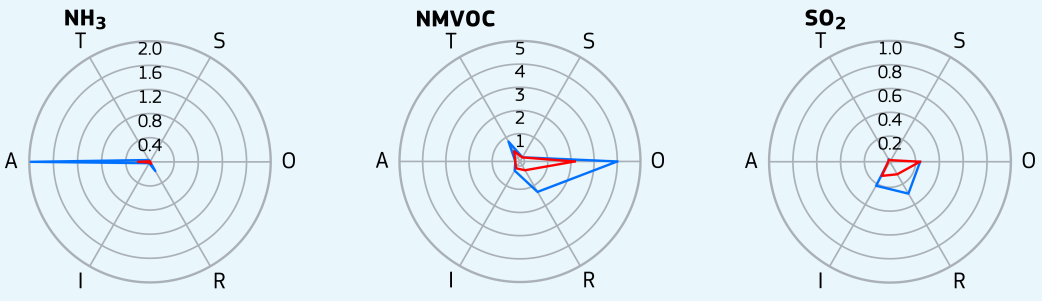


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
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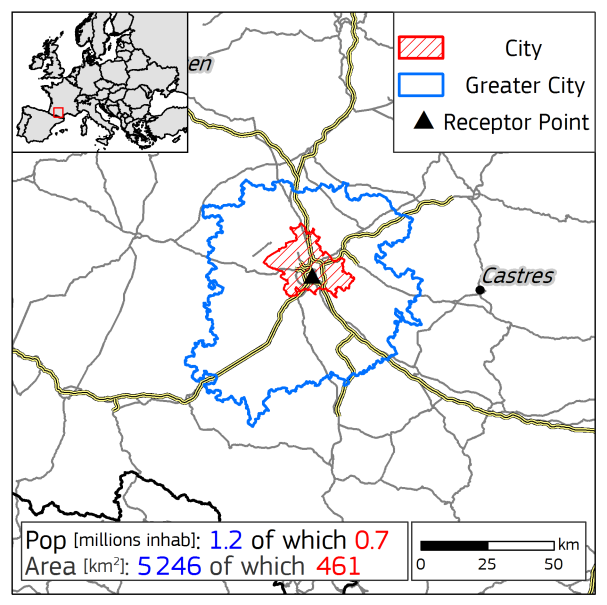
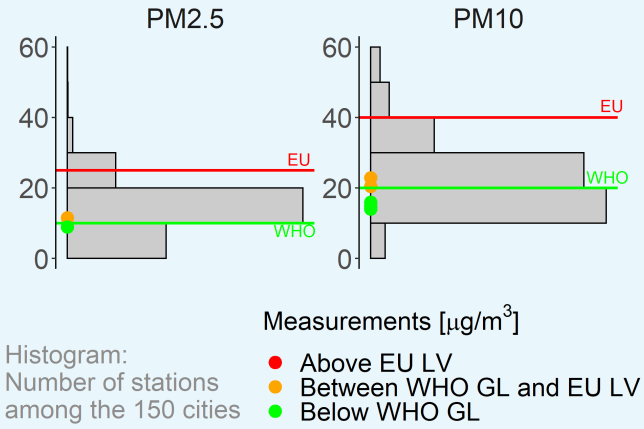
Greater city
Core city

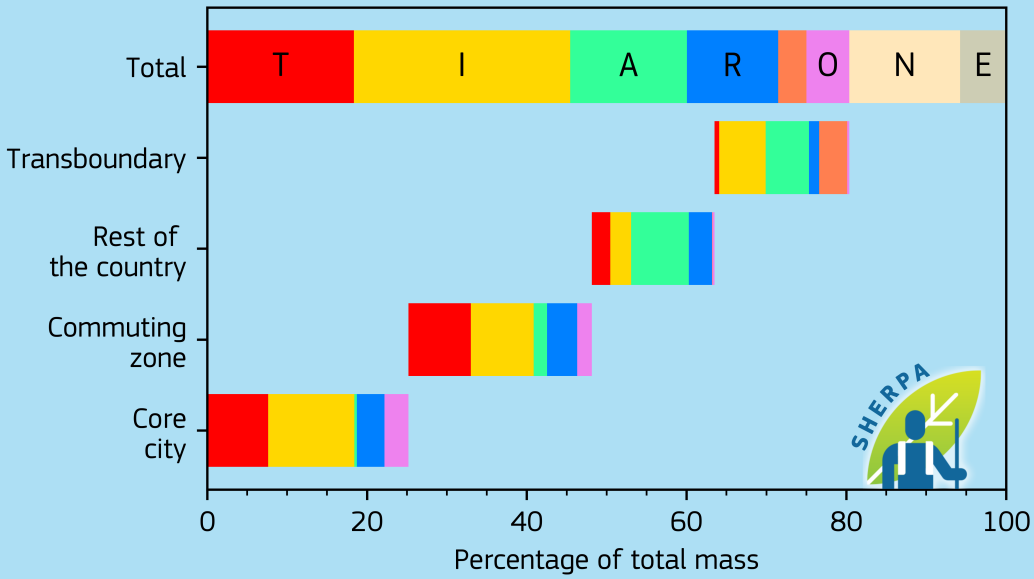
France, Toulouse



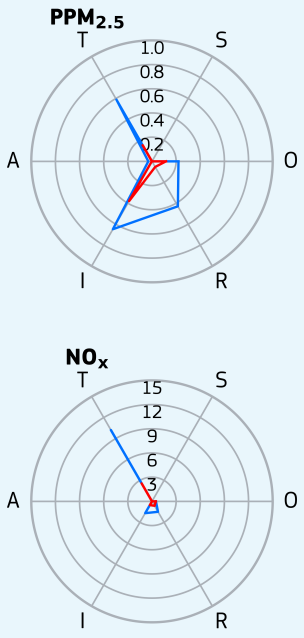
Yearly average urban concentrations (2018)

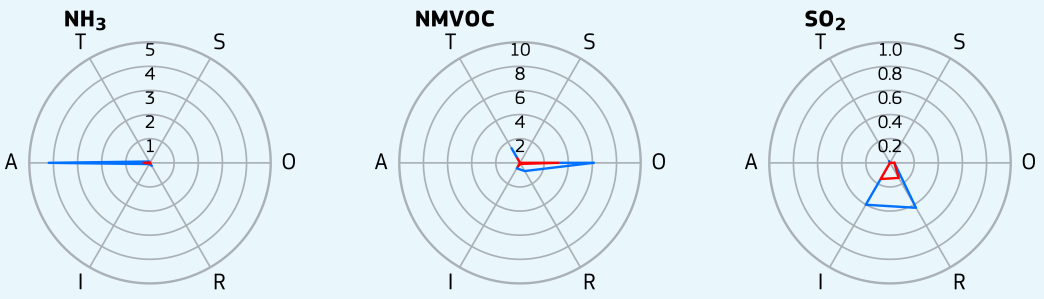


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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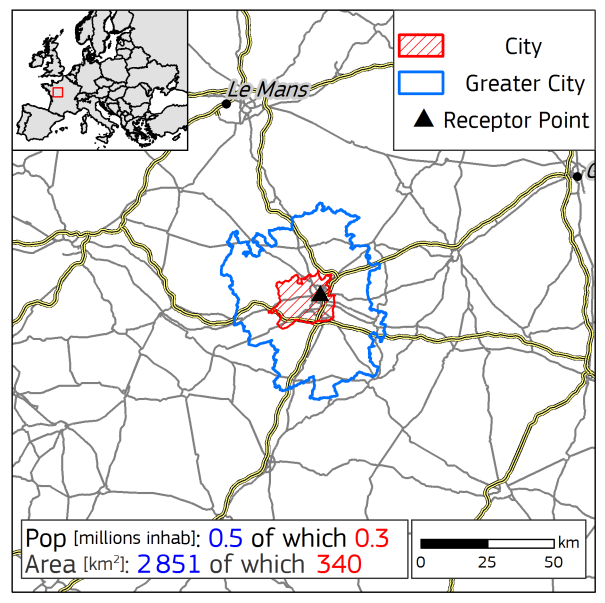
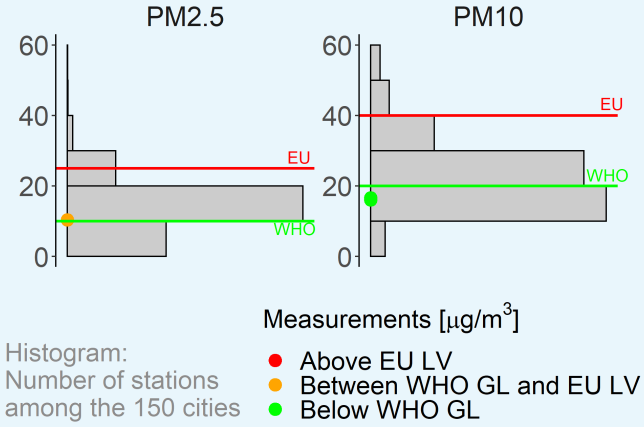
N - Natural
E - External
Greater city
Core city

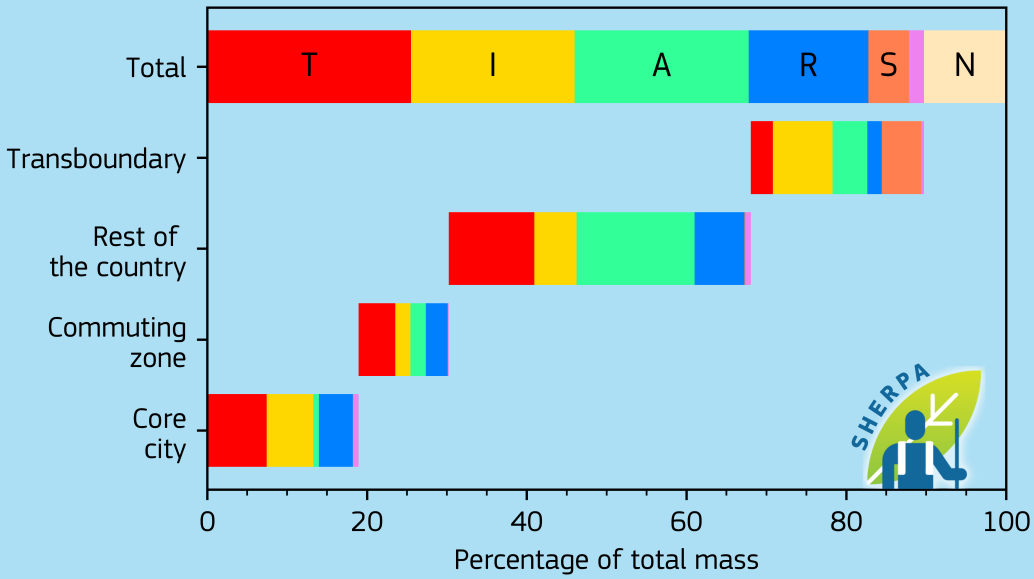
France, Tours



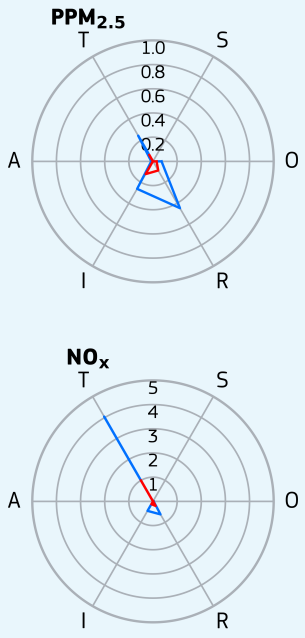
Yearly average urban concentrations (2018)

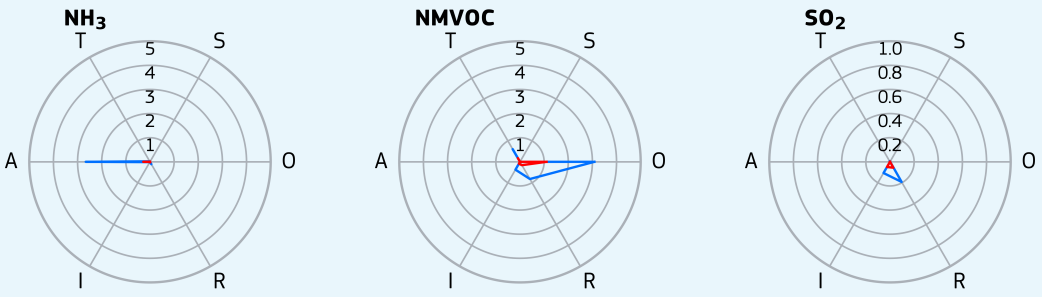


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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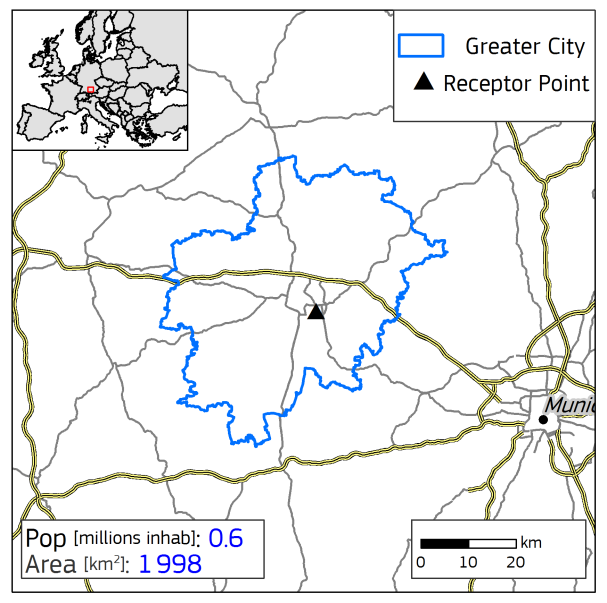
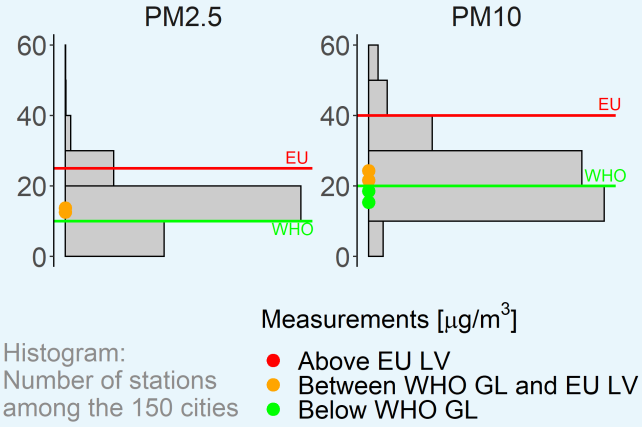
R - Residential
S - Shipping
O - Other
N - Natural
Greater city
Core city

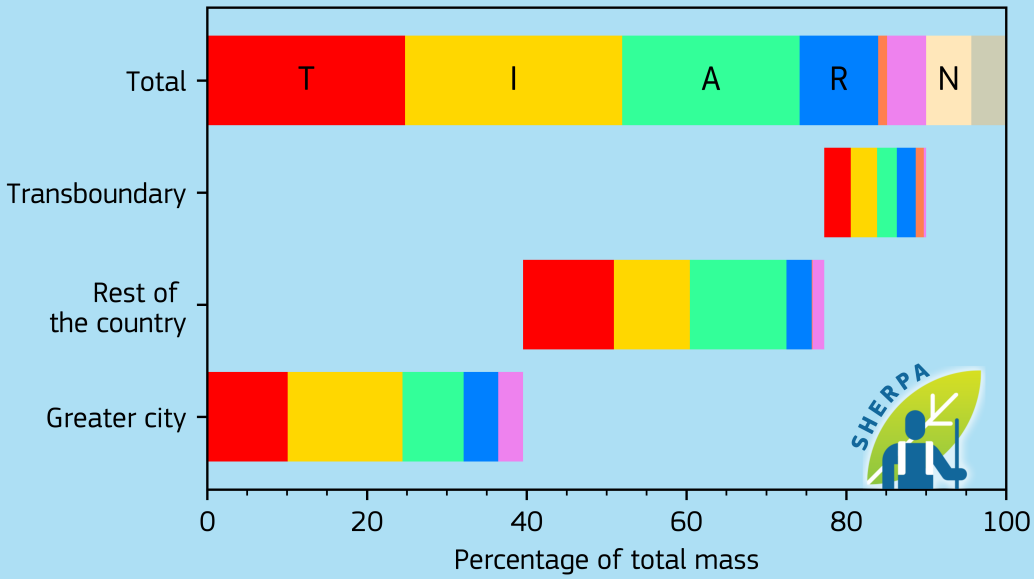
Germany, Augsburg



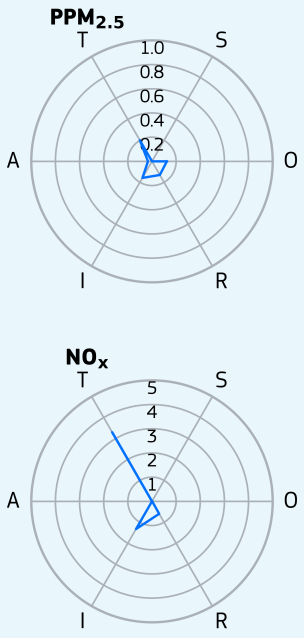
Yearly average urban concentrations (2018)

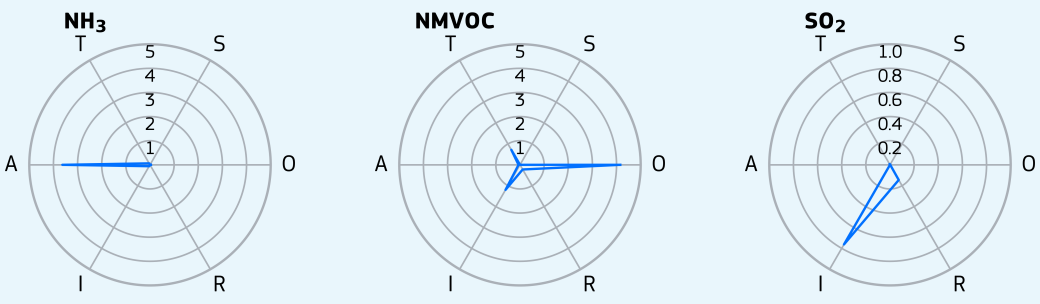


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
- I - Industry
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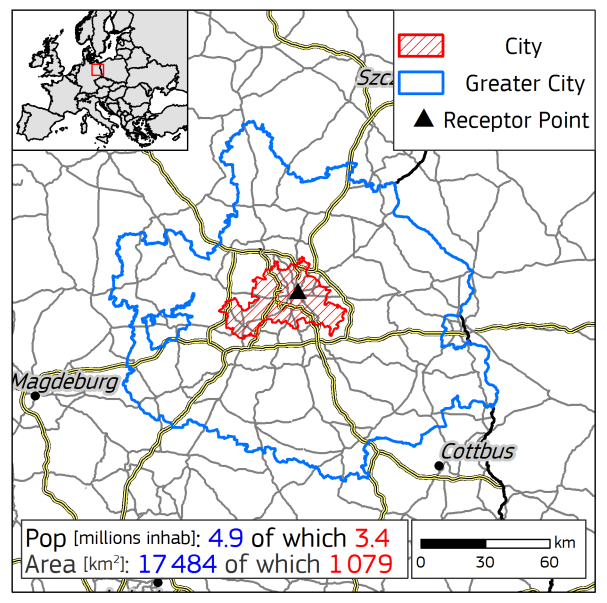
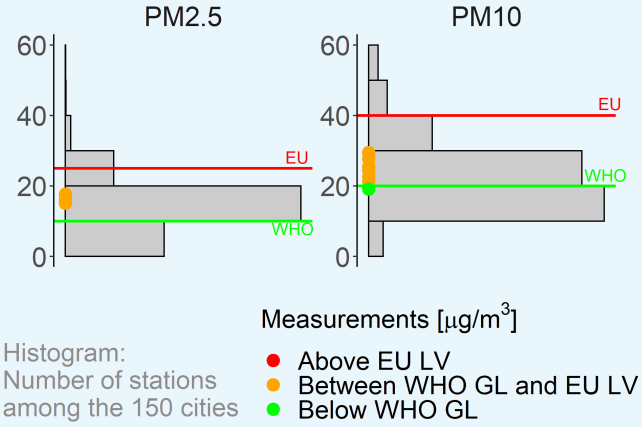
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

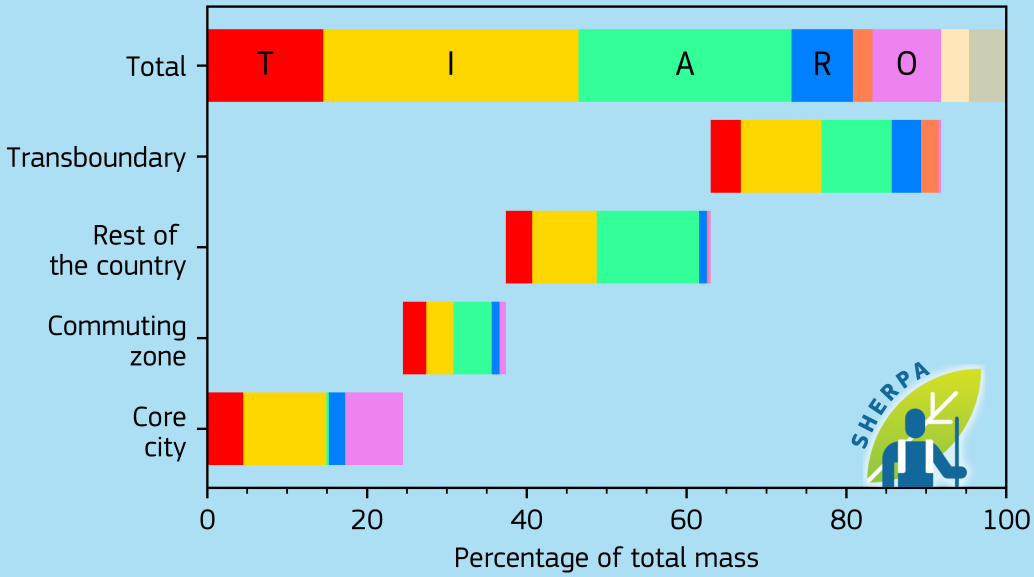
Germany, Berlin



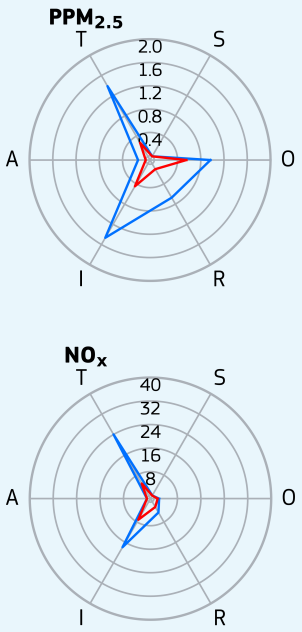
Yearly average urban concentrations (2018)

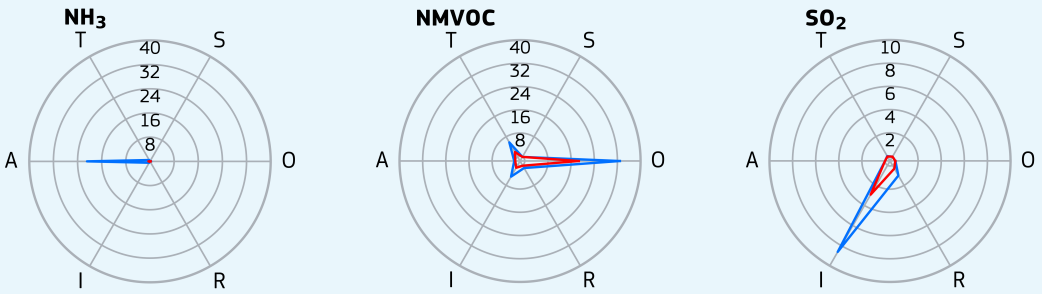


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



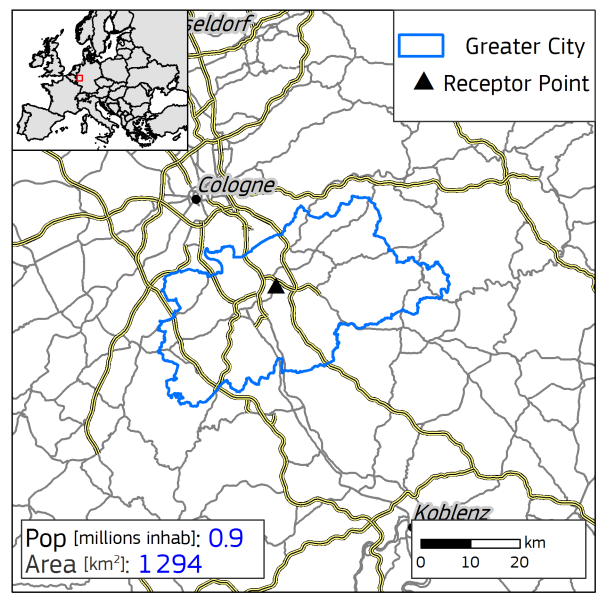
Emissions [kton/year]



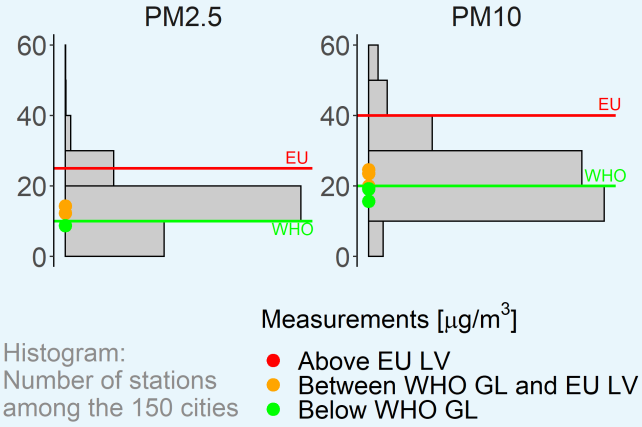


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

Germany, Bonn

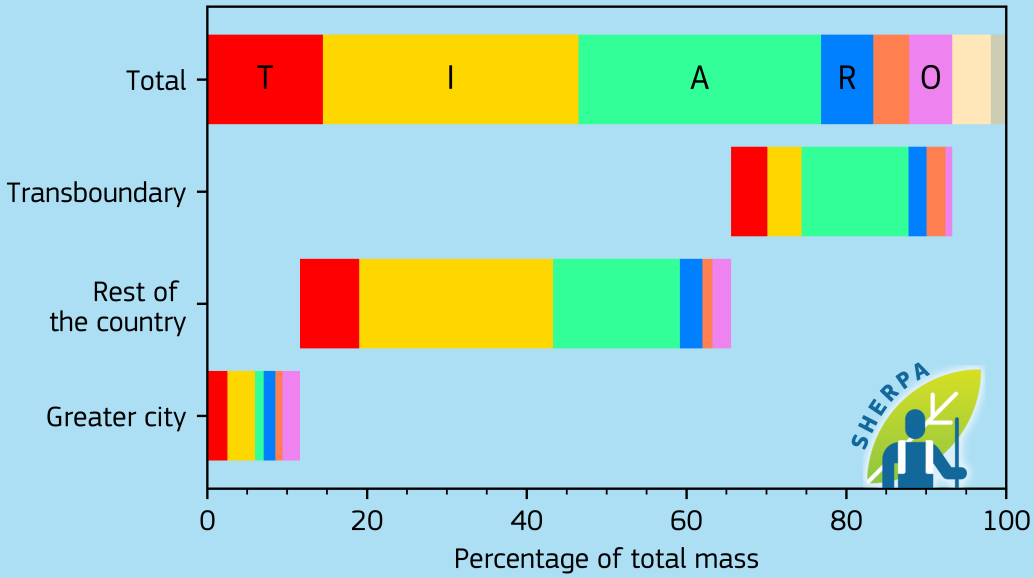


Yearly average urban concentrations (2018)

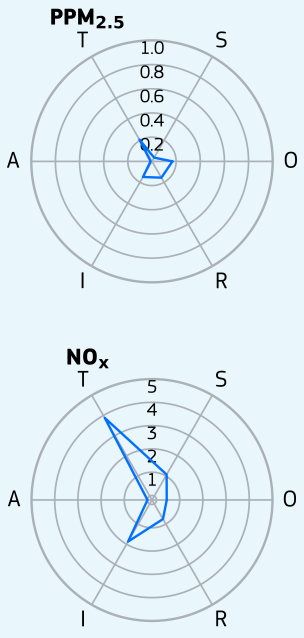


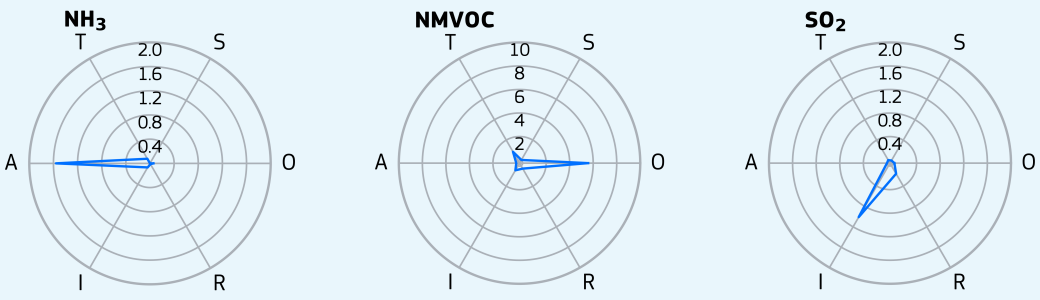
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



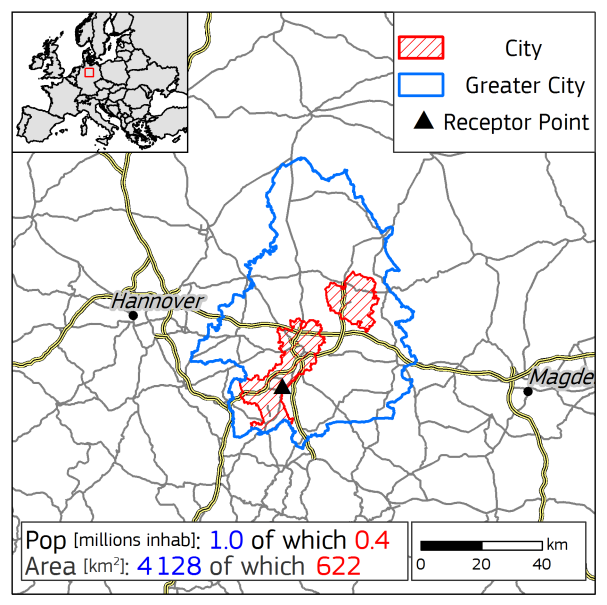
Emissions [kton/year]



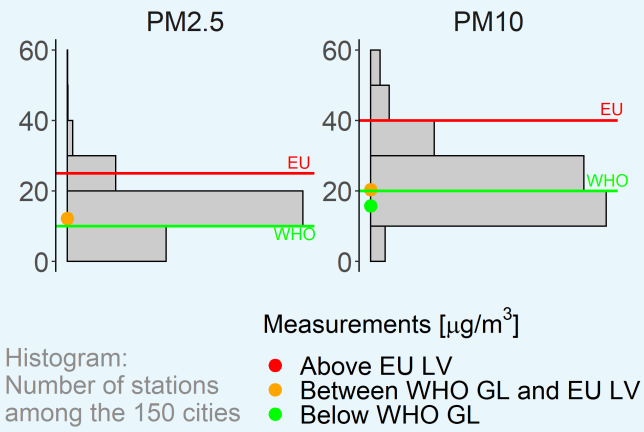


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

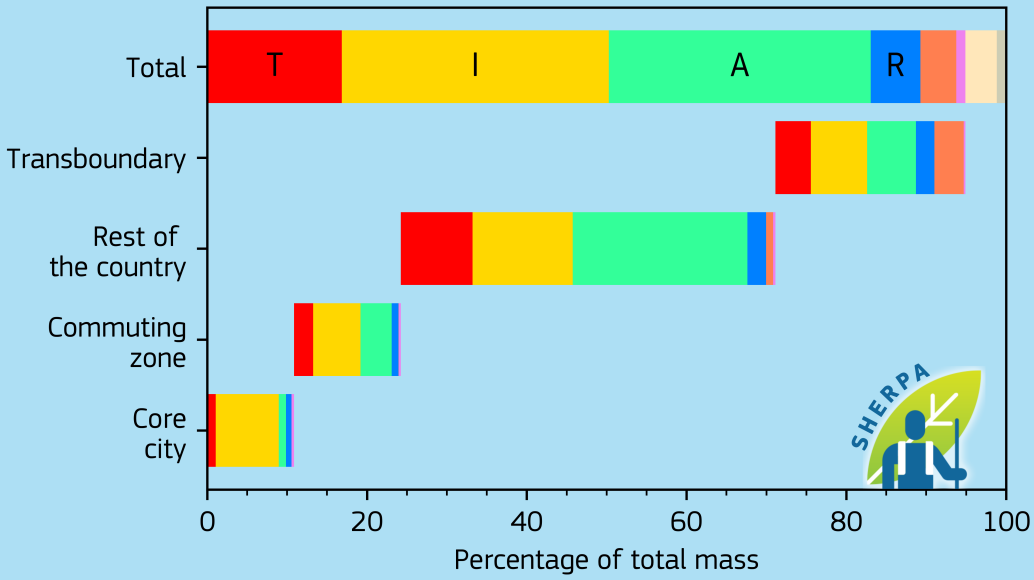
Germany, Braunschweig-Salzgitter-Wolfsburg



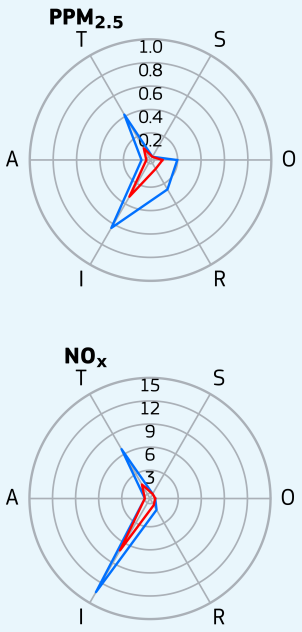
Yearly average urban concentrations (2018)

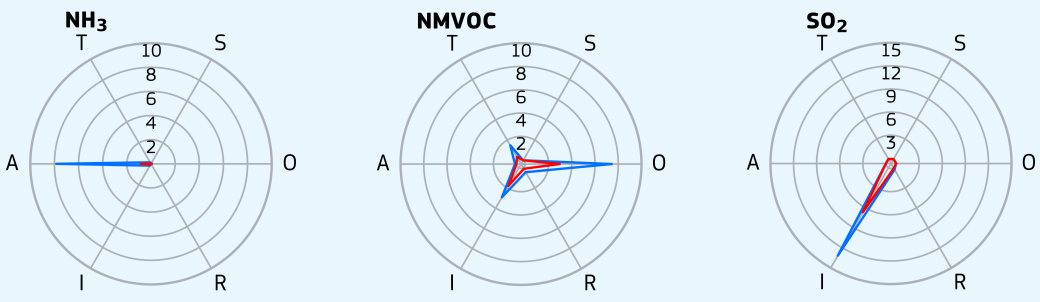


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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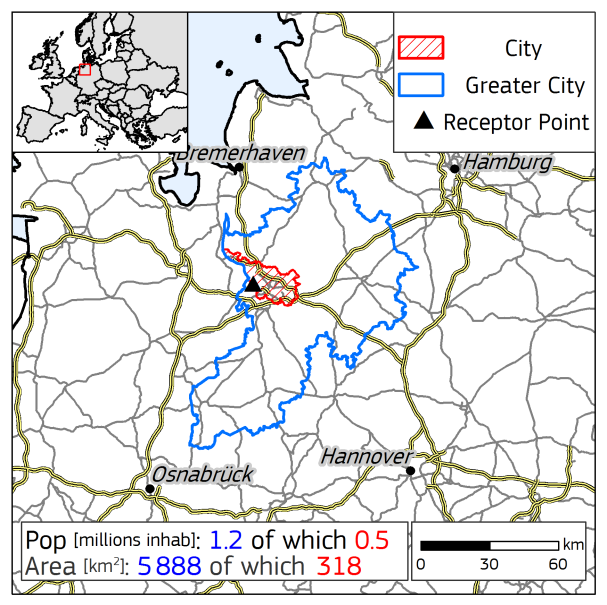
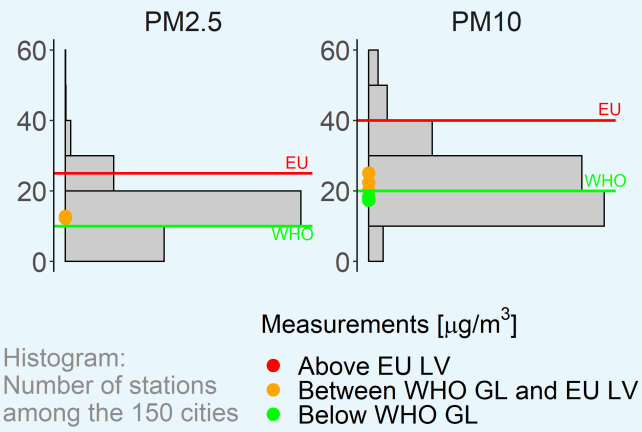
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

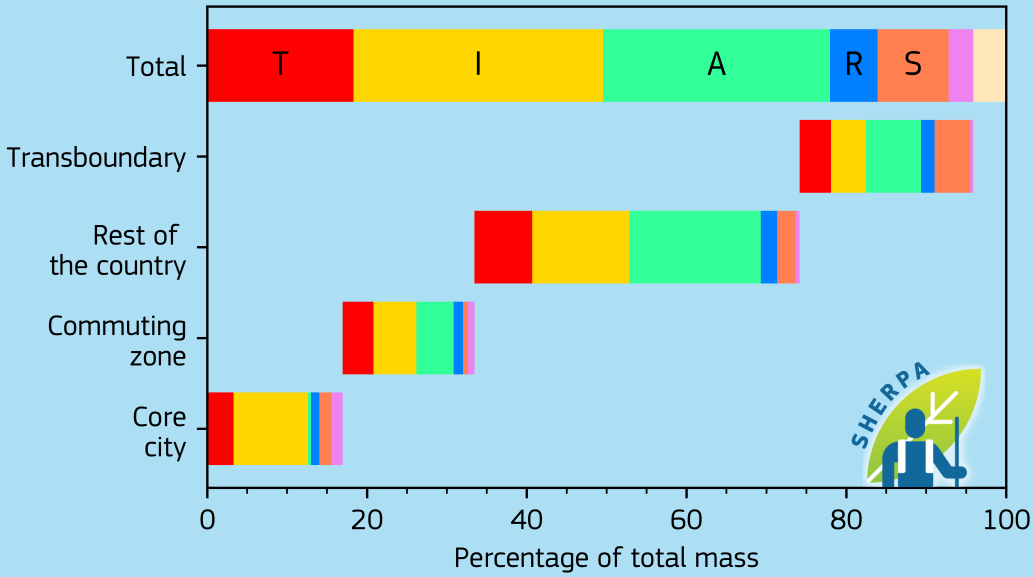
Germany, Bremen



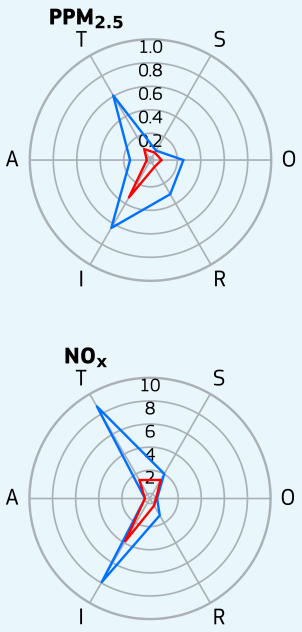
Yearly average urban concentrations (2018)

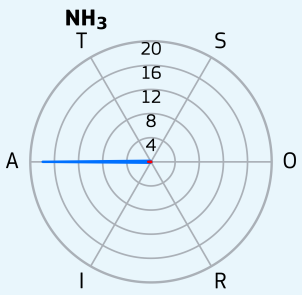


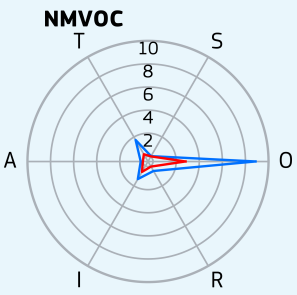
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

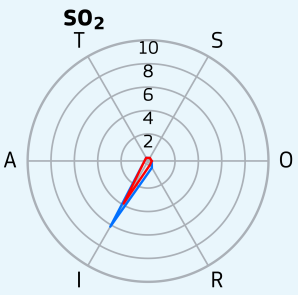


Emissions [kton/year]



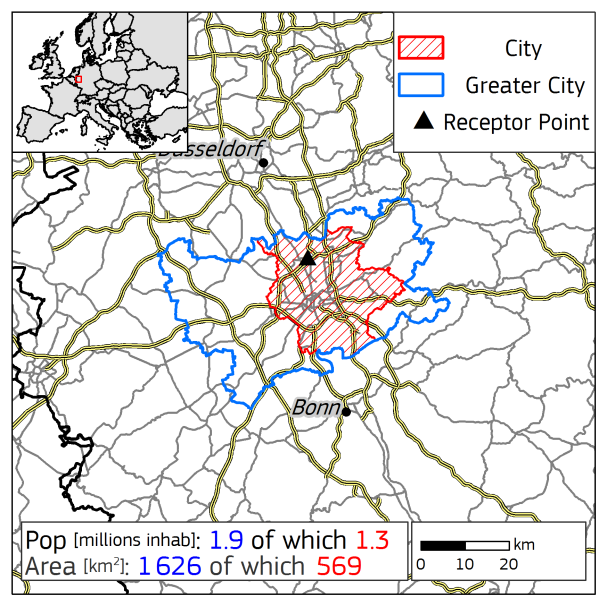




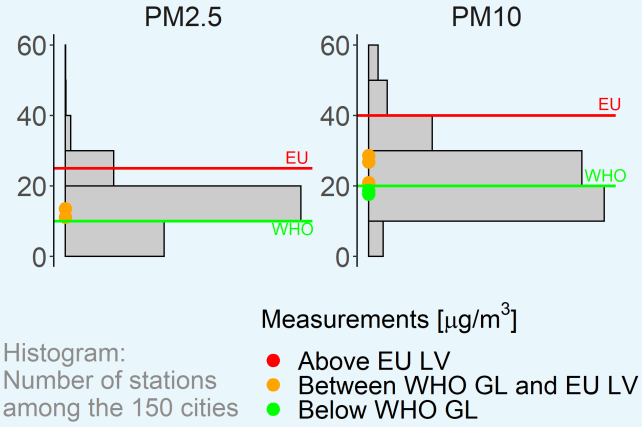


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- Greater city
- Core city

Germany, Cologne

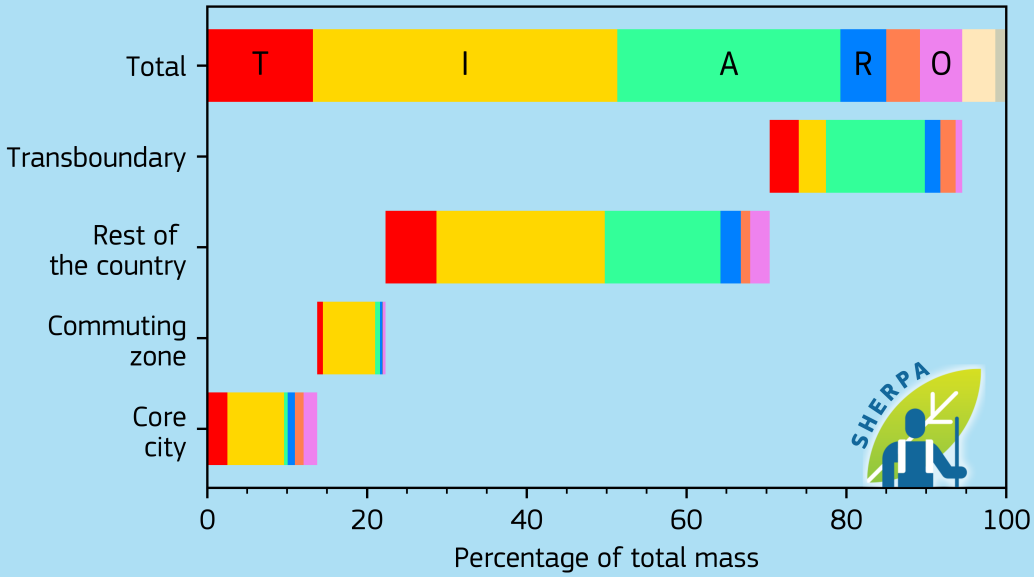


Yearly average urban concentrations (2018)

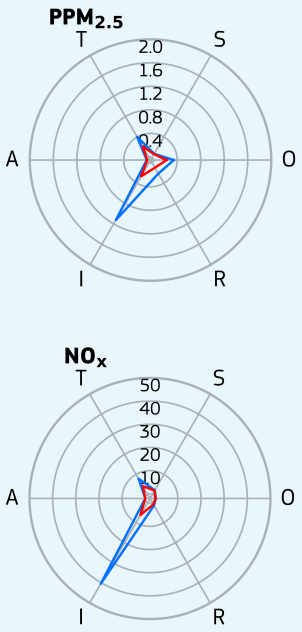


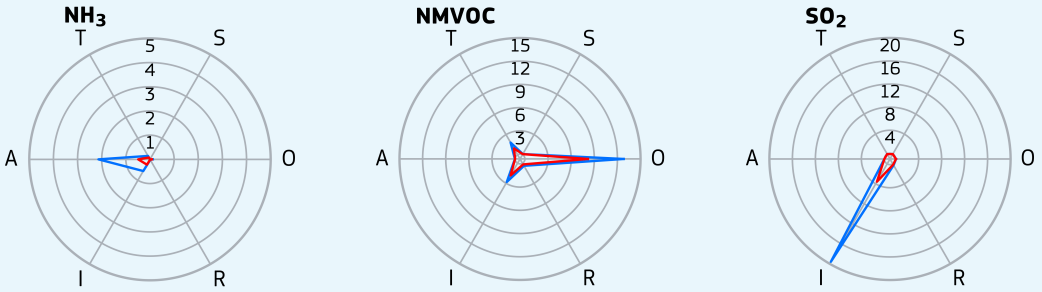
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



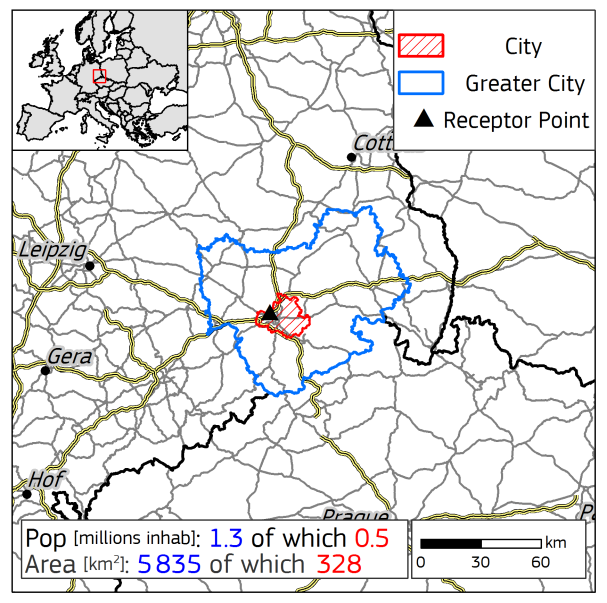
Emissions [kton/year]



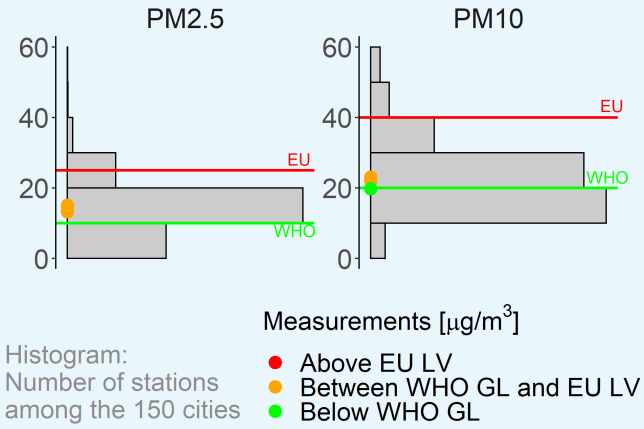


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

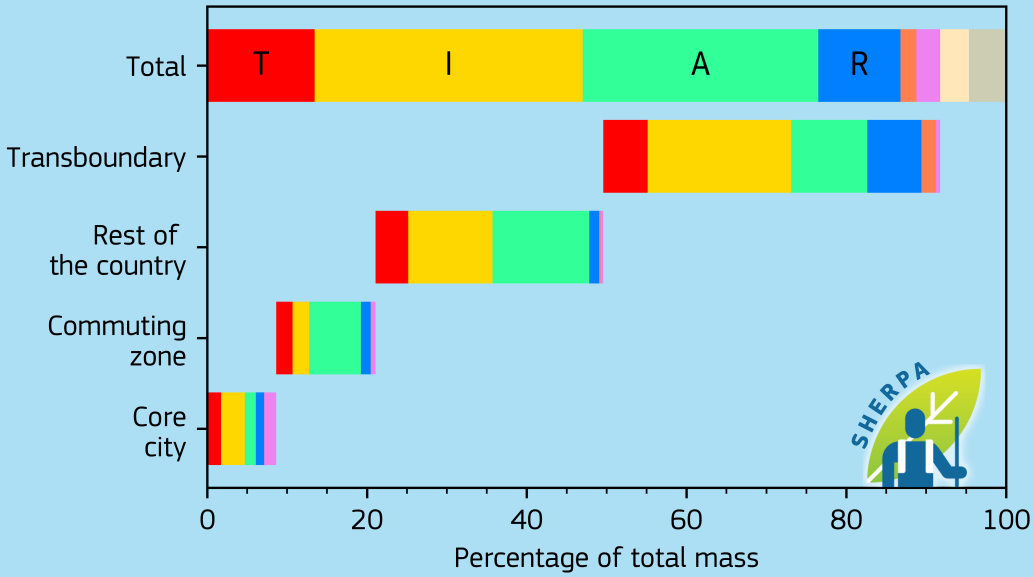
Germany, Dresden



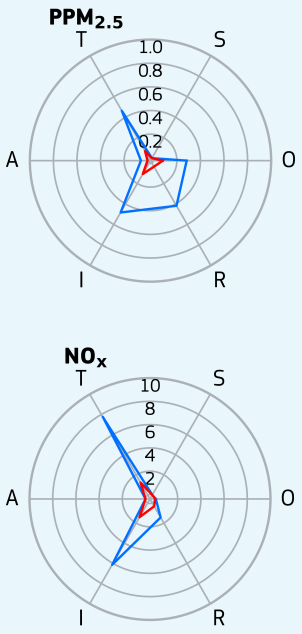
Yearly average urban concentrations (2018)

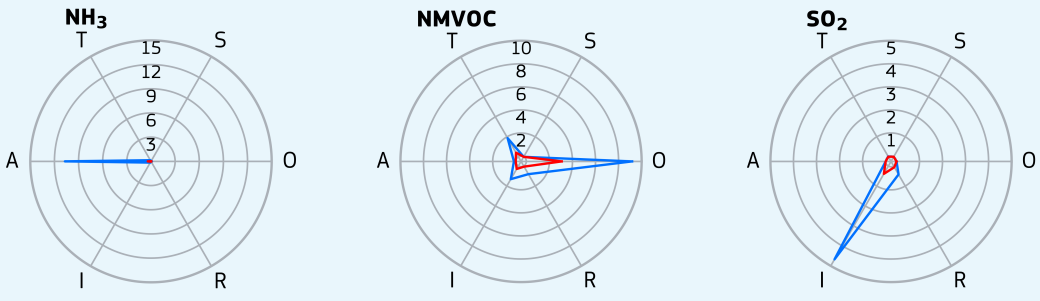


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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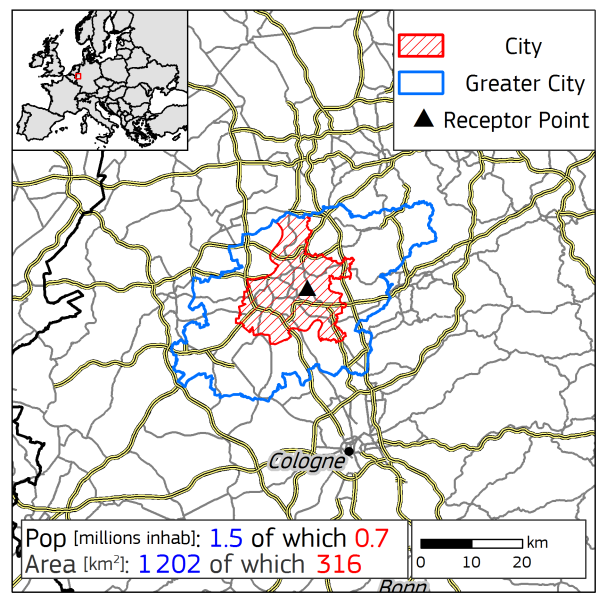
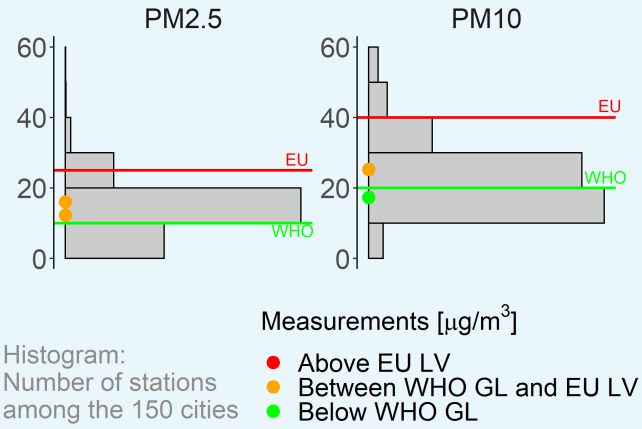
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

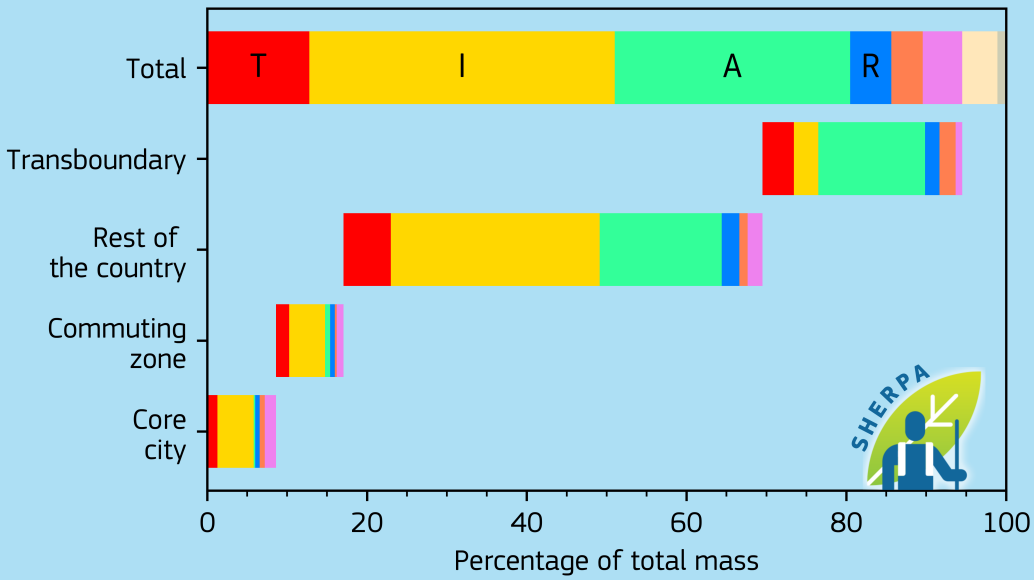
Germany, Düsseldorf



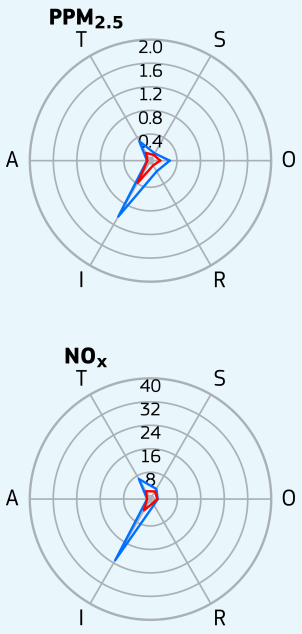
Yearly average urban concentrations (2018)

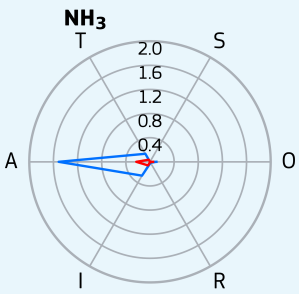


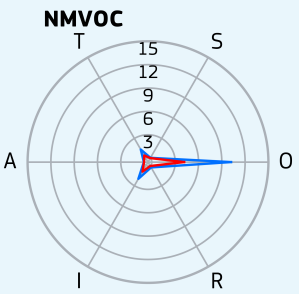
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

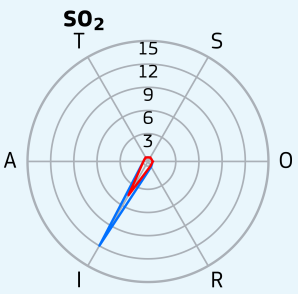


Emissions [kton/year]



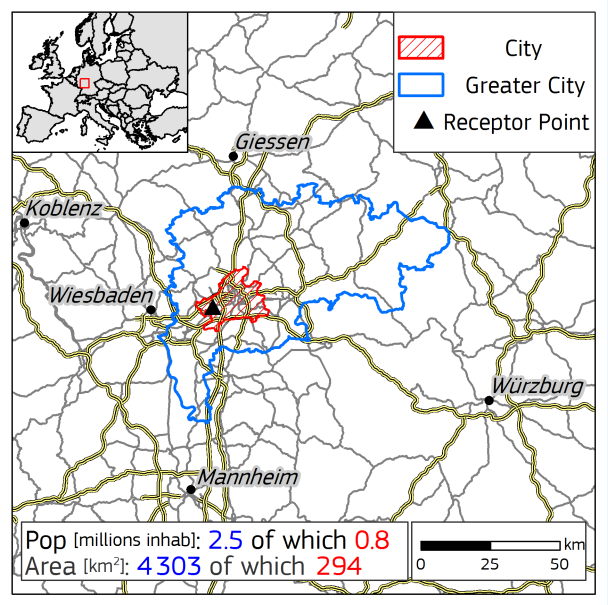




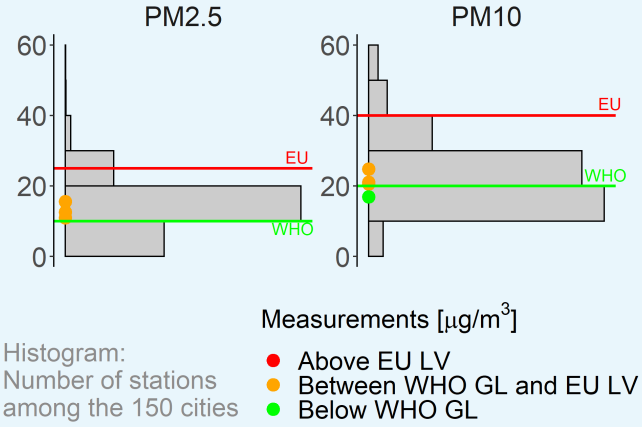


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

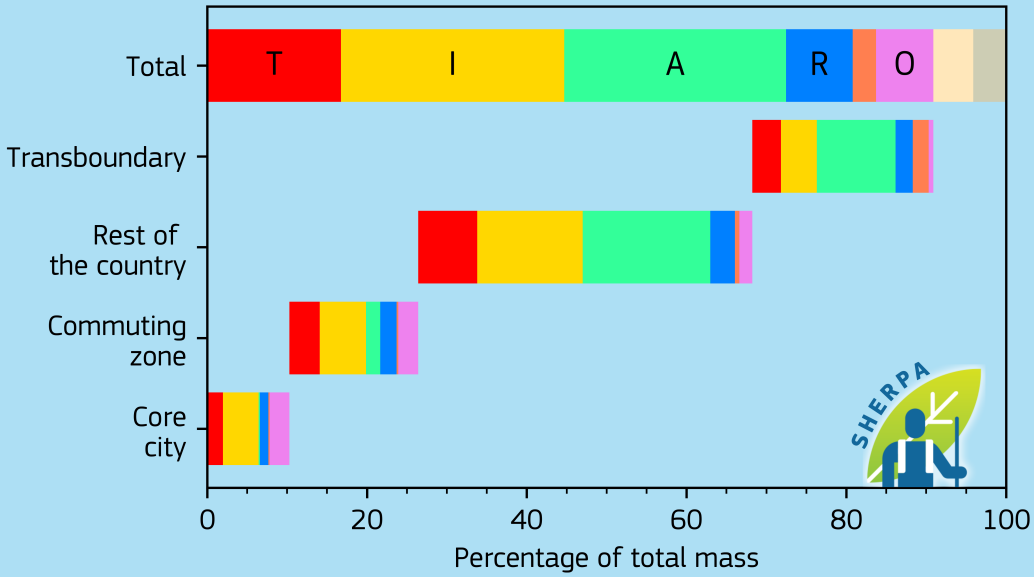
Germany, Frankfurt



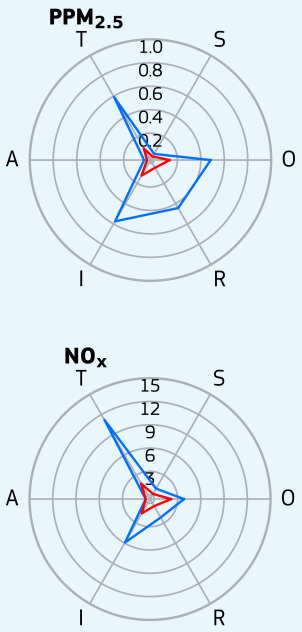
Yearly average urban concentrations (2018)

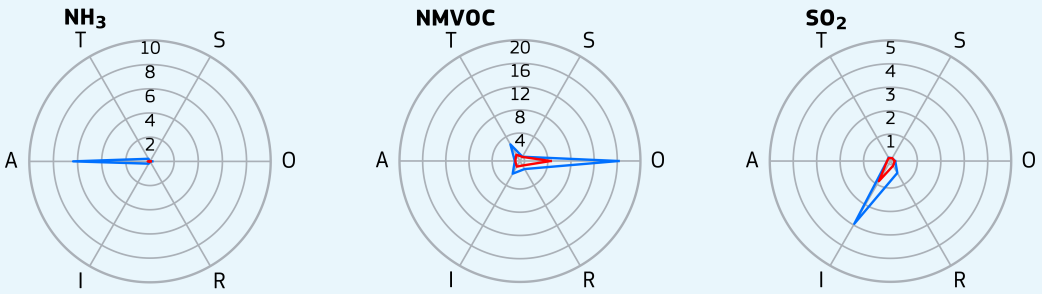


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
I - Industry
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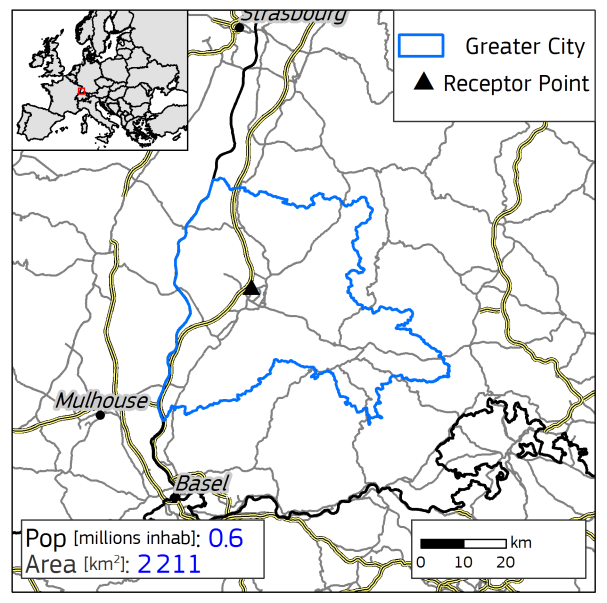
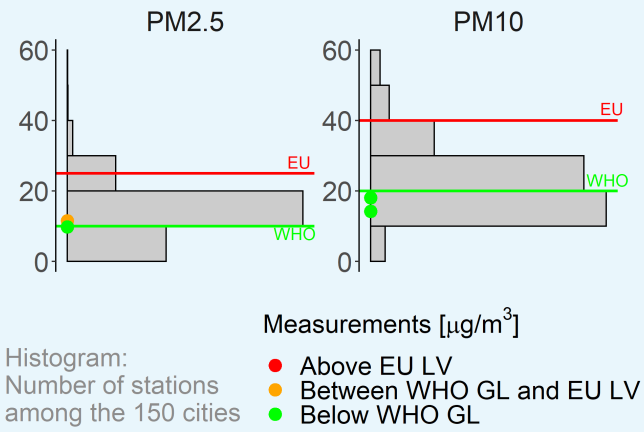
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

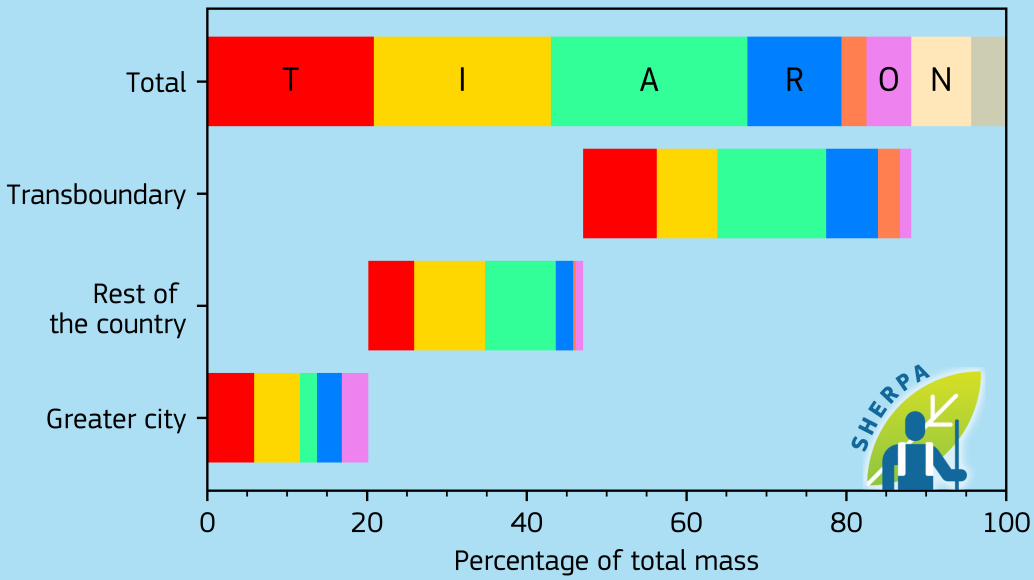
Germany, Freiburg im Breisgau



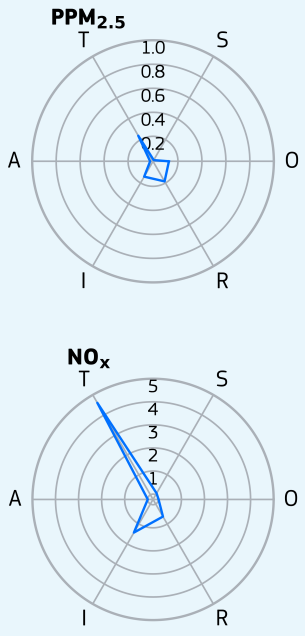
Yearly average urban concentrations (2018)

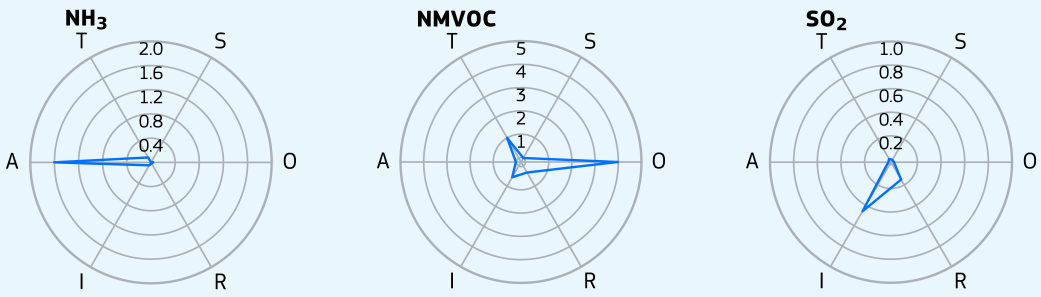


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



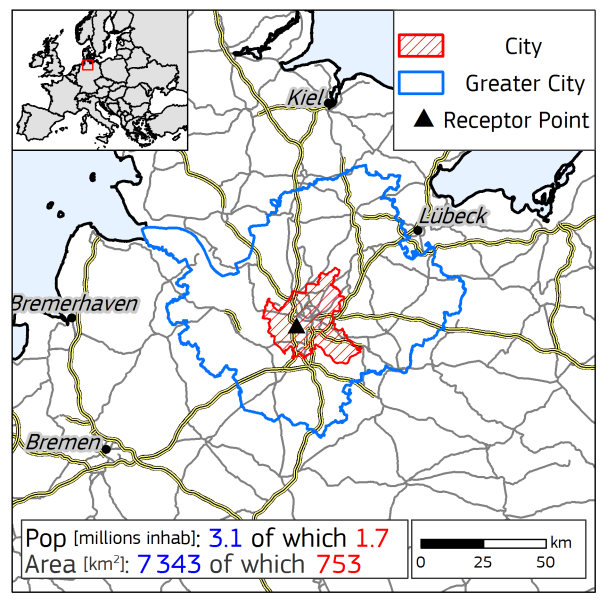
Emissions [kton/year]



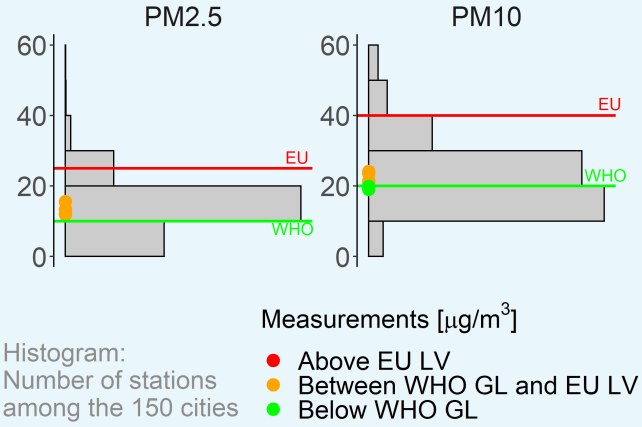


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

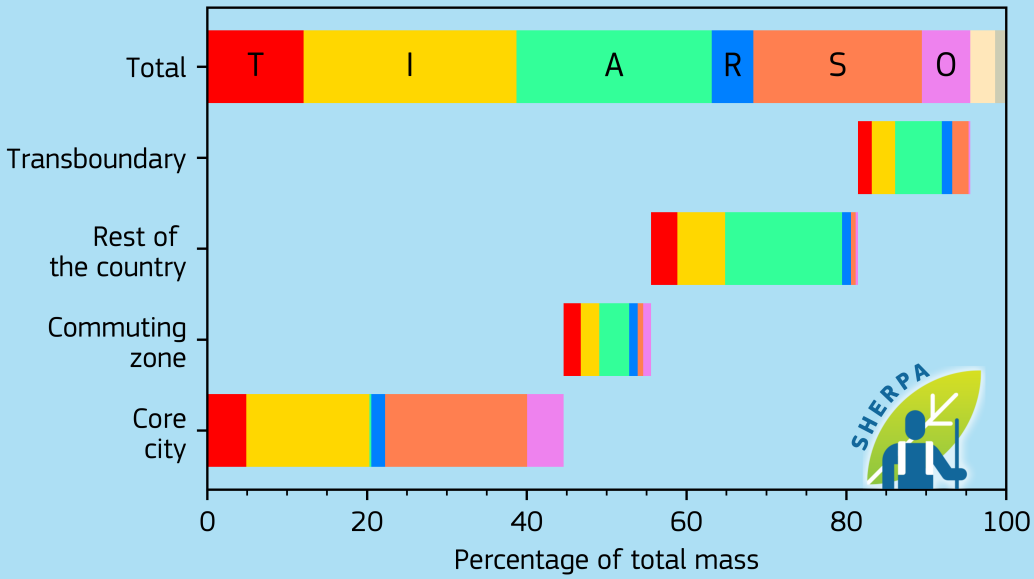
Germany, Hamburg



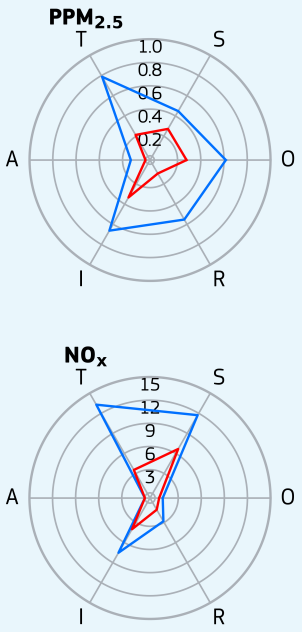
Yearly average urban concentrations (2018)

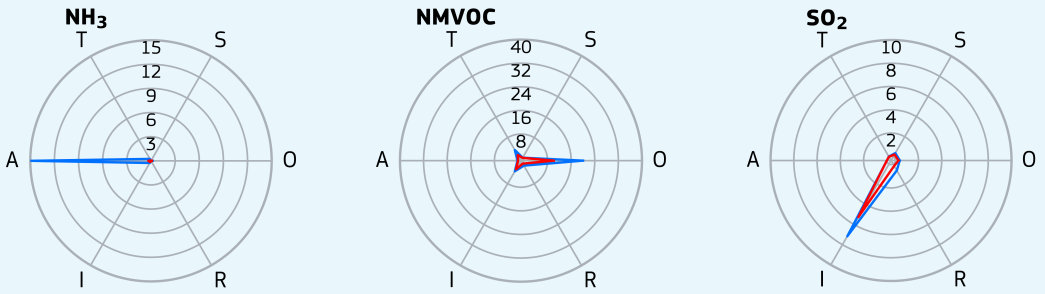


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



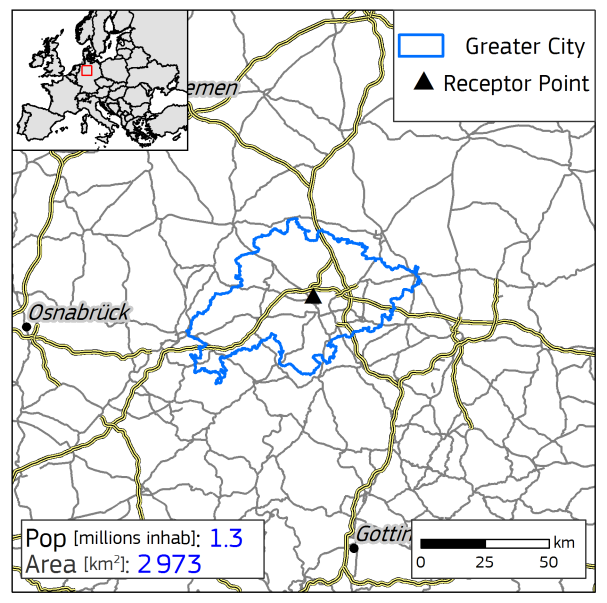
Emissions [kton/year]



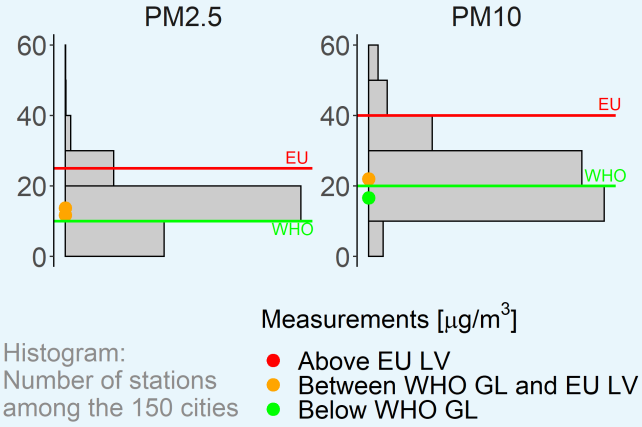


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

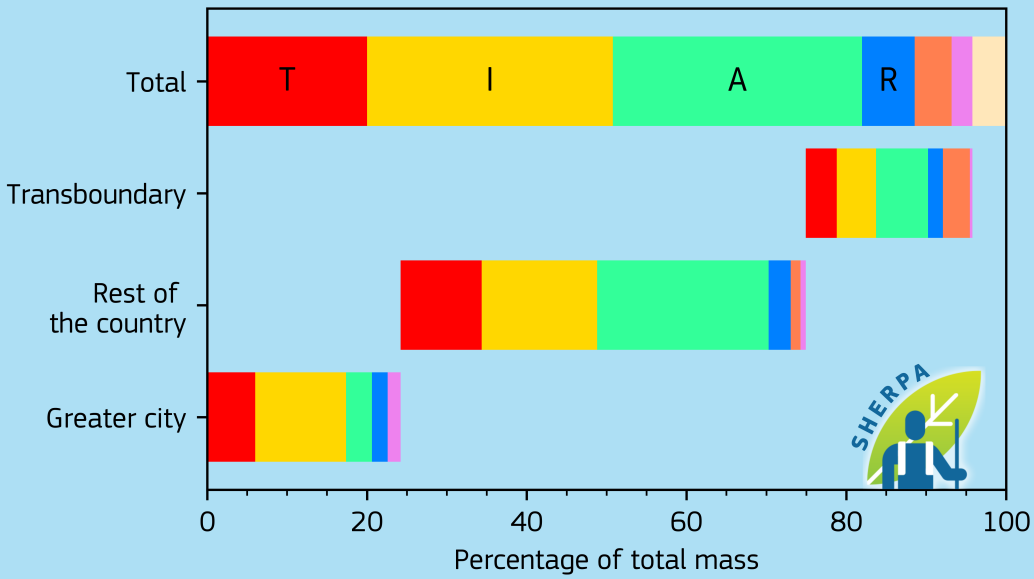
Germany, Hannover



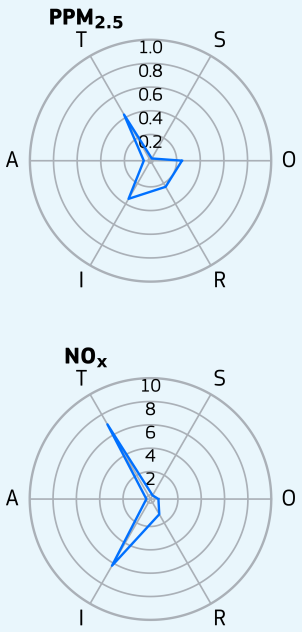
Yearly average urban concentrations (2018)

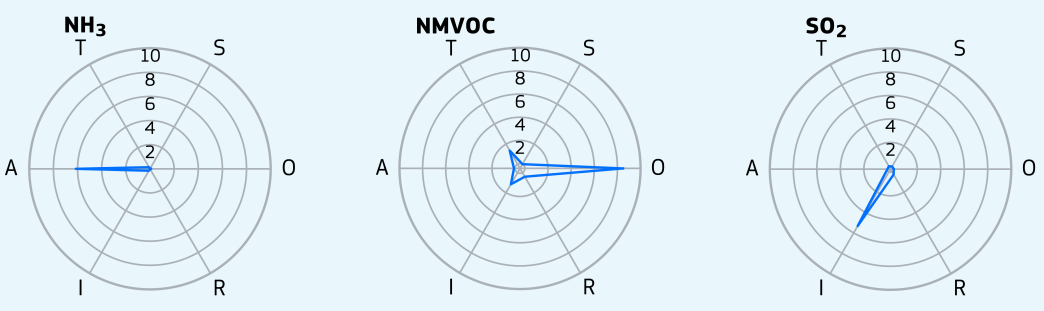


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



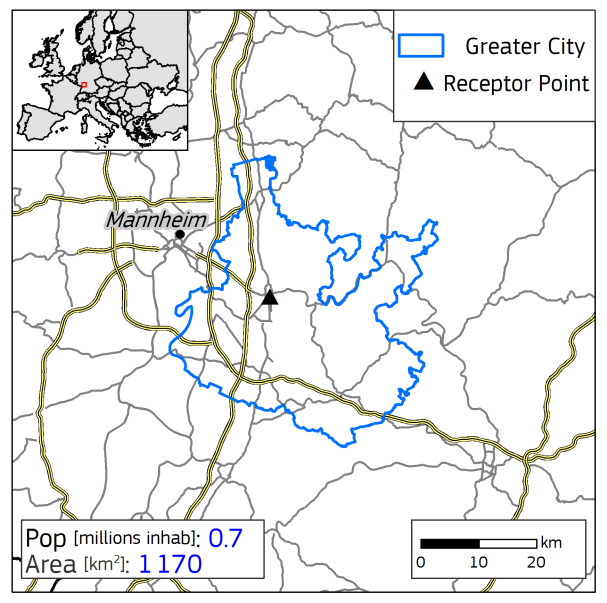
Emissions [kton/year]



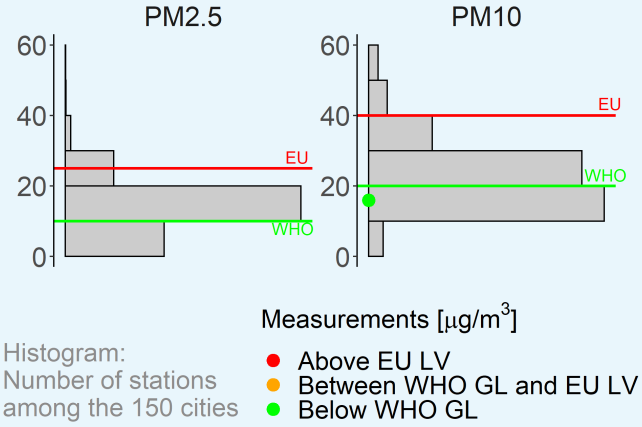


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

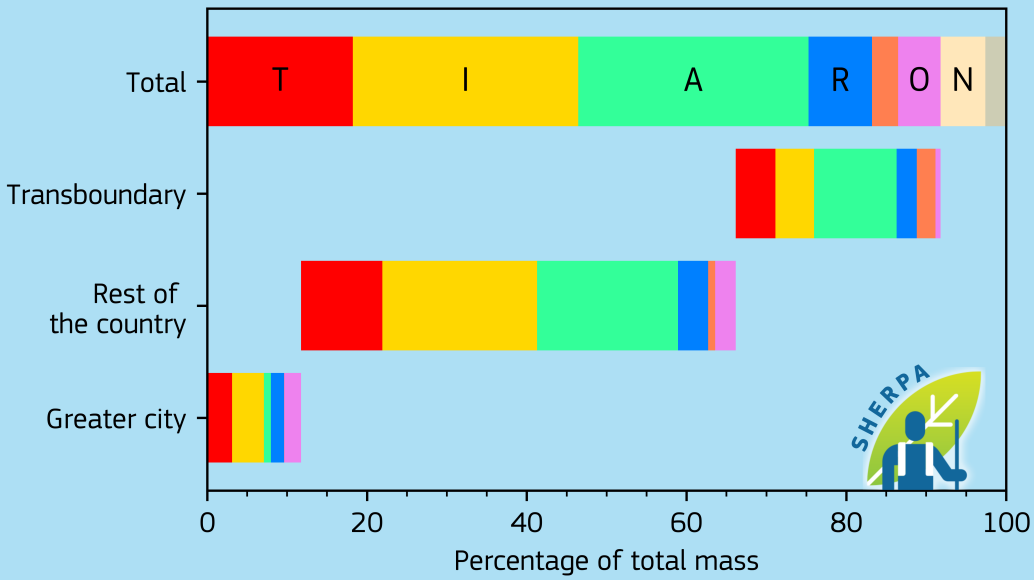
Germany, Heidelberg



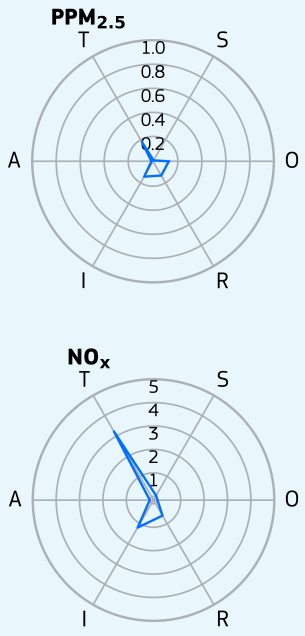
Yearly average urban concentrations (2018)

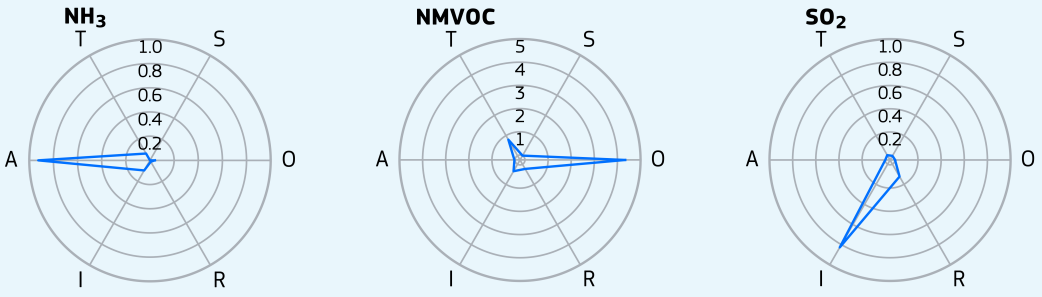


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



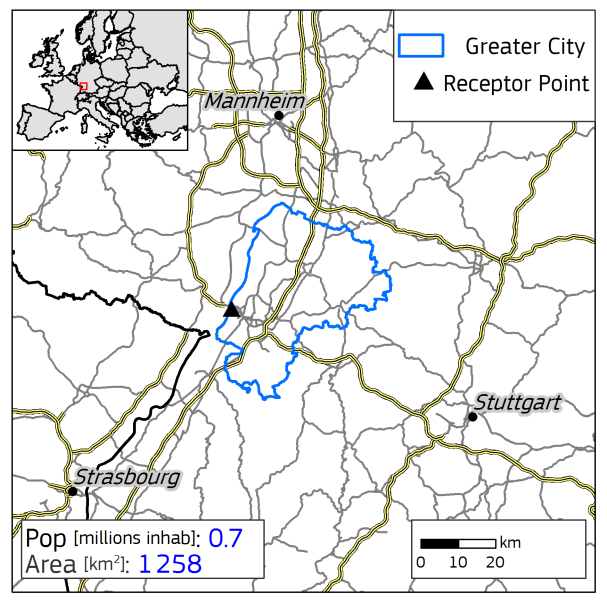
Emissions [kton/year]



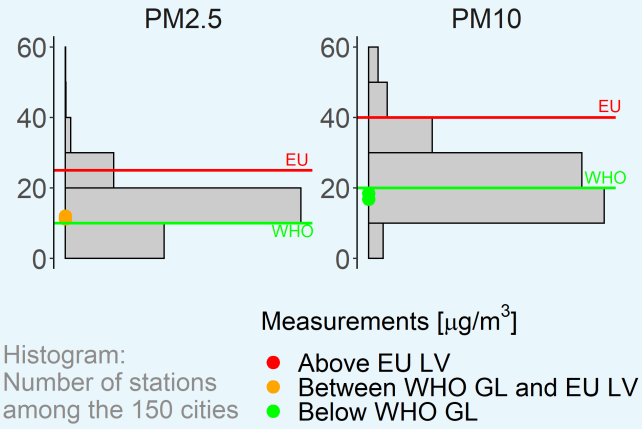


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city

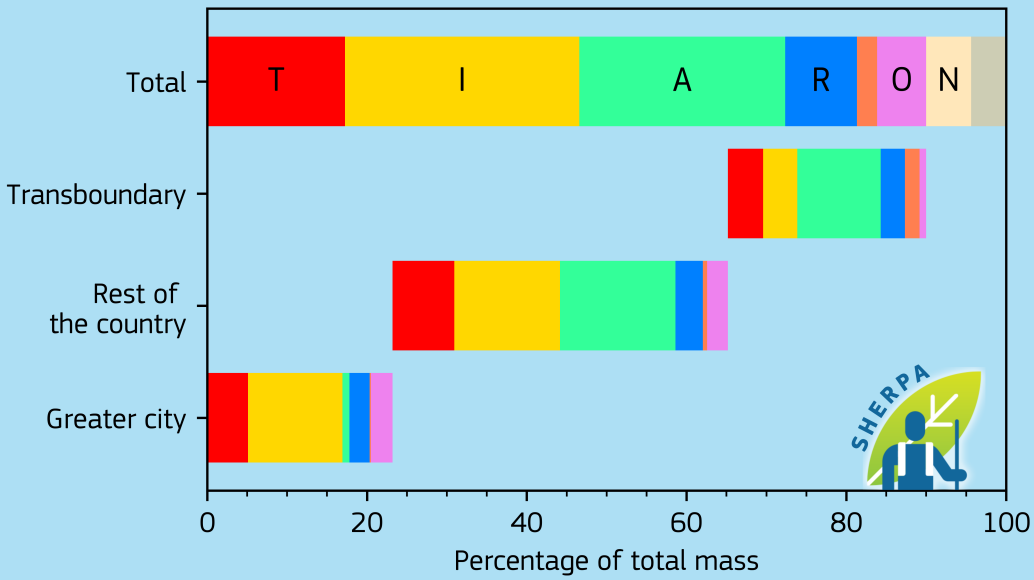
Germany, Karlsruhe



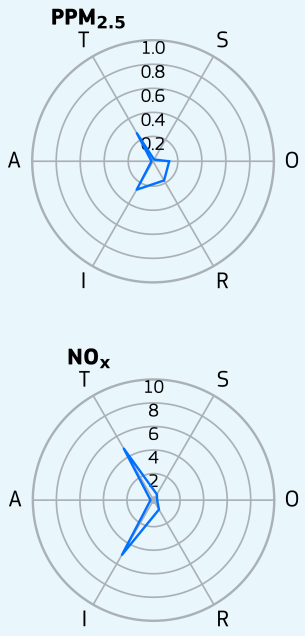
Yearly average urban concentrations (2018)

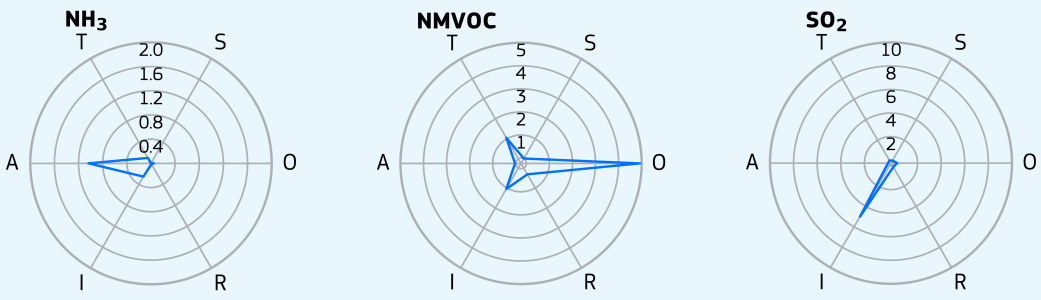


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]



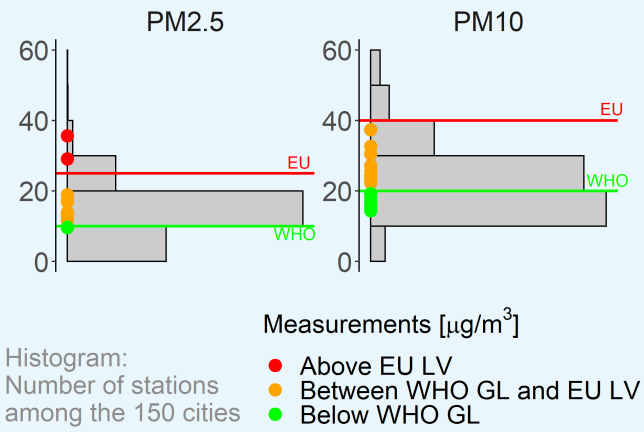


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

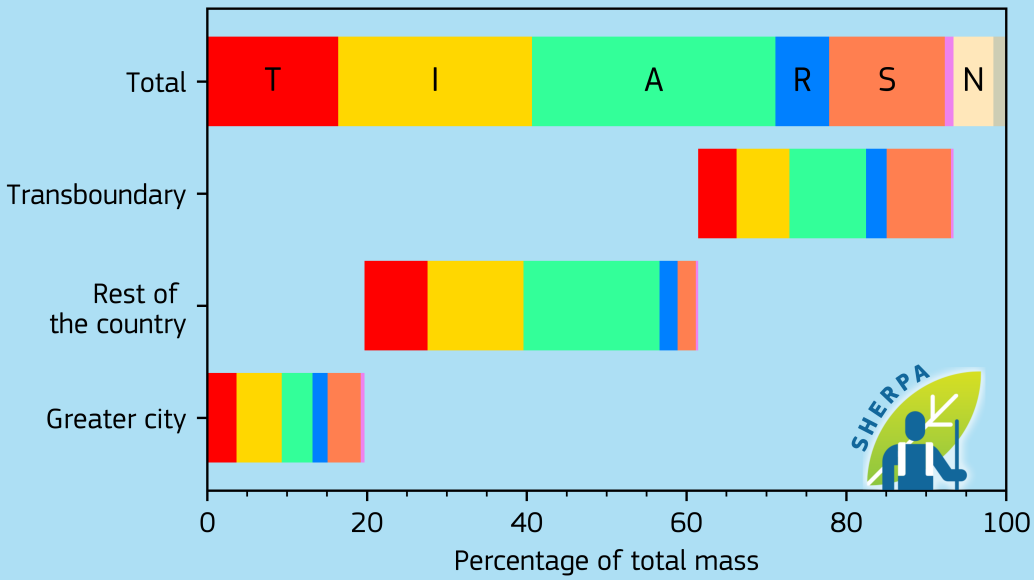
Germany, Kiel



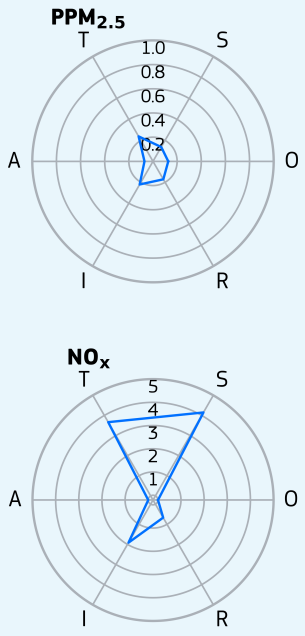
Yearly average urban concentrations (2018)

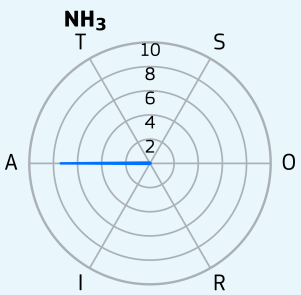


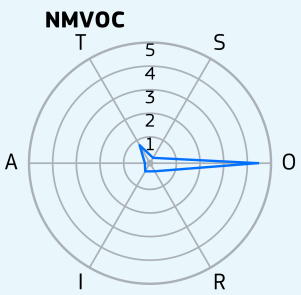
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

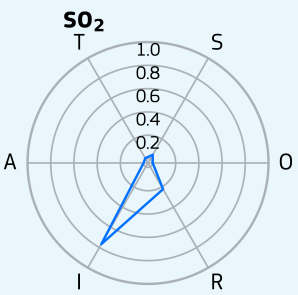


Emissions [kton/year]



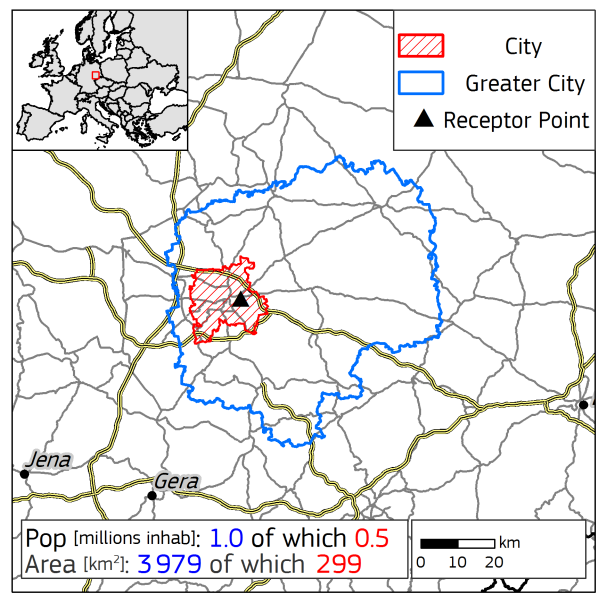




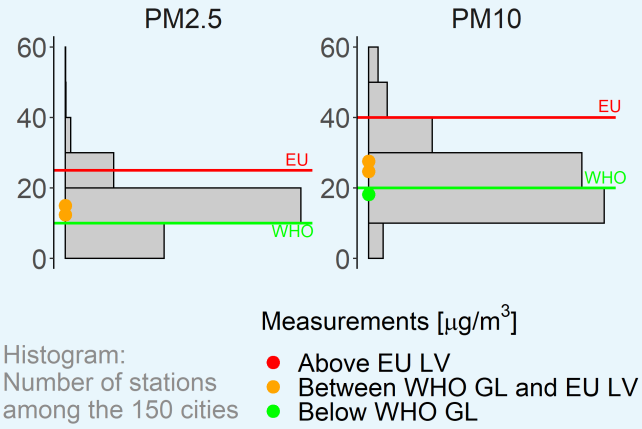


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

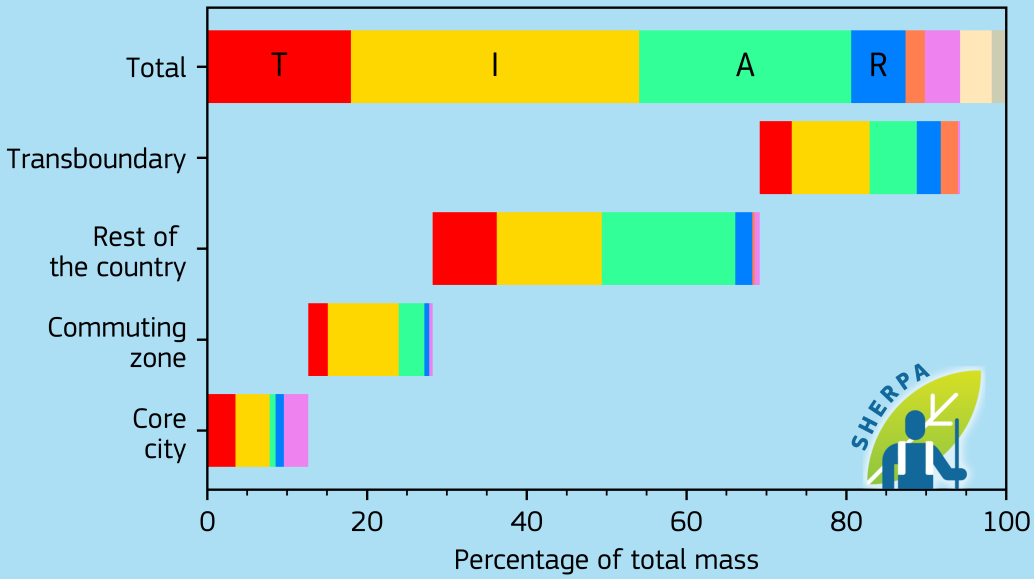
Germany, Leipzig



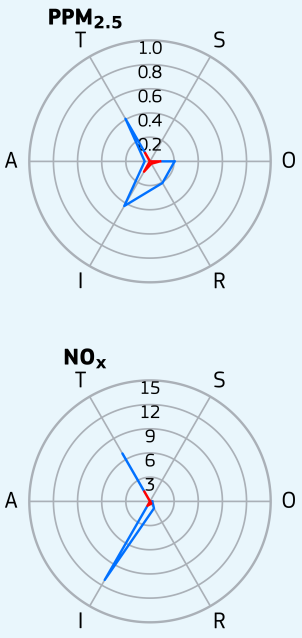
Yearly average urban concentrations (2018)

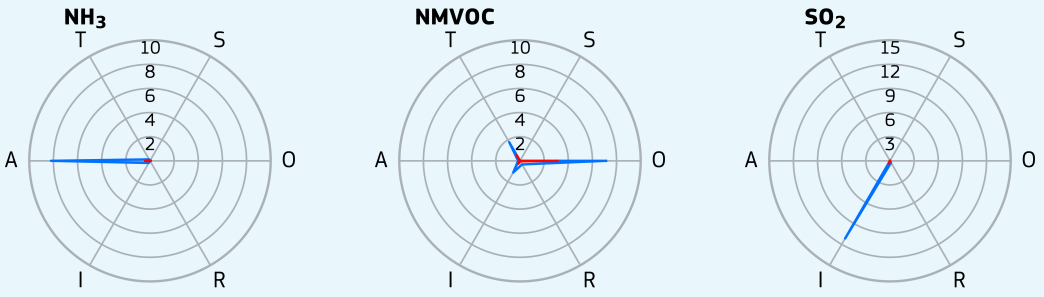


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



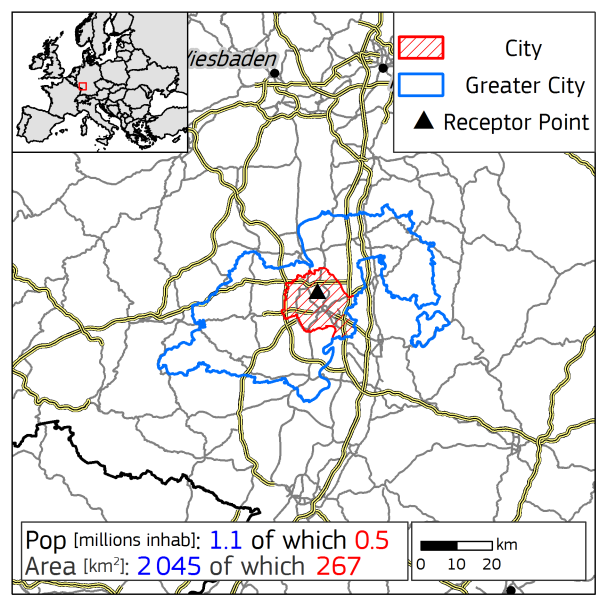
Emissions [kton/year]



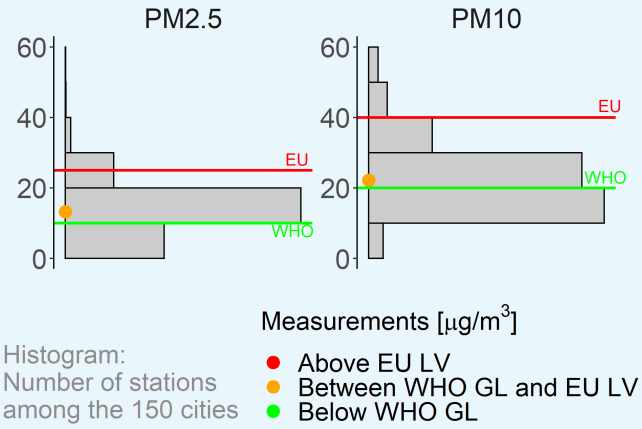


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

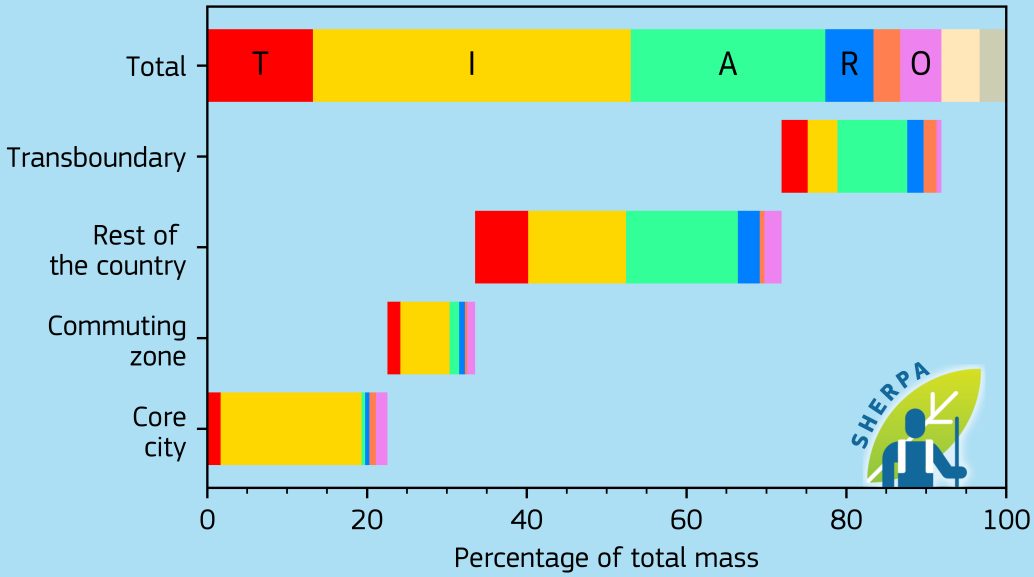
Germany, Mannheim-Ludwigshafen



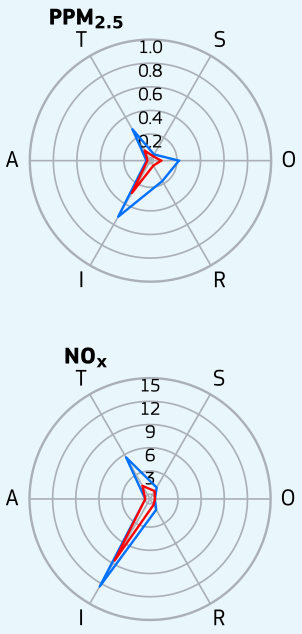
Yearly average urban concentrations (2018)

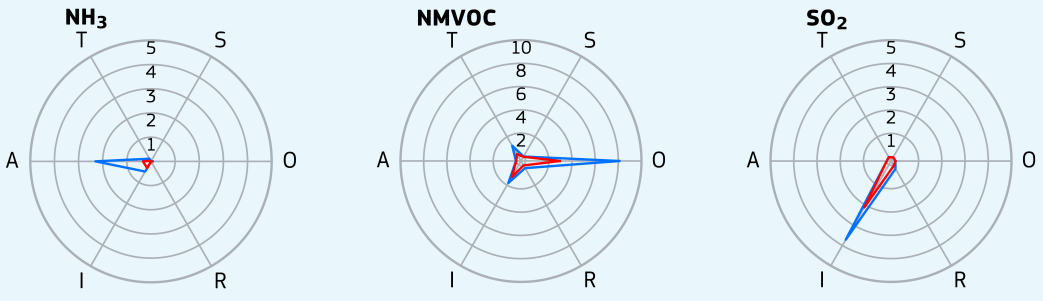


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



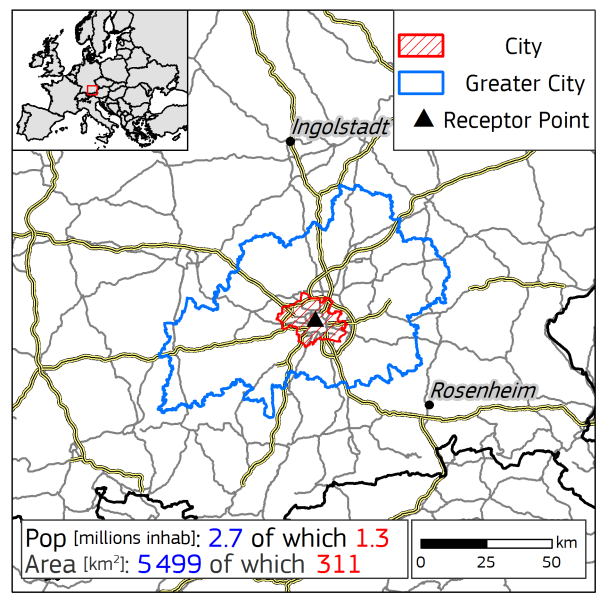
Emissions [kton/year]



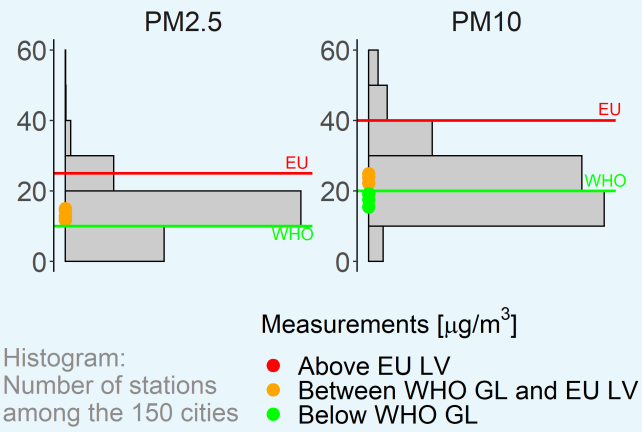


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

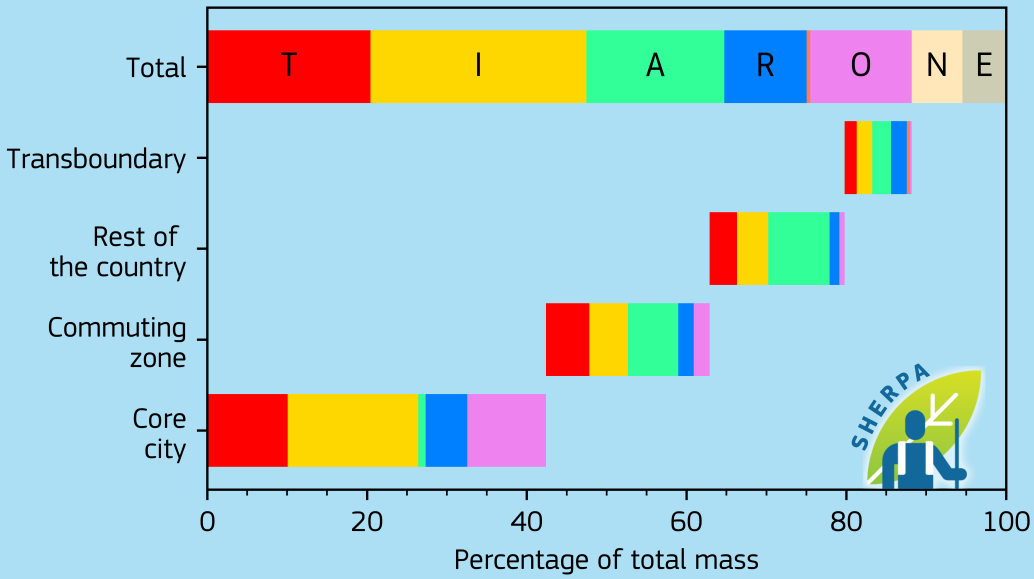
Germany, Munich



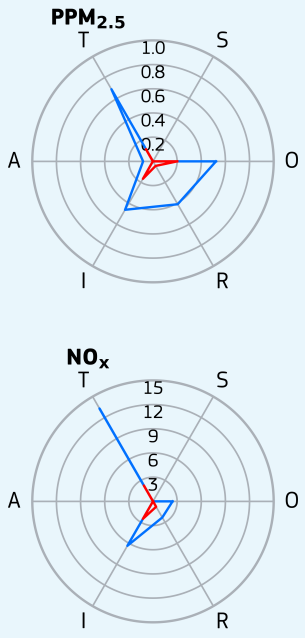
Yearly average urban concentrations (2018)

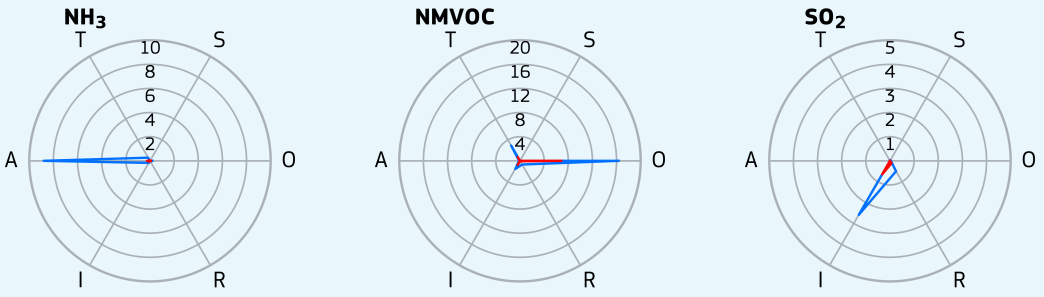


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



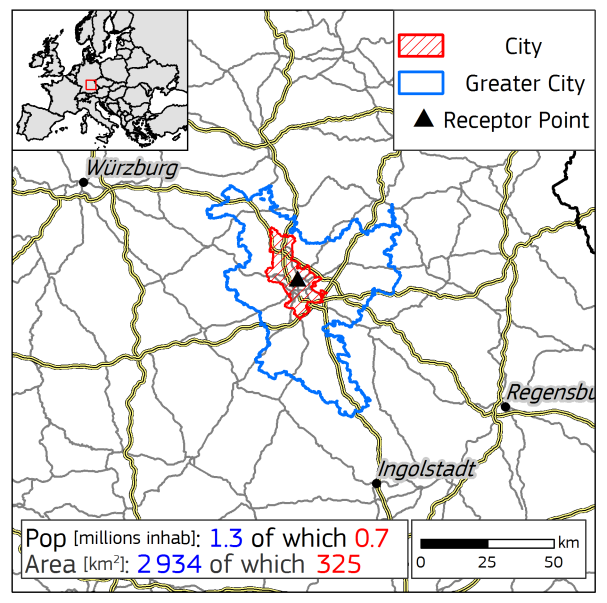
Emissions [kton/year]



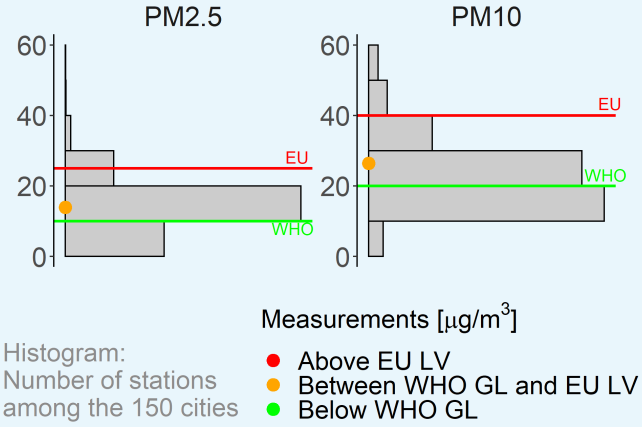


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

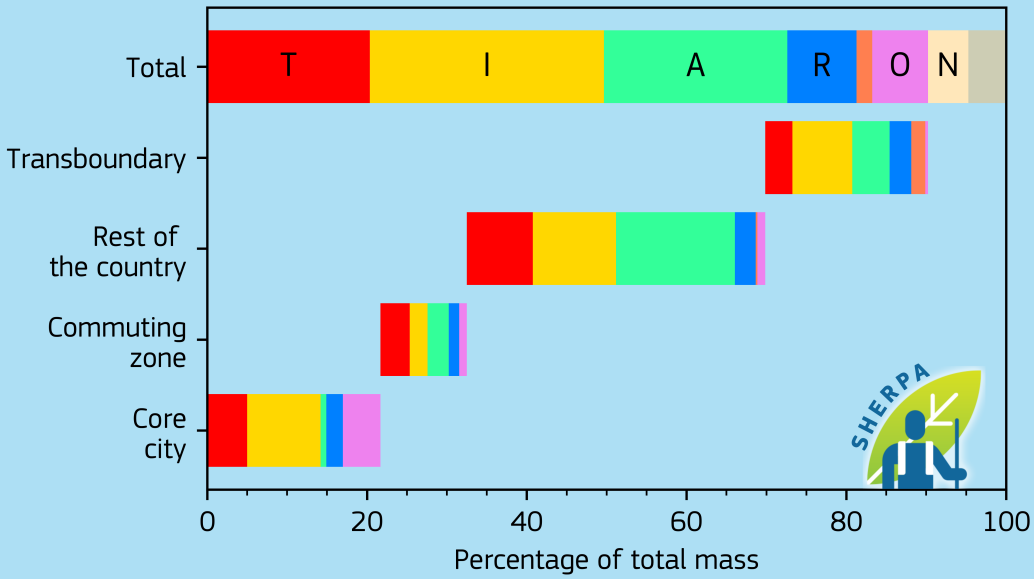
Germany, Nuremberg



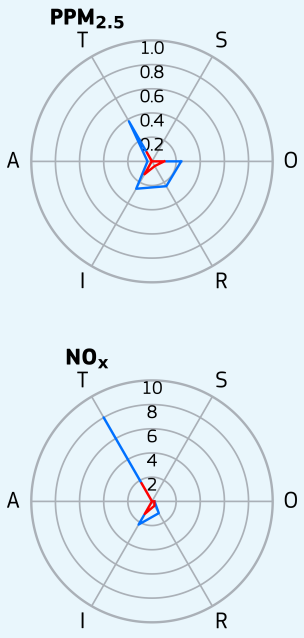
Yearly average urban concentrations (2018)

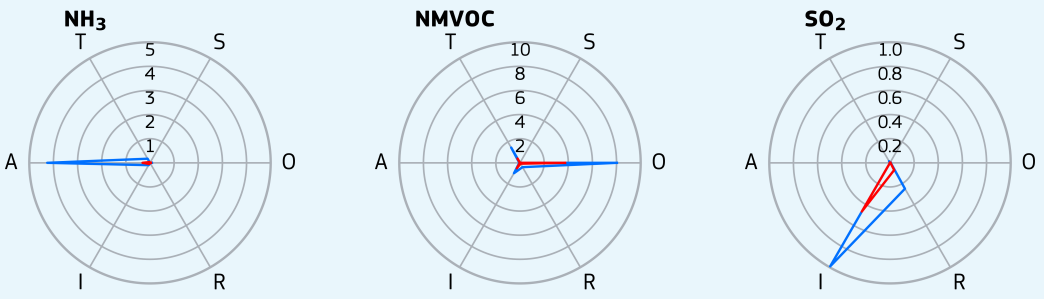


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



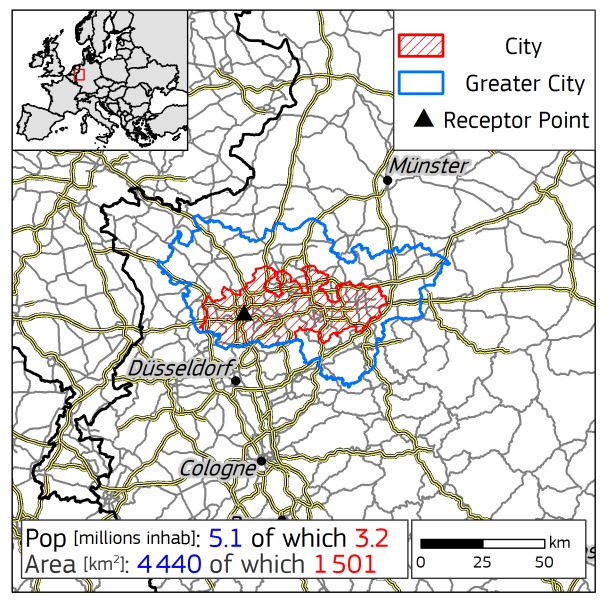
Emissions [kton/year]



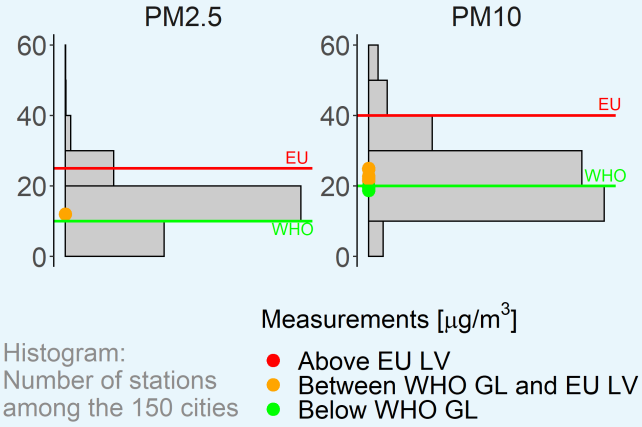


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

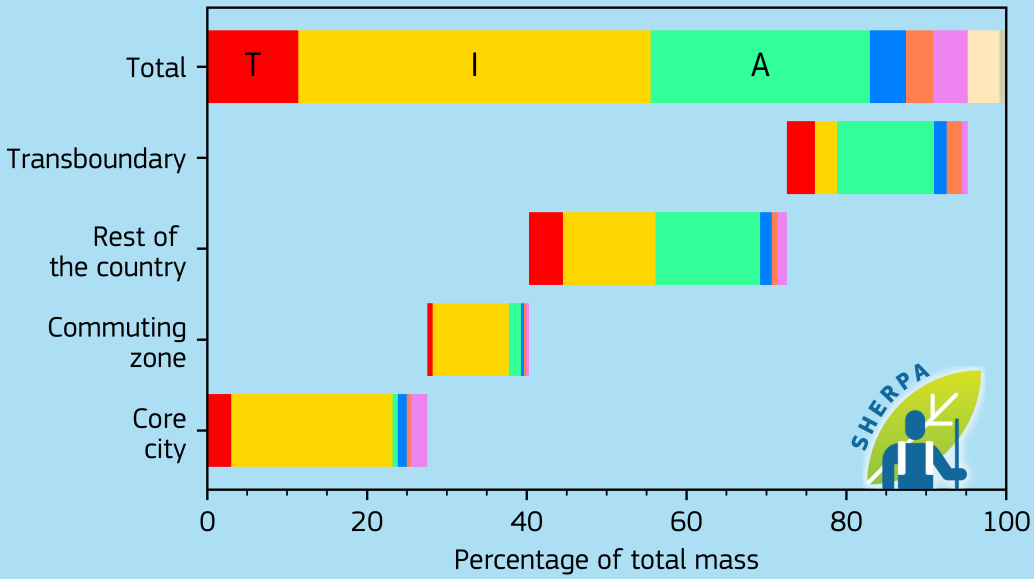
Germany, Ruhr Area



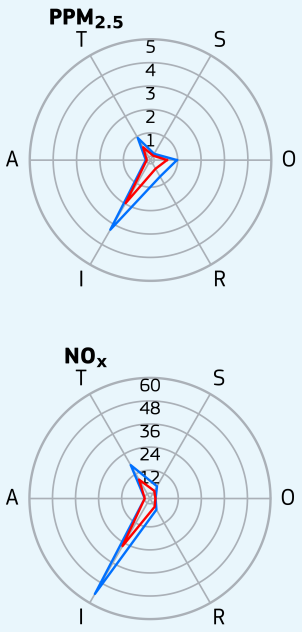
Yearly average urban concentrations (2018)

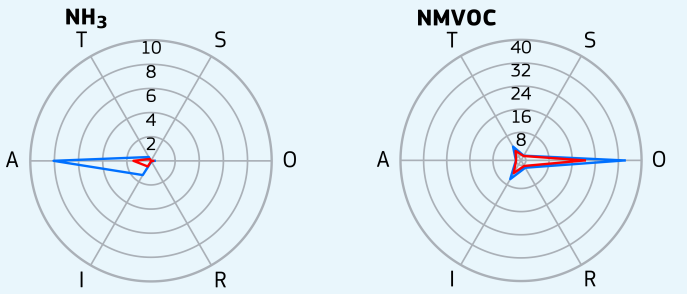


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



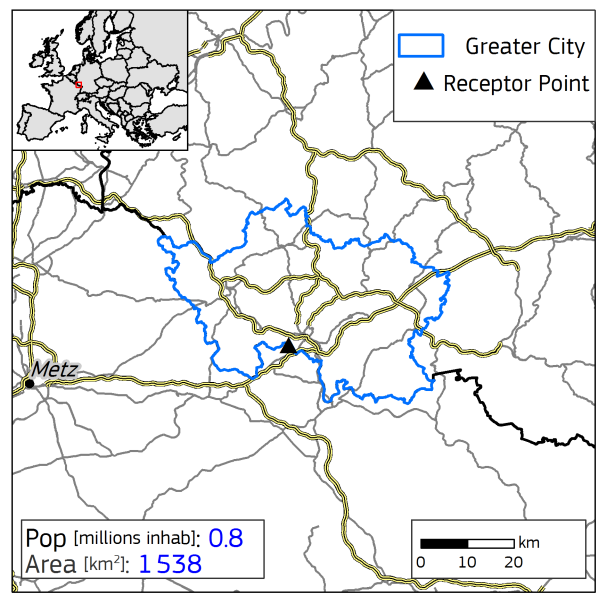
Emissions [kton/year]



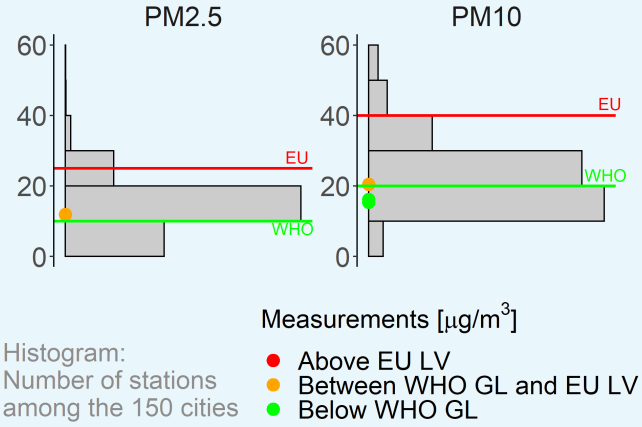


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

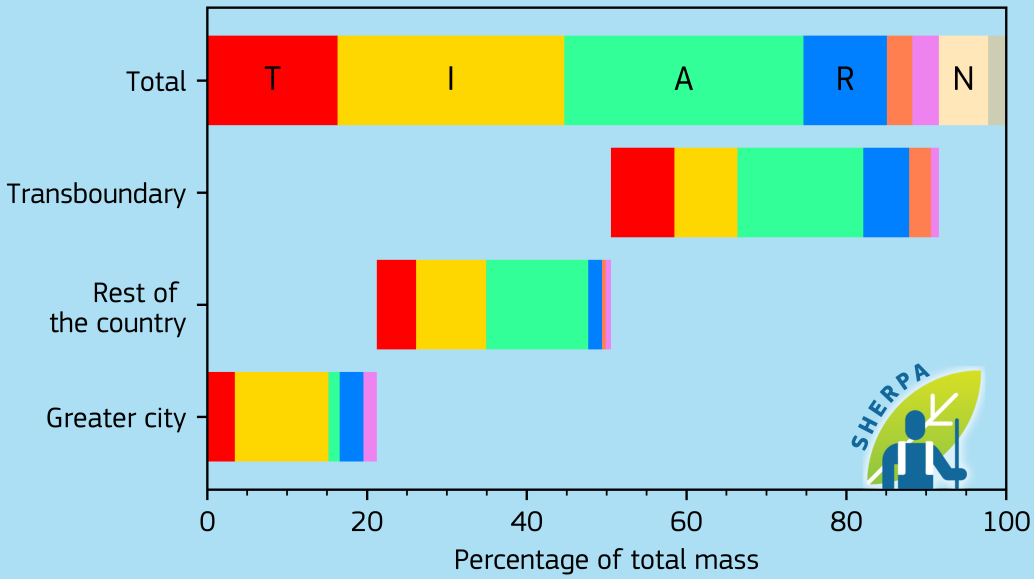
Germany, Saarbrücken



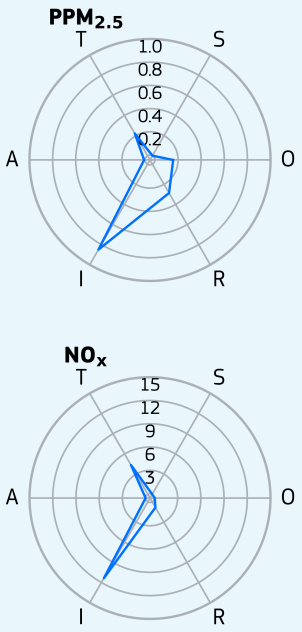
Yearly average urban concentrations (2018)

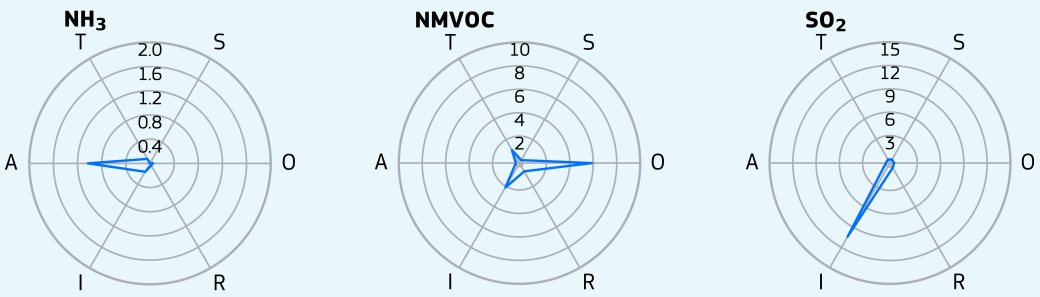


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



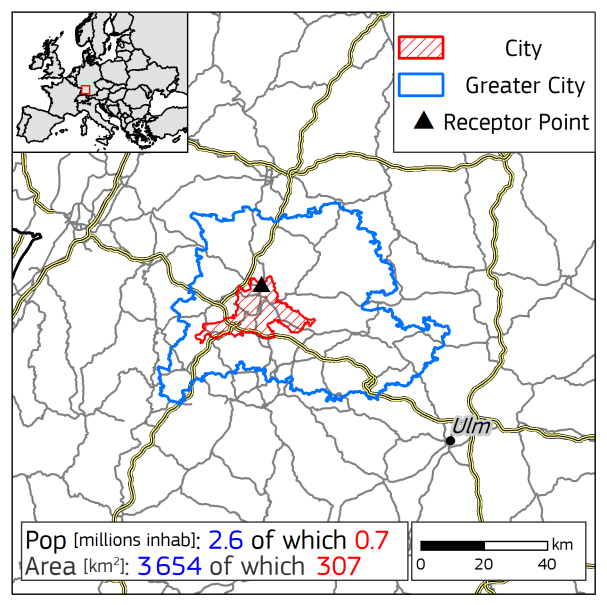
Emissions [kton/year]



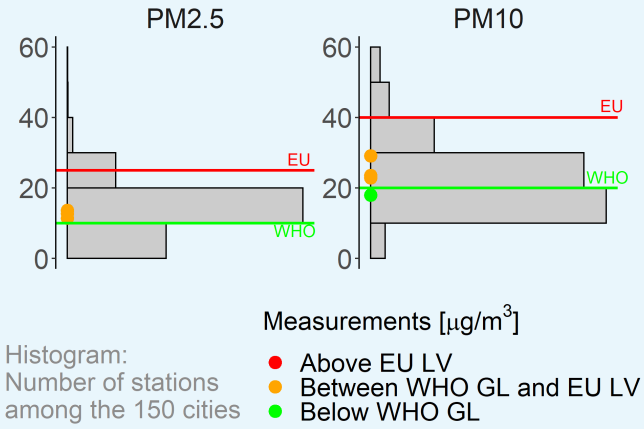


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city

Germany, Stuttgart

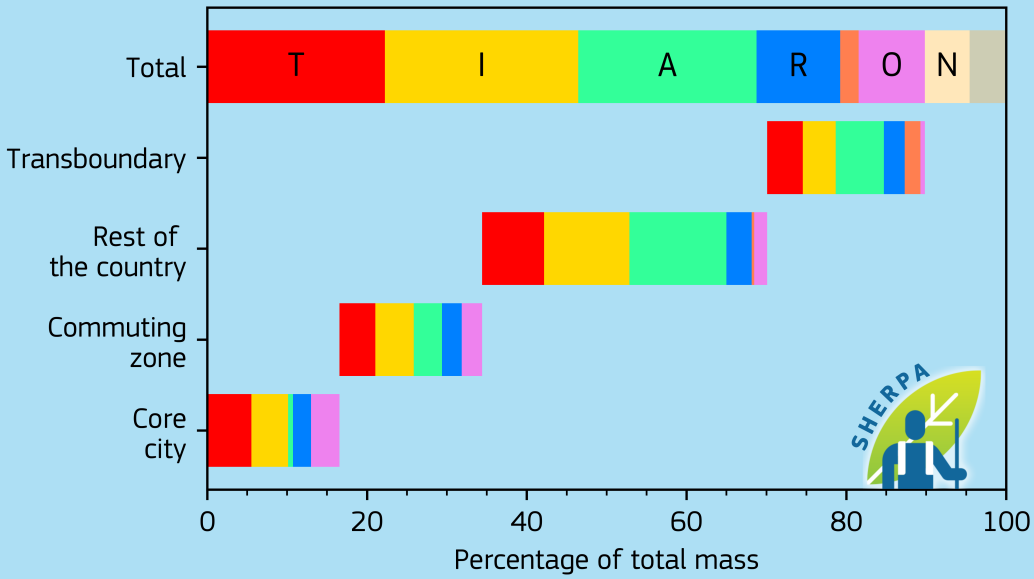


Yearly average urban concentrations (2018)

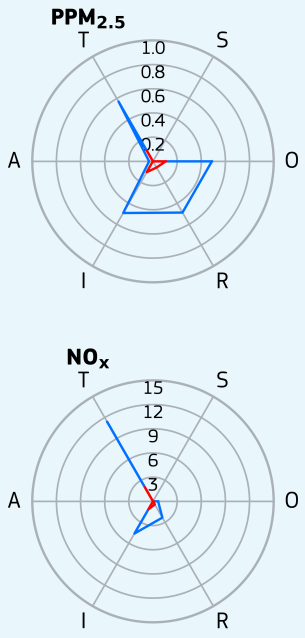


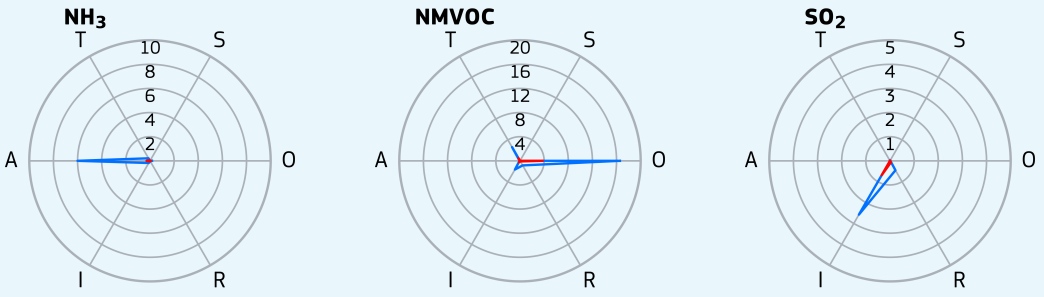
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



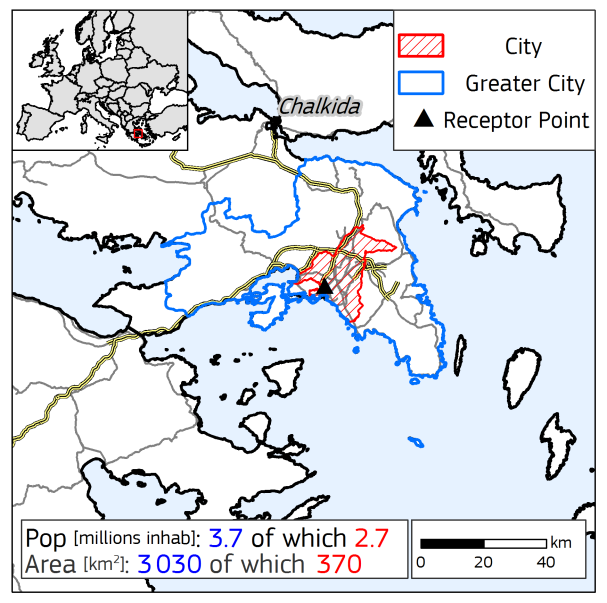
Emissions [kton/year]



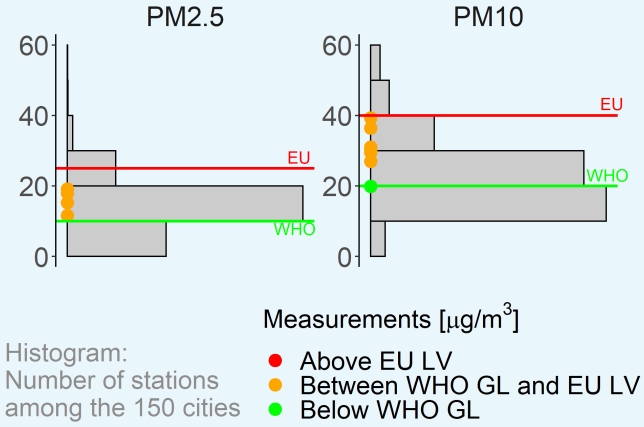


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

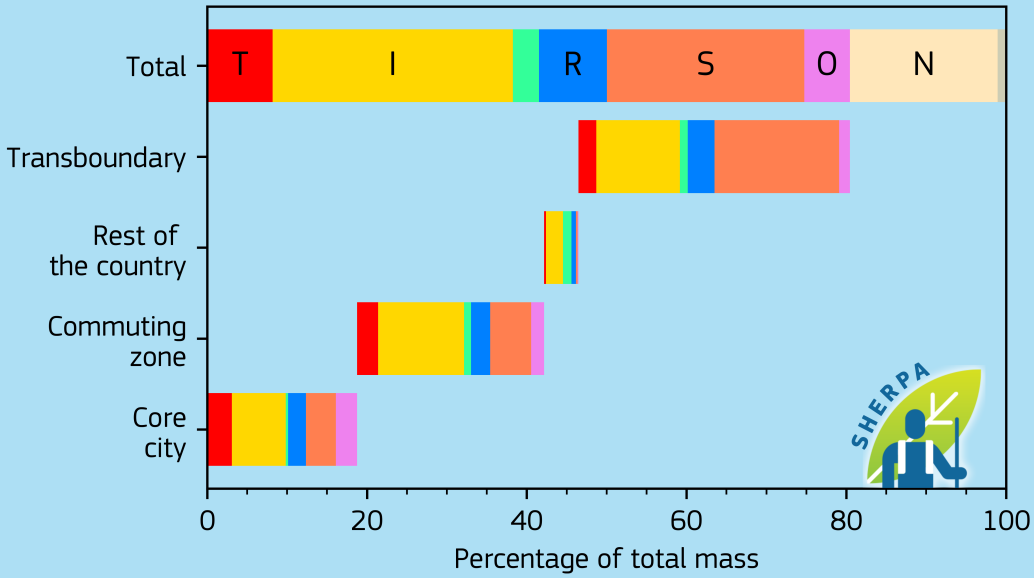
Greece, Athens



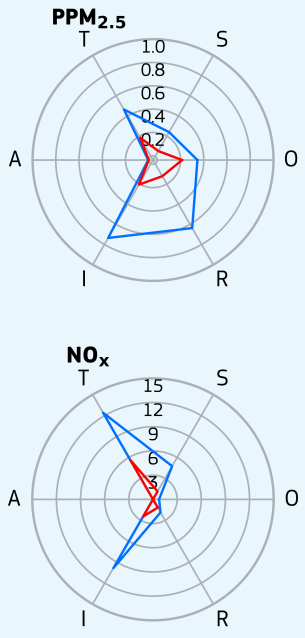
Yearly average urban concentrations (2018)

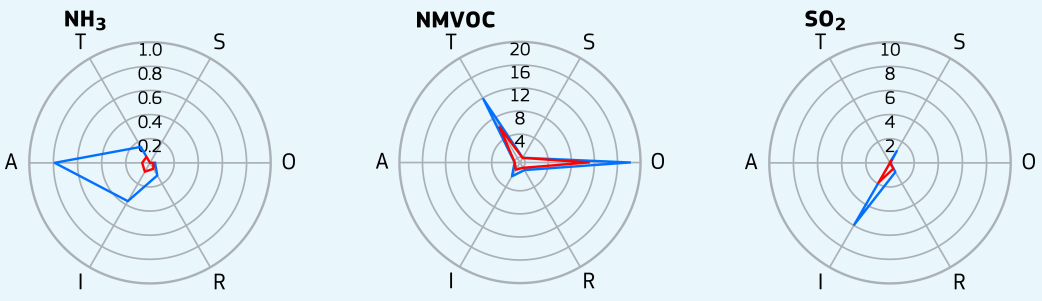


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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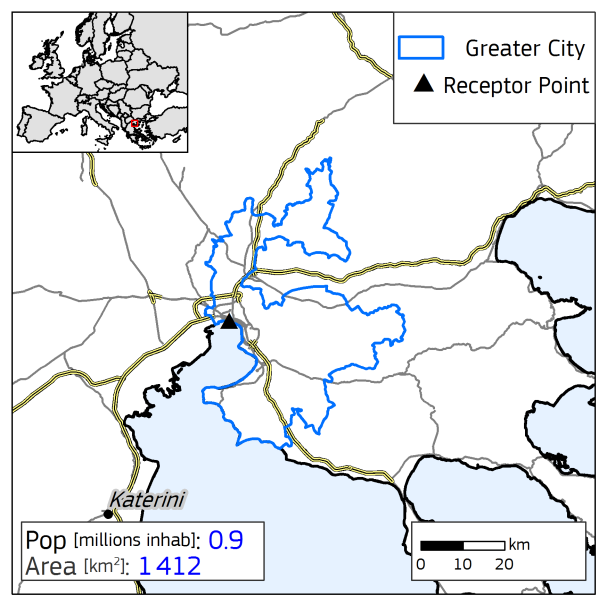
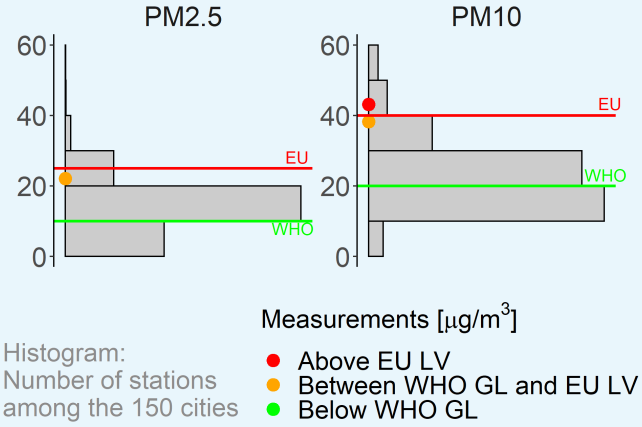
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

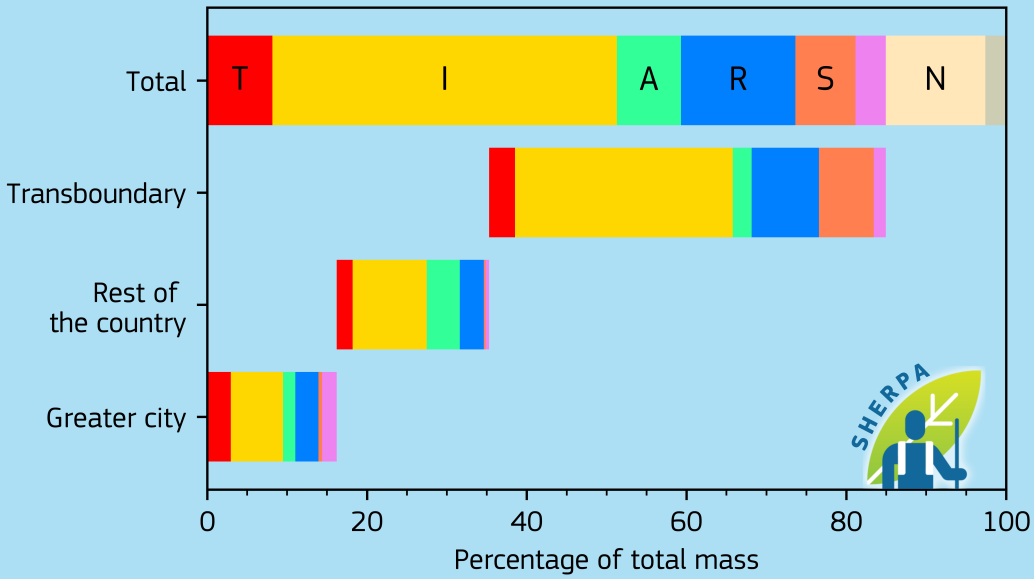
Greece, Thessaloniki



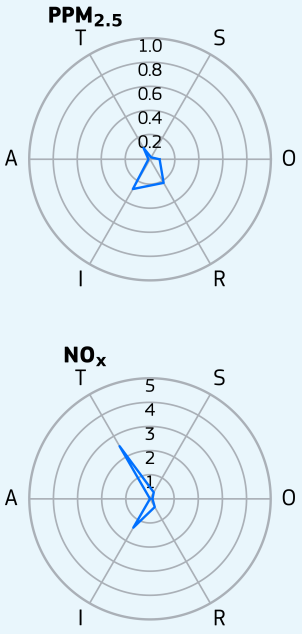
Yearly average urban concentrations (2018)

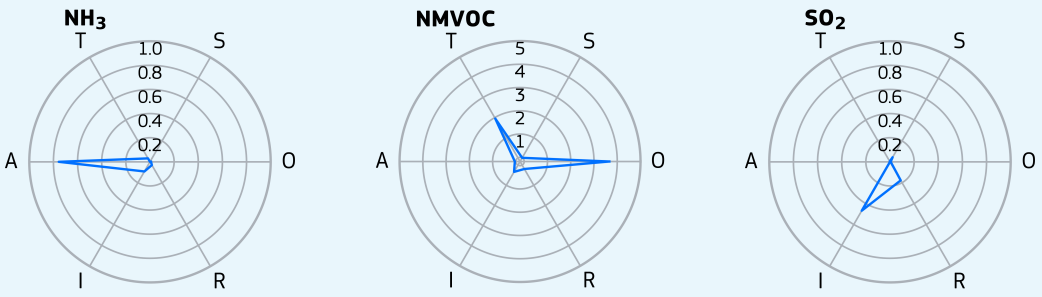


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



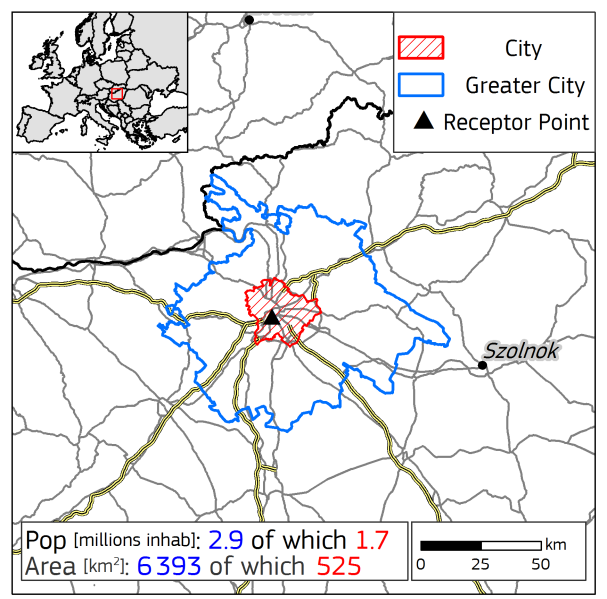
Emissions [kton/year]



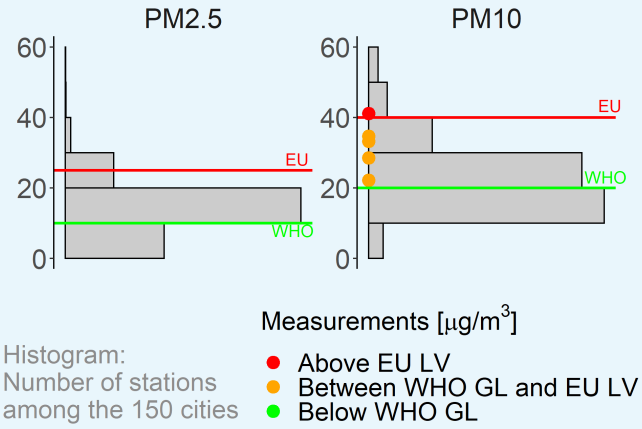


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

Hungary, Budapest

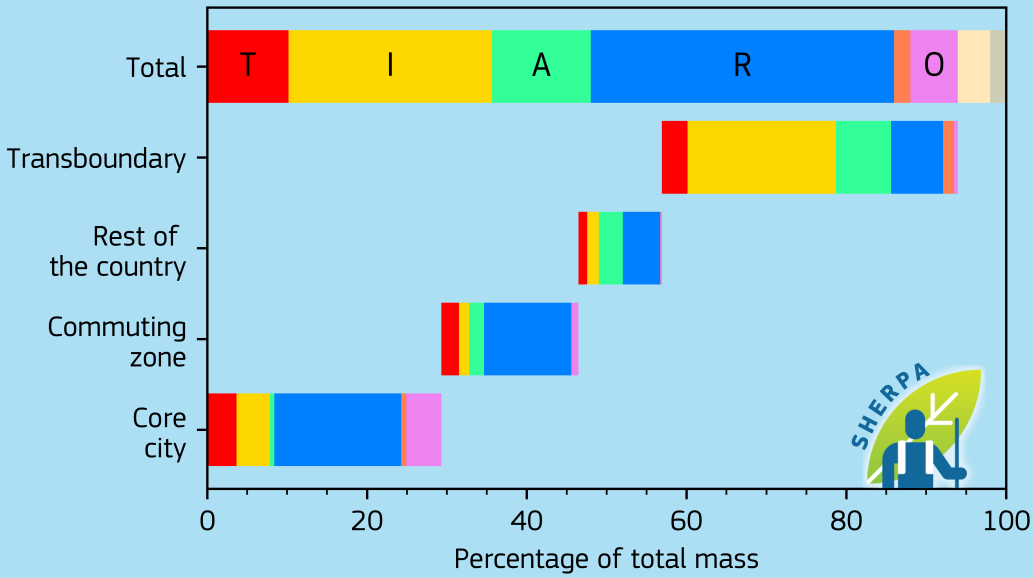


Yearly average urban concentrations (2018)

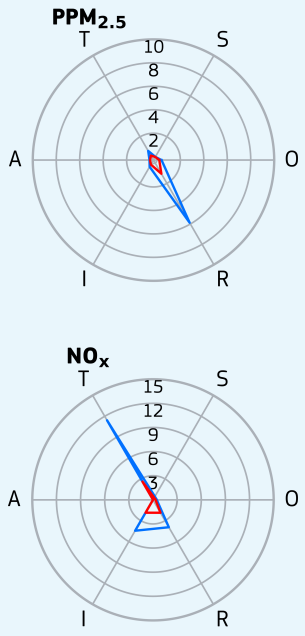


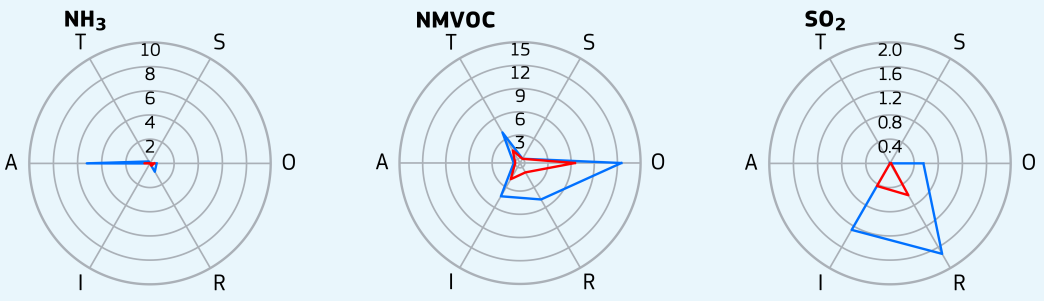
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



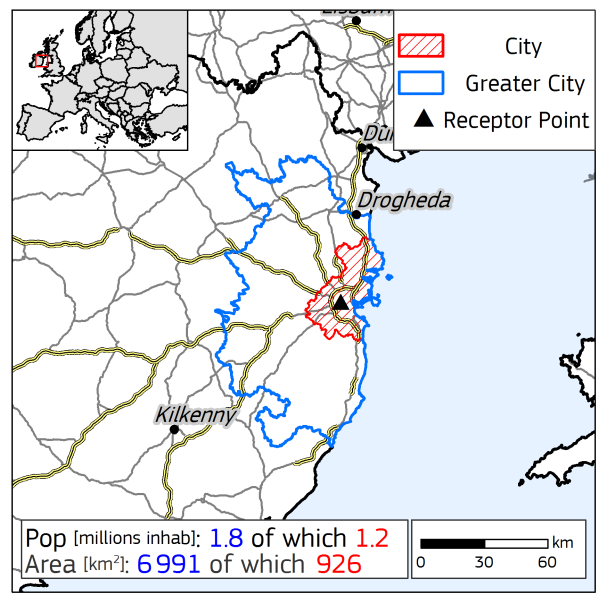
Emissions [kton/year]



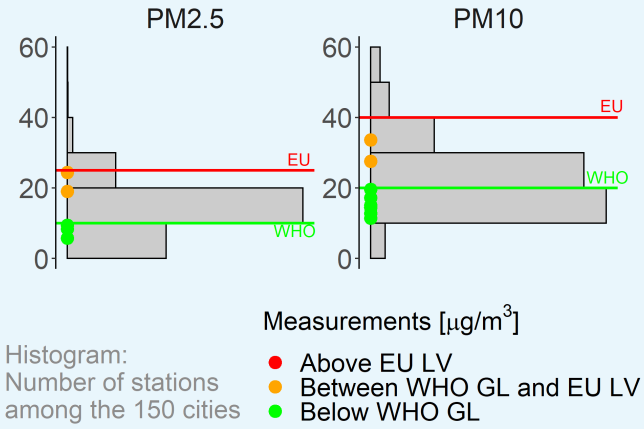


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

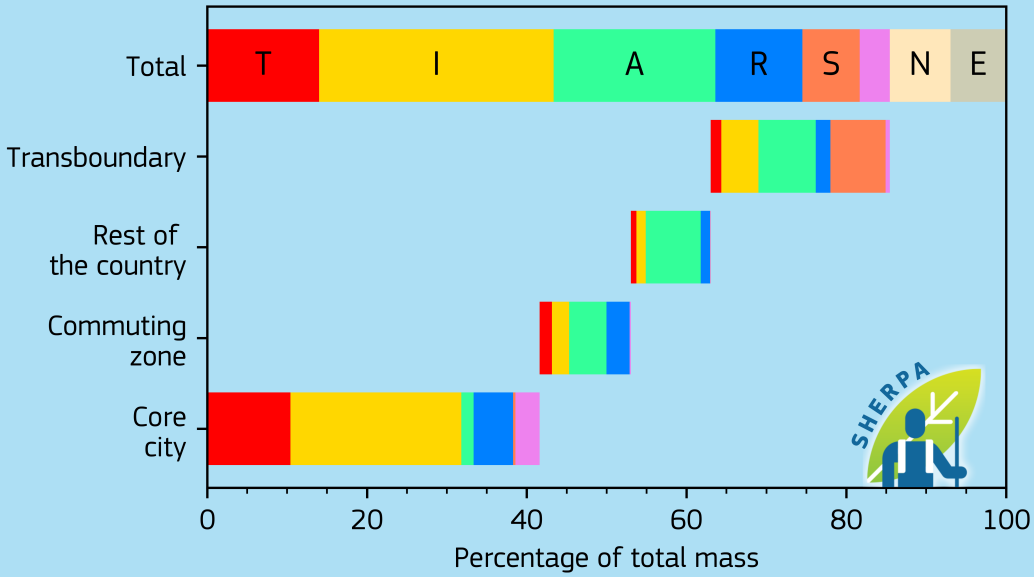
Ireland, Dublin



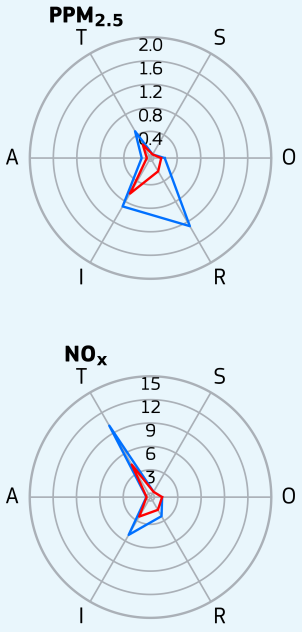
Yearly average urban concentrations (2018)

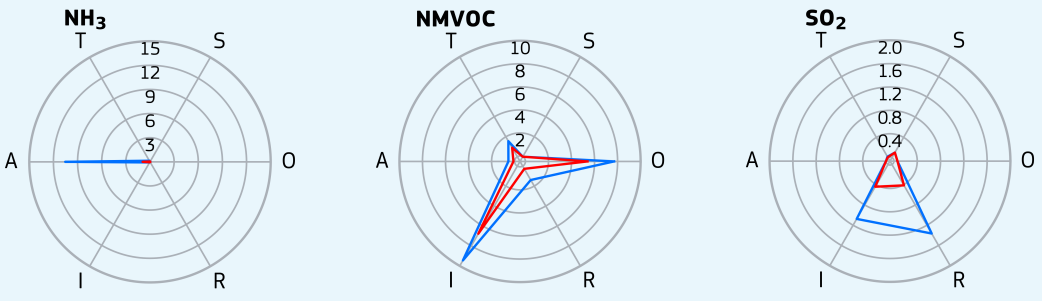


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



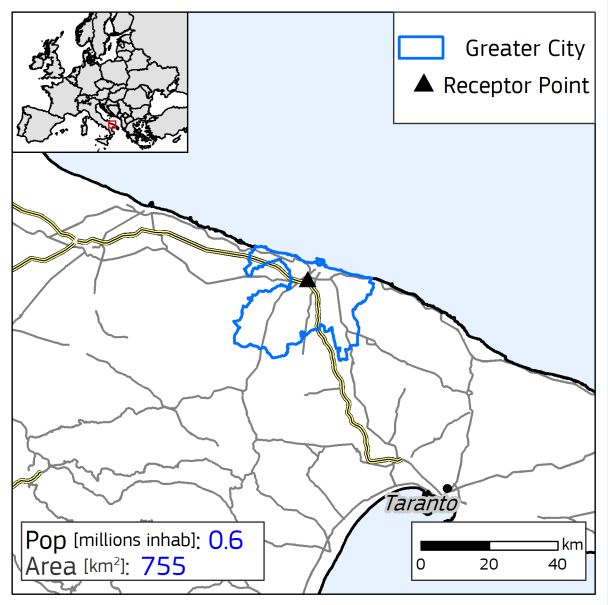
Emissions [kton/year]



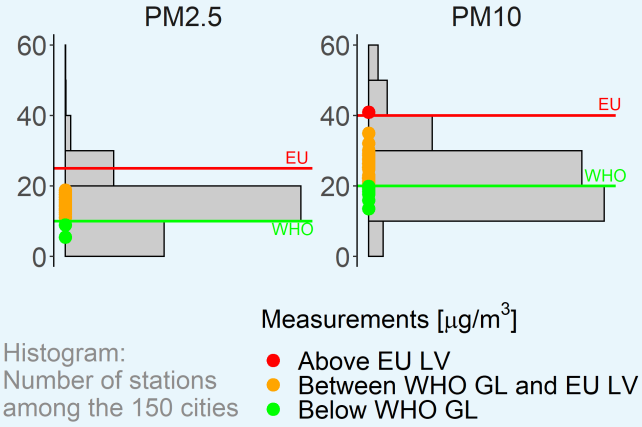


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

Italy, Bari

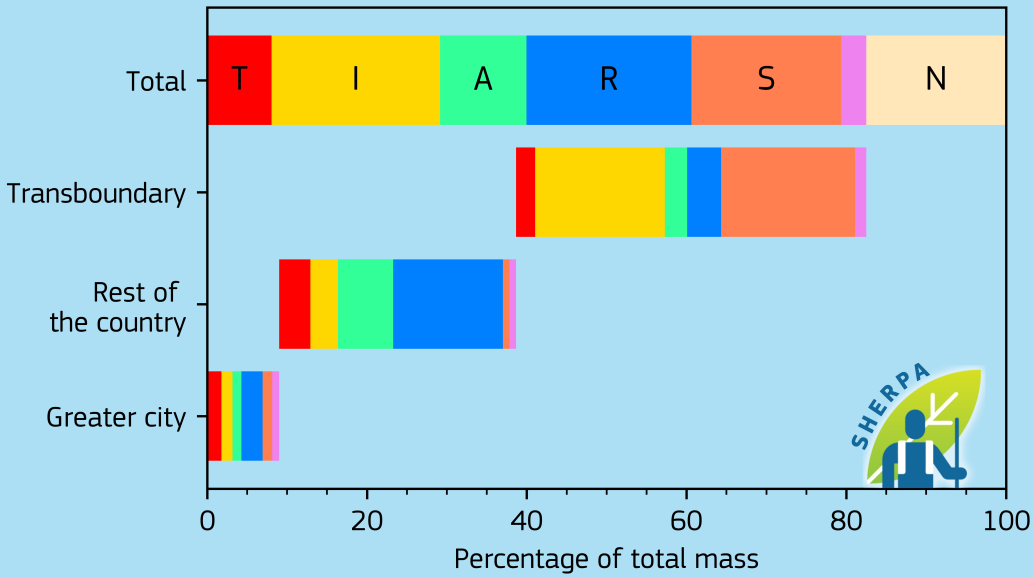


Yearly average urban concentrations (2018)

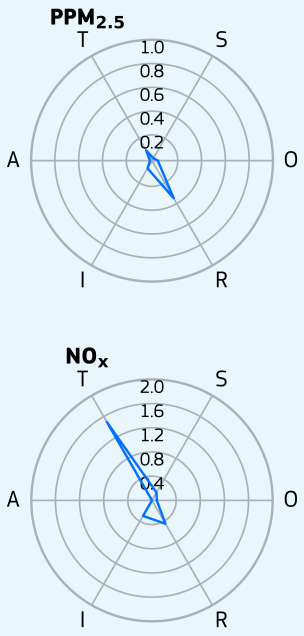


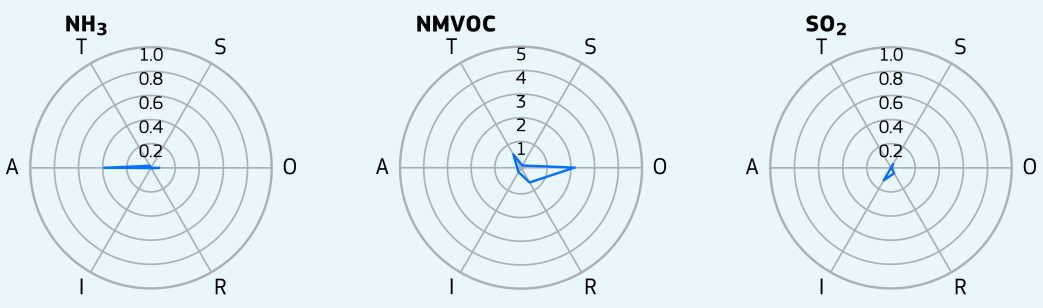
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
- I - Industry
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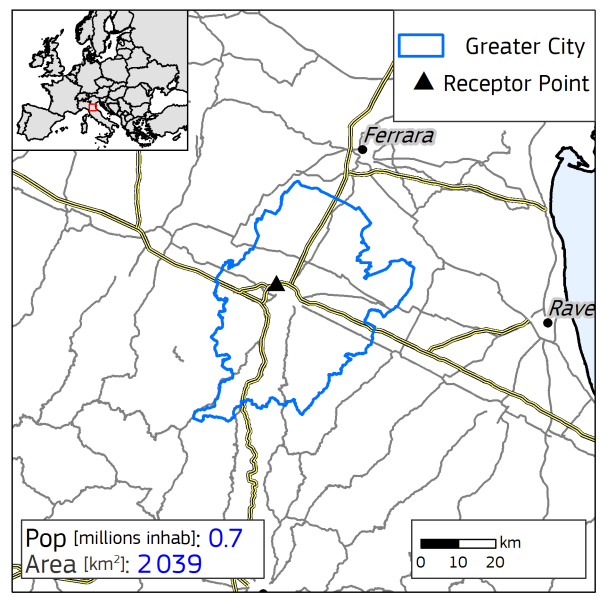
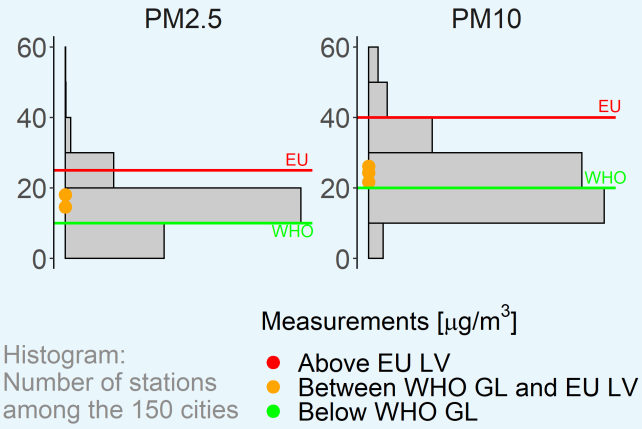
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- Greater city

Italy, Bologna



Yearly average urban concentrations (2018)



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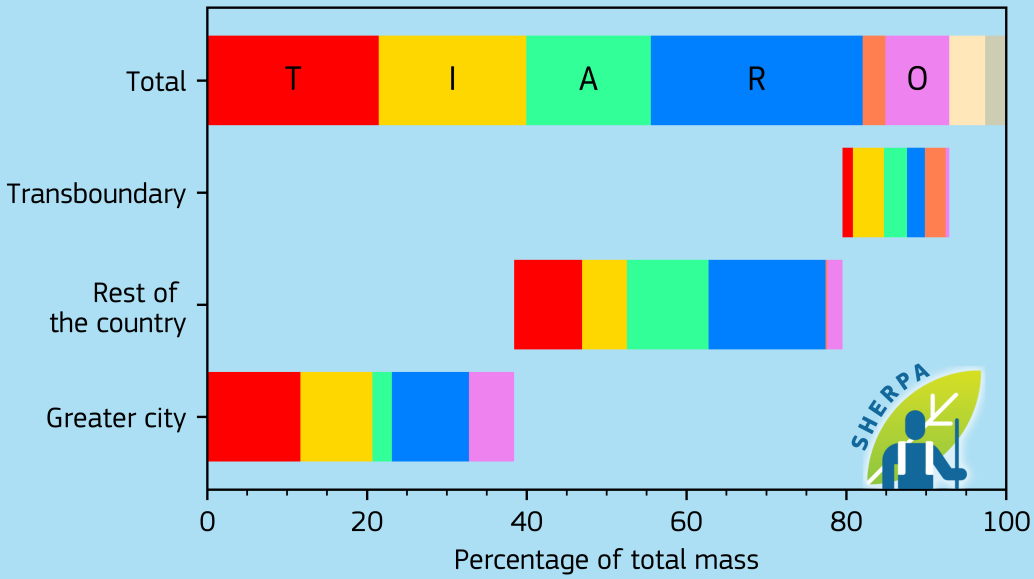
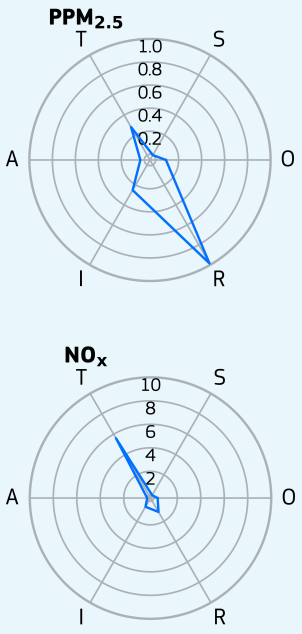
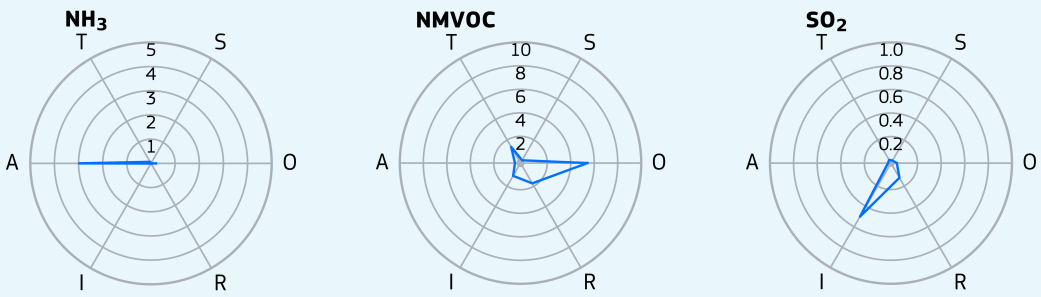


Emissions [kton/year]





- T - Transport
- I - Industry
- A - Agriculture
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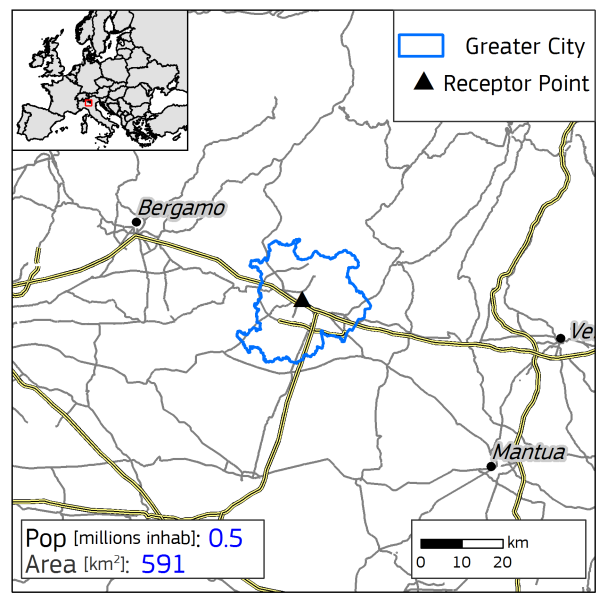
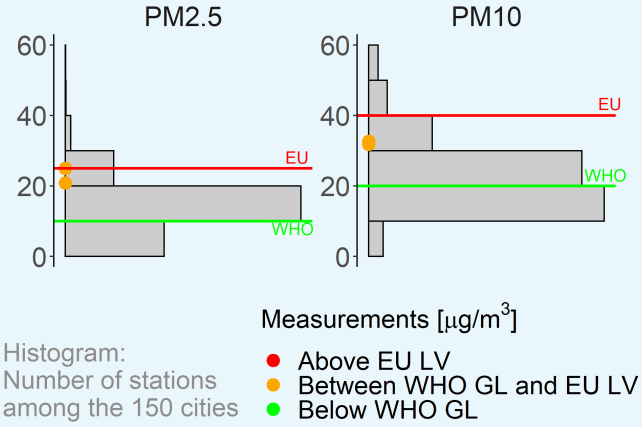
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

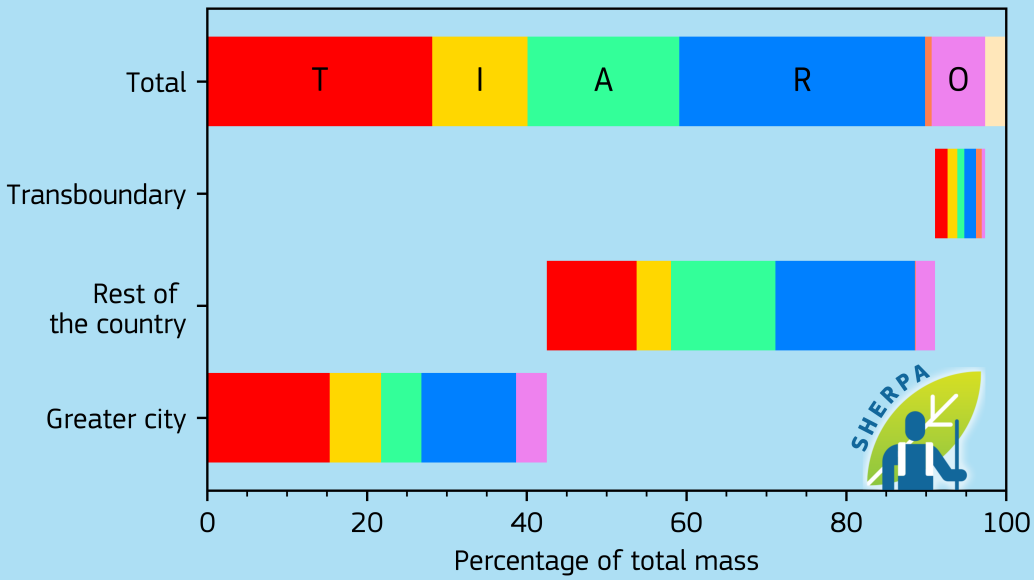
Italy, Brescia



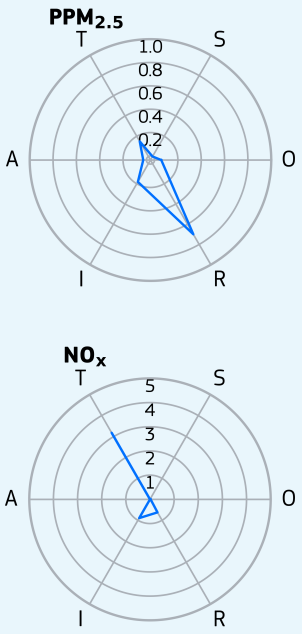
Yearly average urban concentrations (2018)

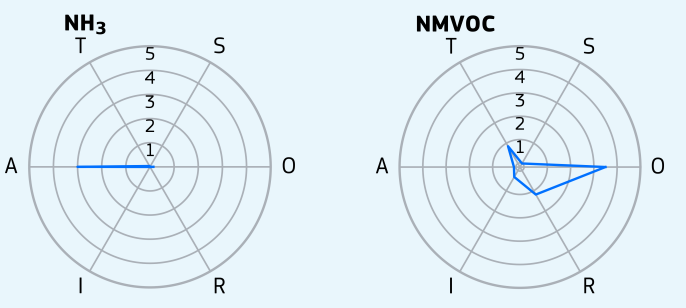


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
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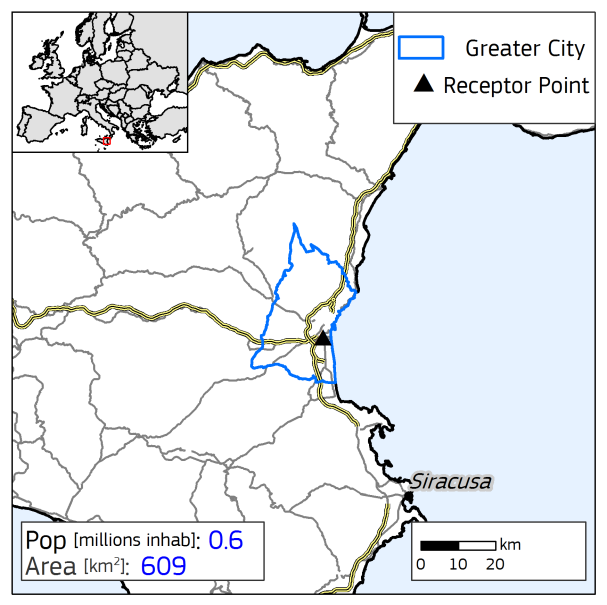
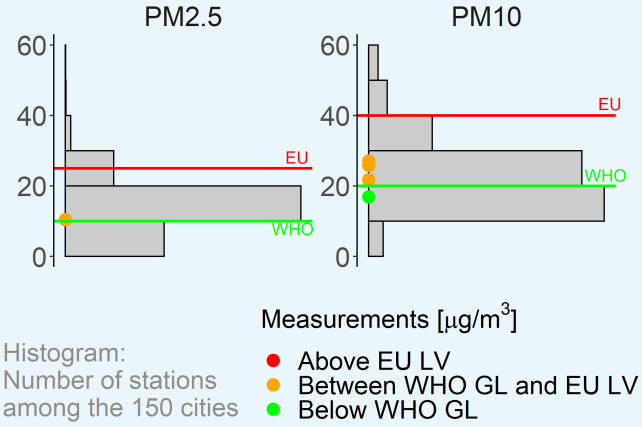
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

Italy, Catania

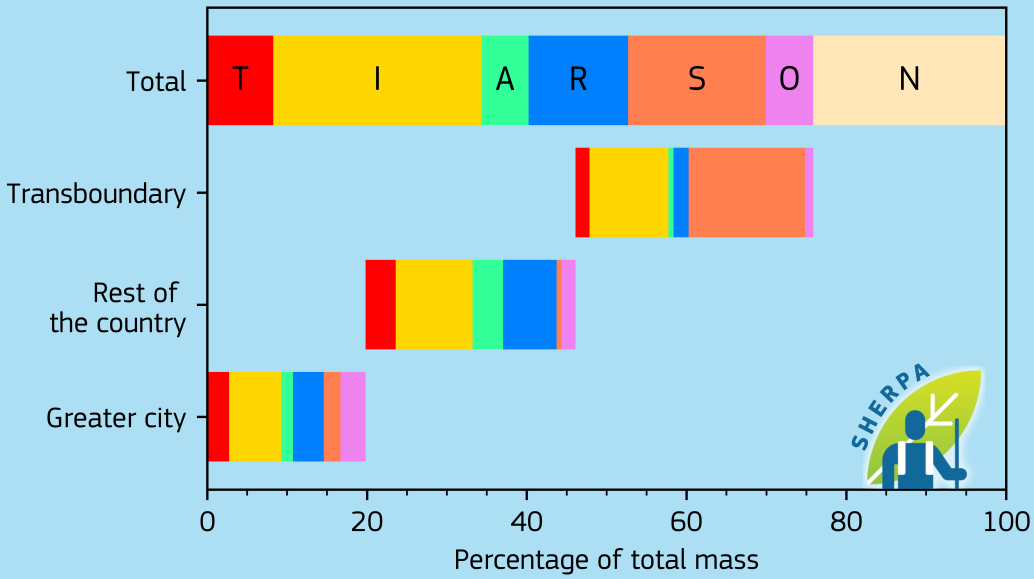


Yearly average urban concentrations (2018)

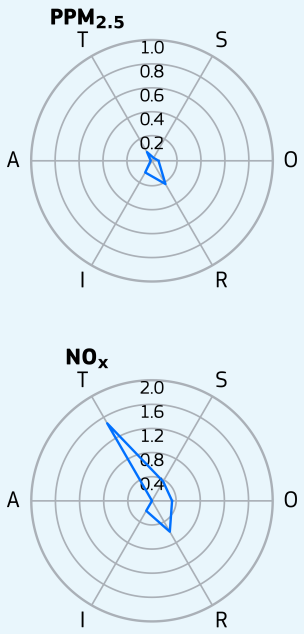


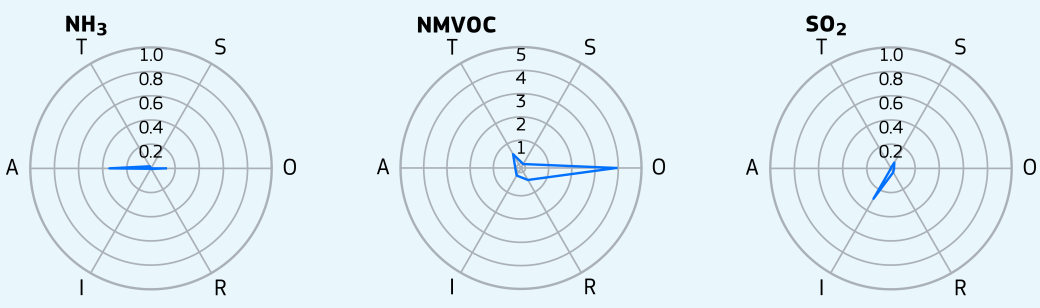
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
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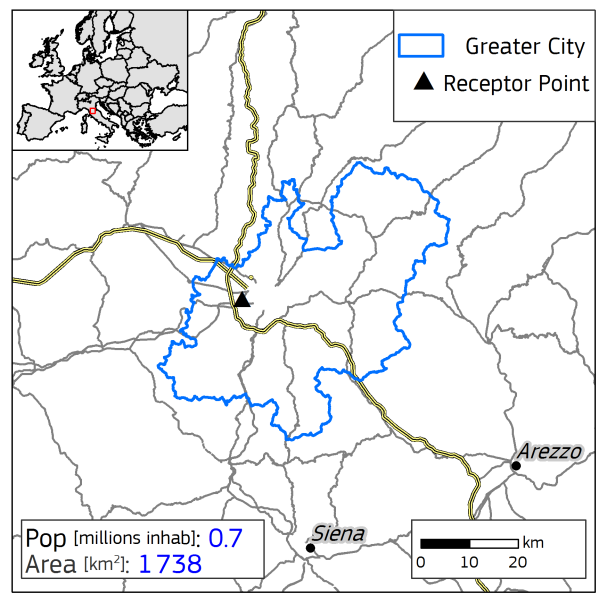
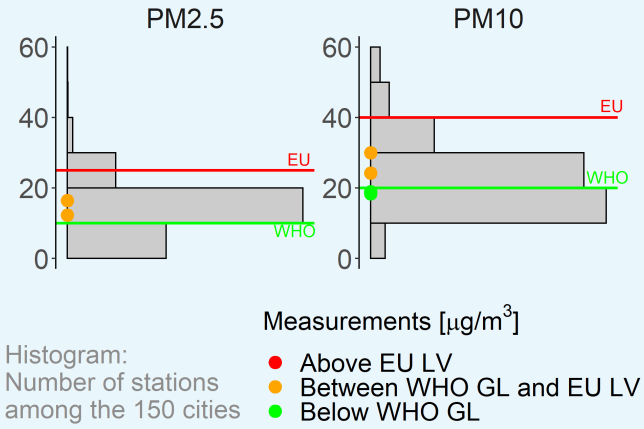
Greater city

Italy, Florence

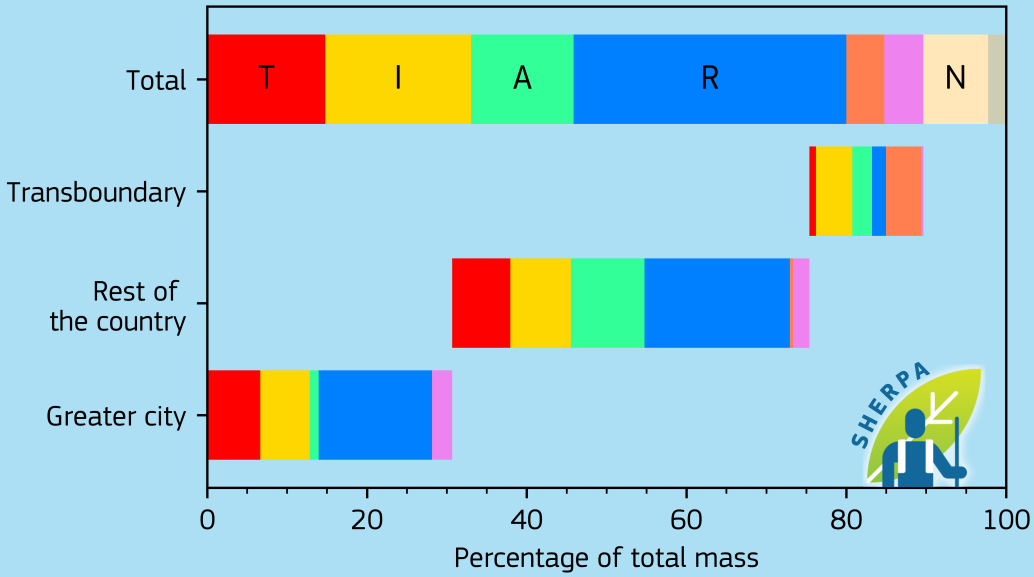


Yearly average urban concentrations (2018)

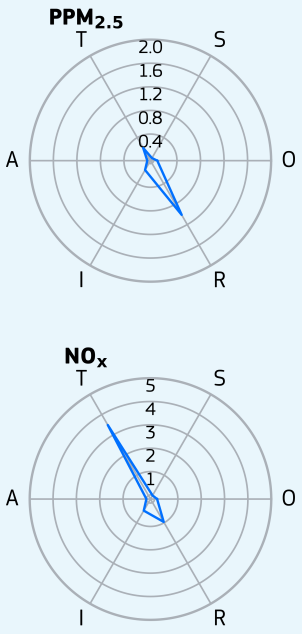


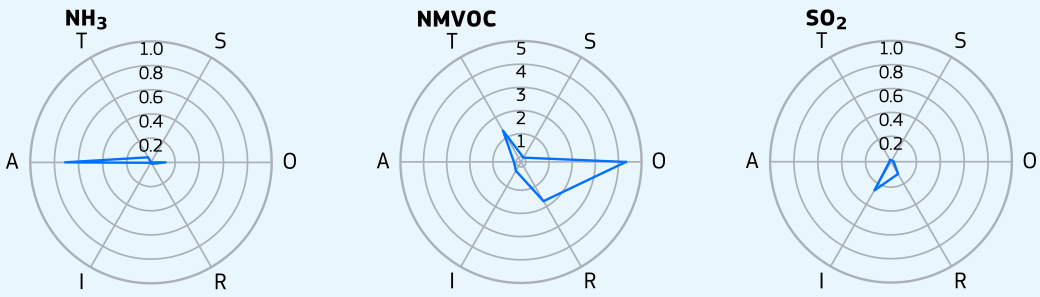
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



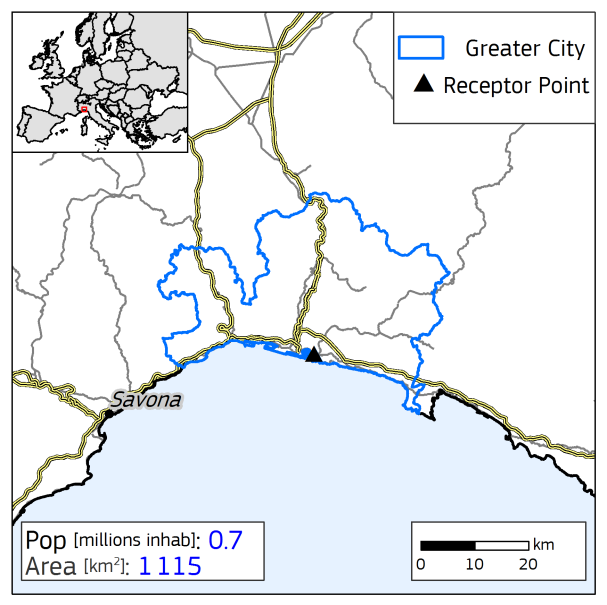
Emissions [kton/year]



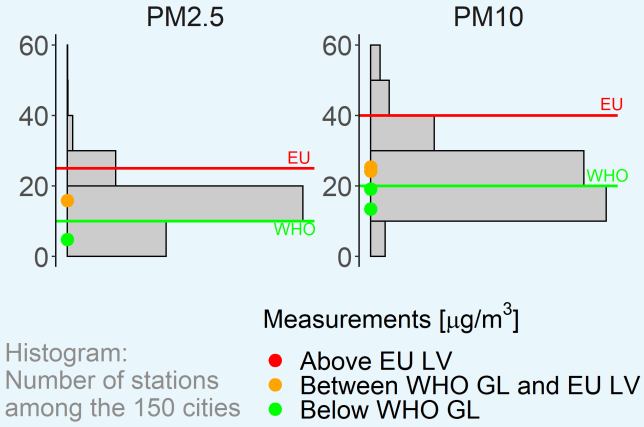


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

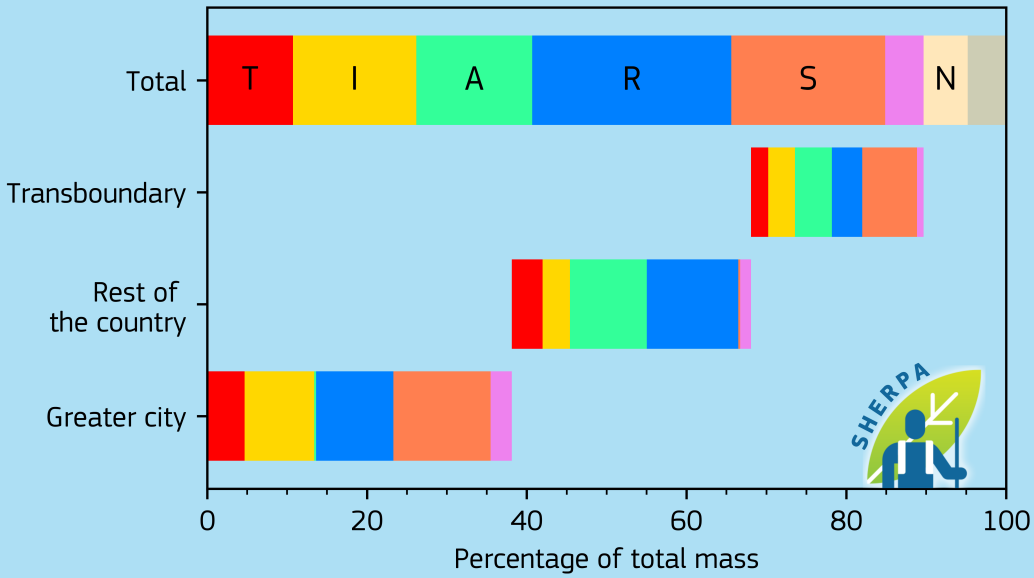
Italy, Genoa



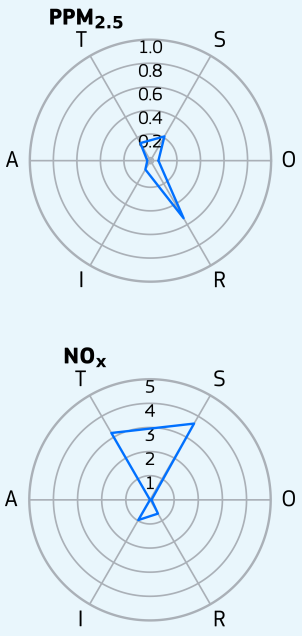
Yearly average urban concentrations (2018)

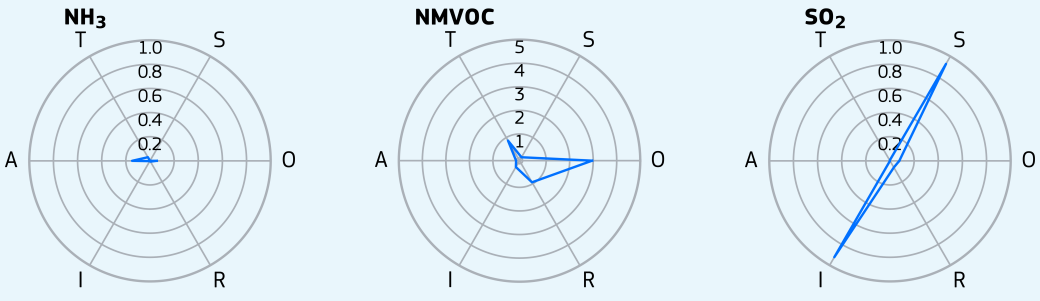


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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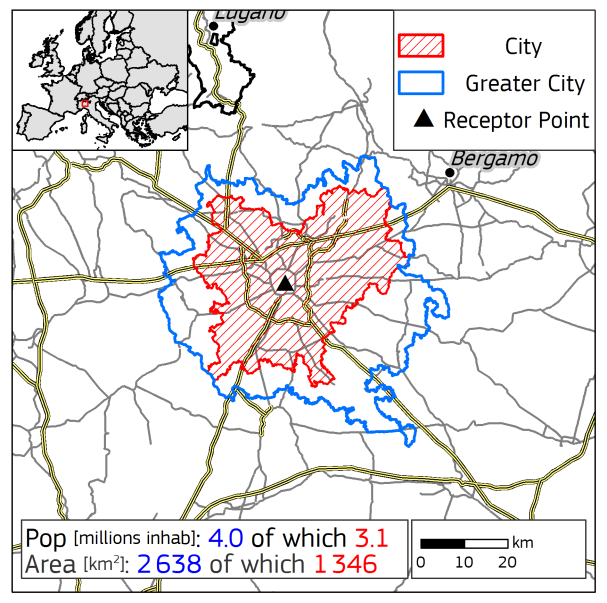
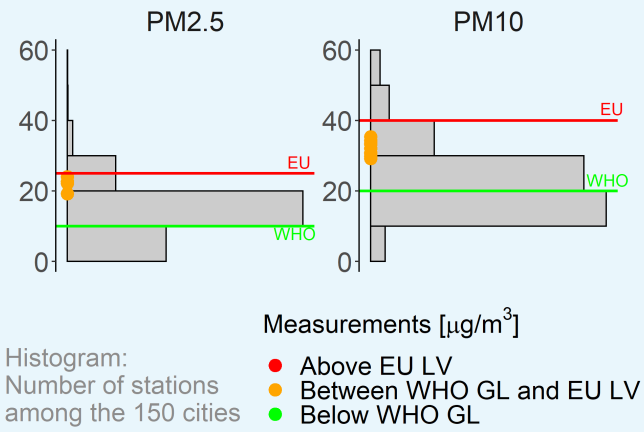
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

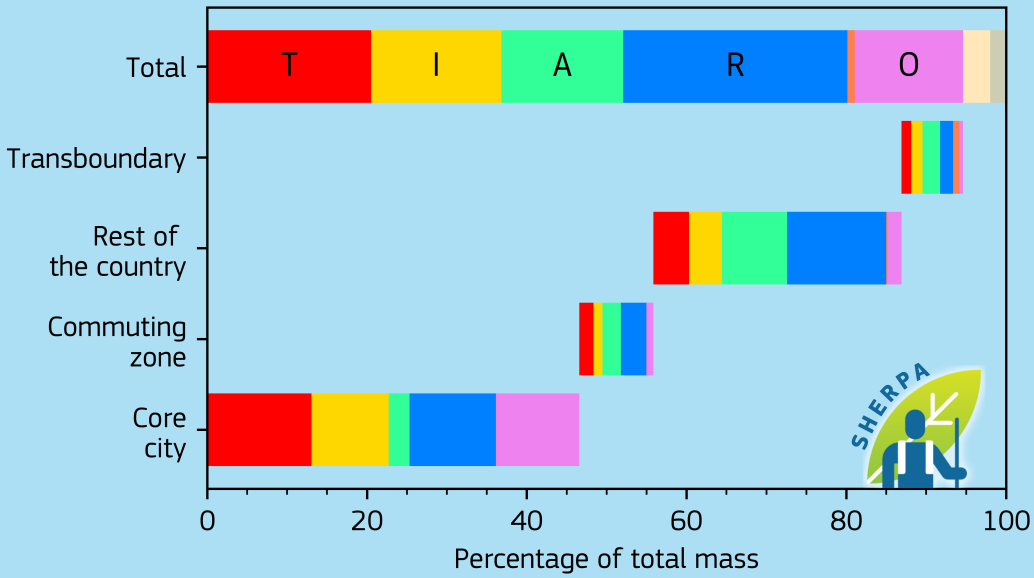
Italy, Milan



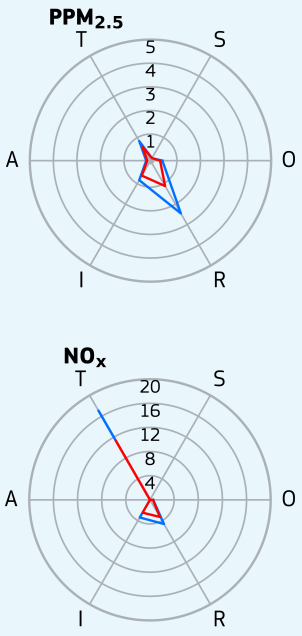
Yearly average urban concentrations (2018)

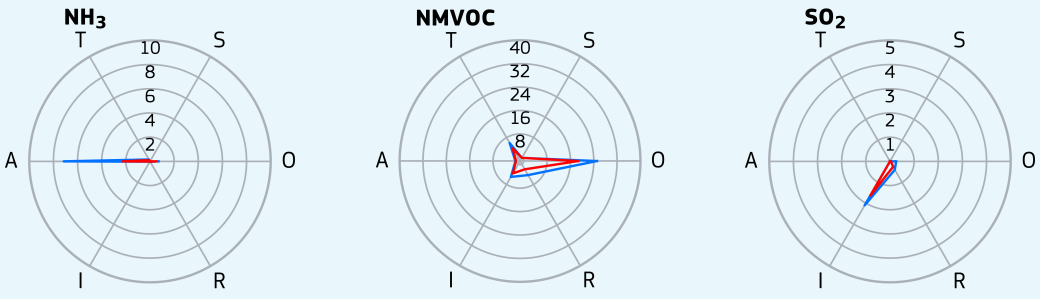


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
I - Industry
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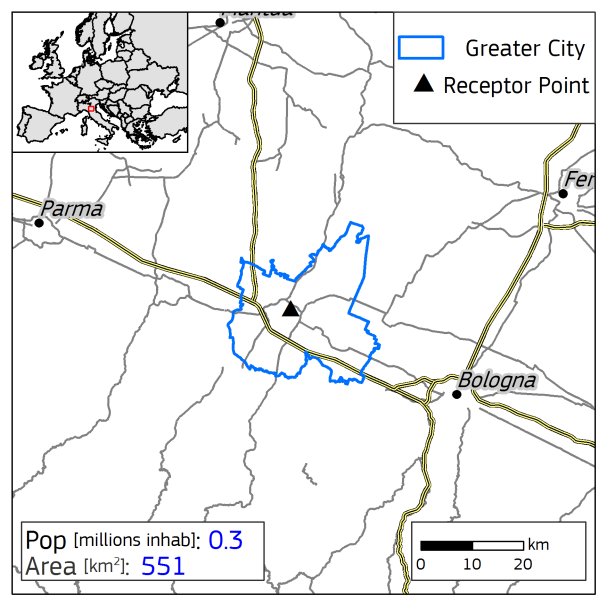
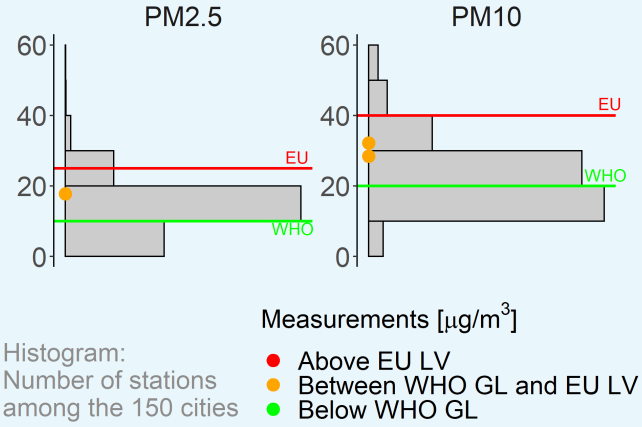
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

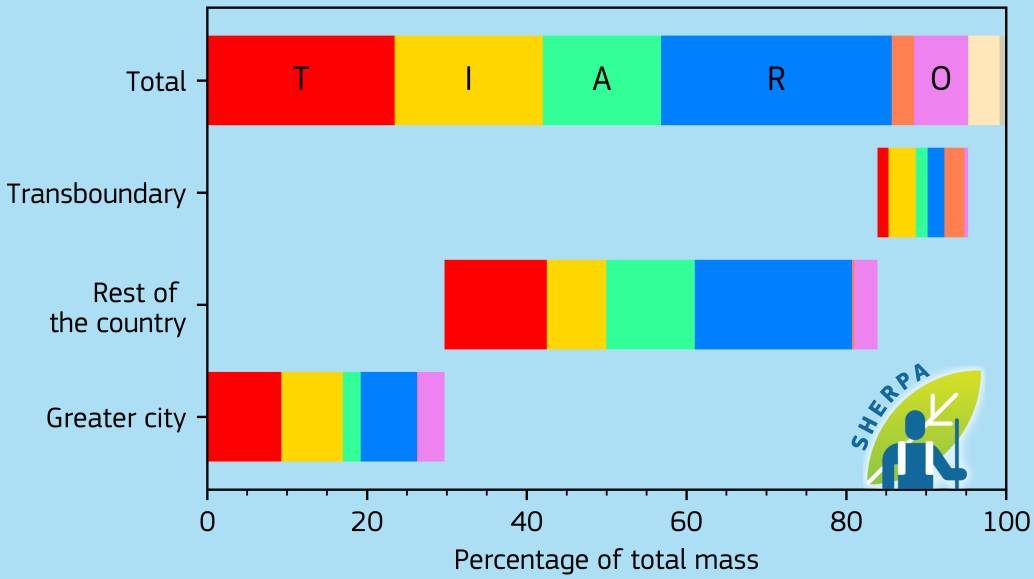
Italy, Modena



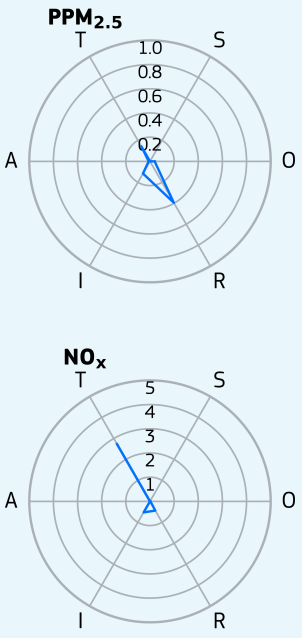
Yearly average urban concentrations (2018)

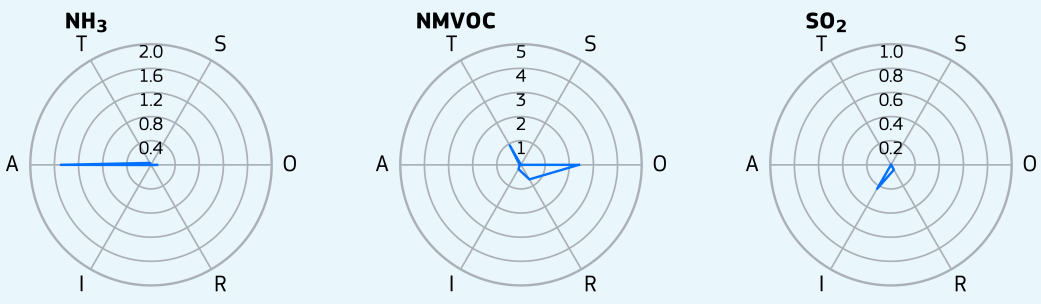


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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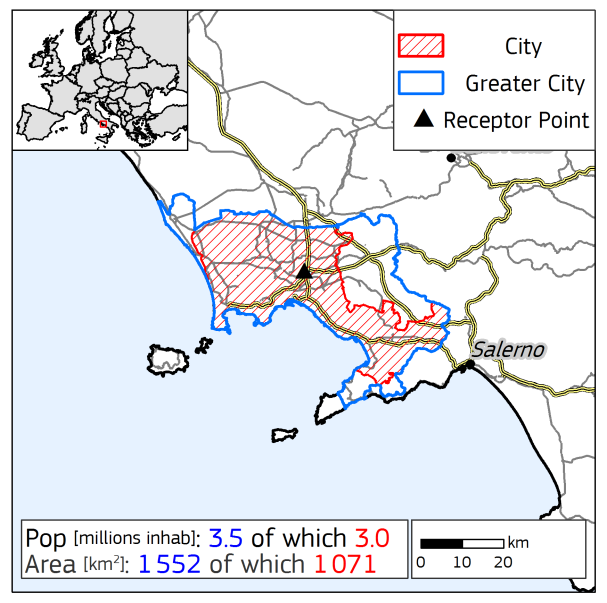
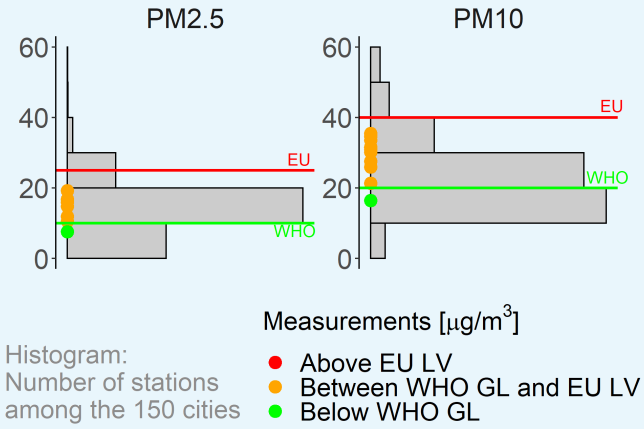
- Greater city

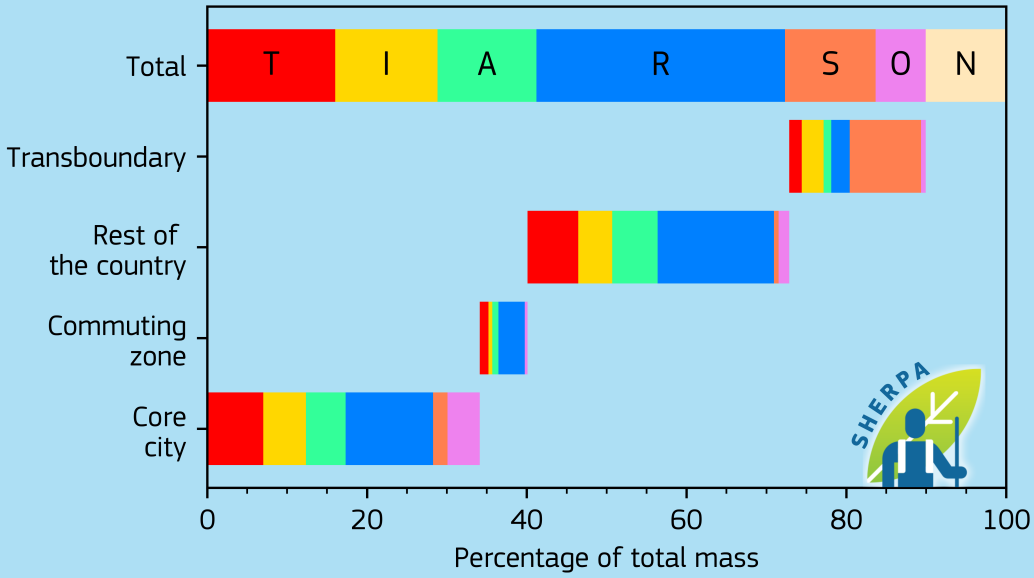
Italy, Naples



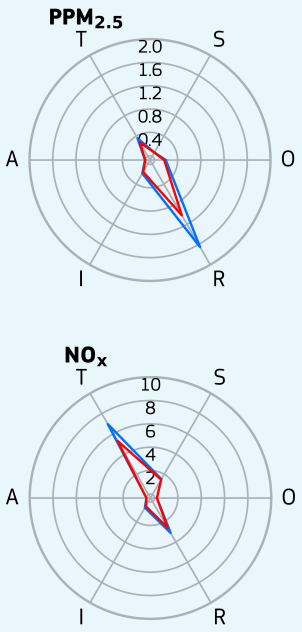
Yearly average urban concentrations (2018)

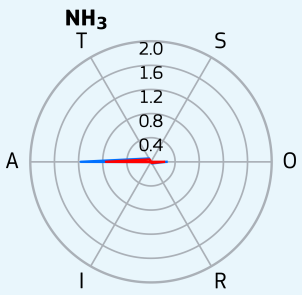


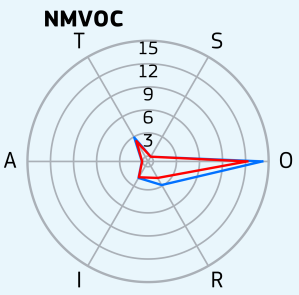
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

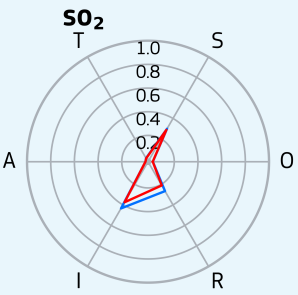


Emissions [kton/year]



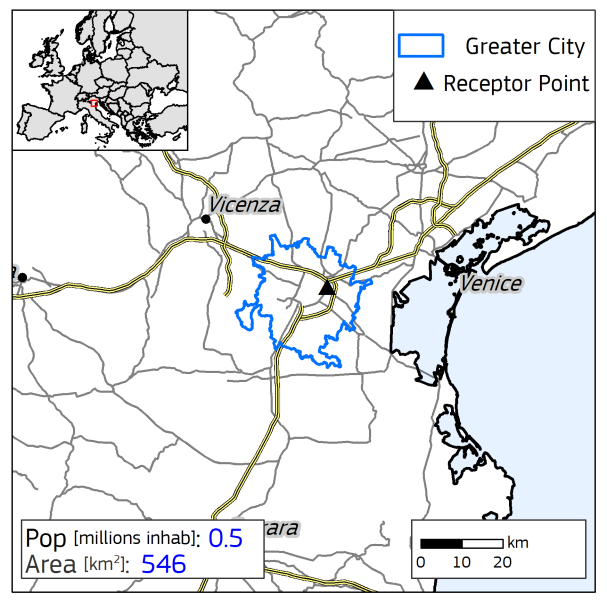




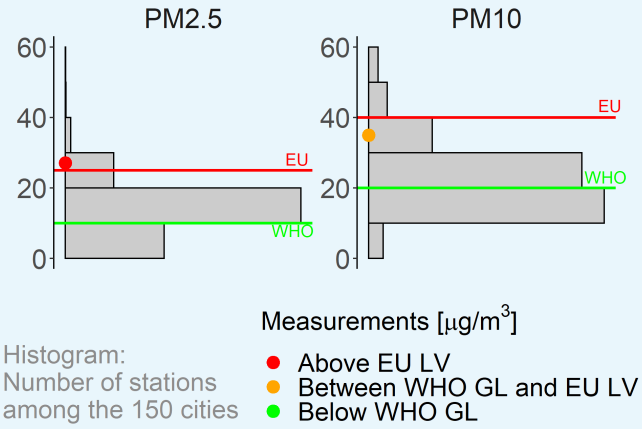


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city
Core city

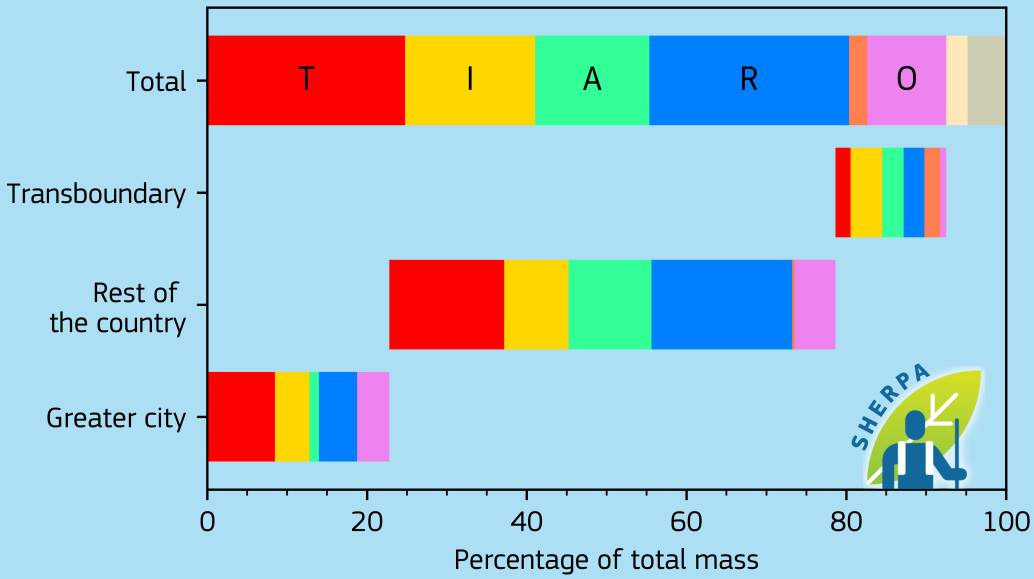
Italy, Padua



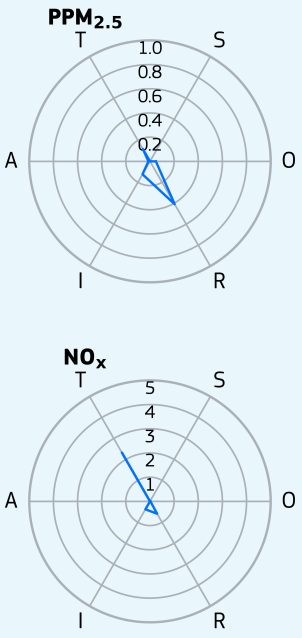
Yearly average urban concentrations (2018)

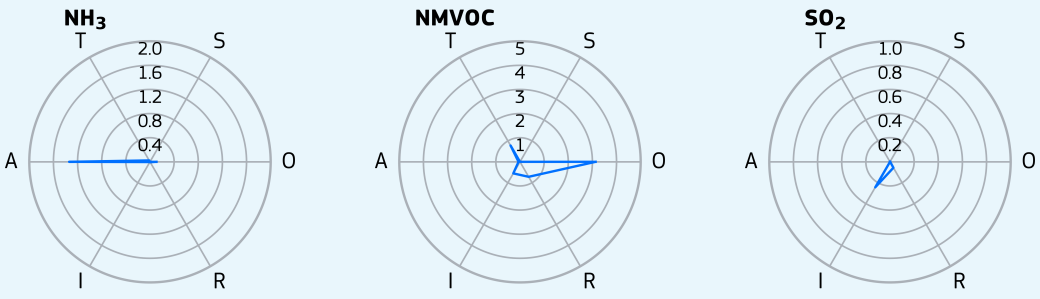


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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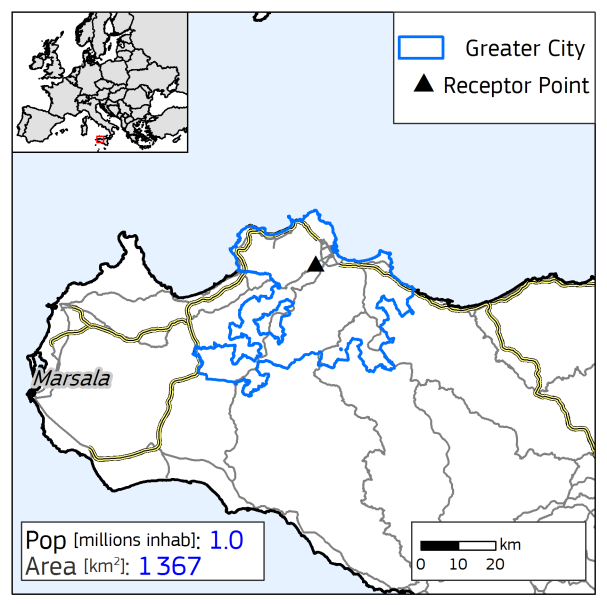
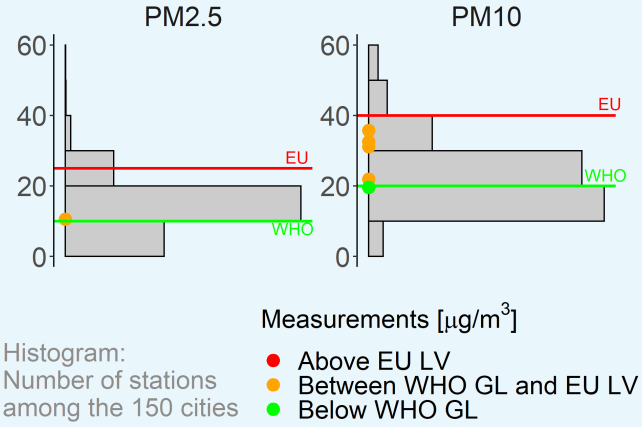
- Greater city

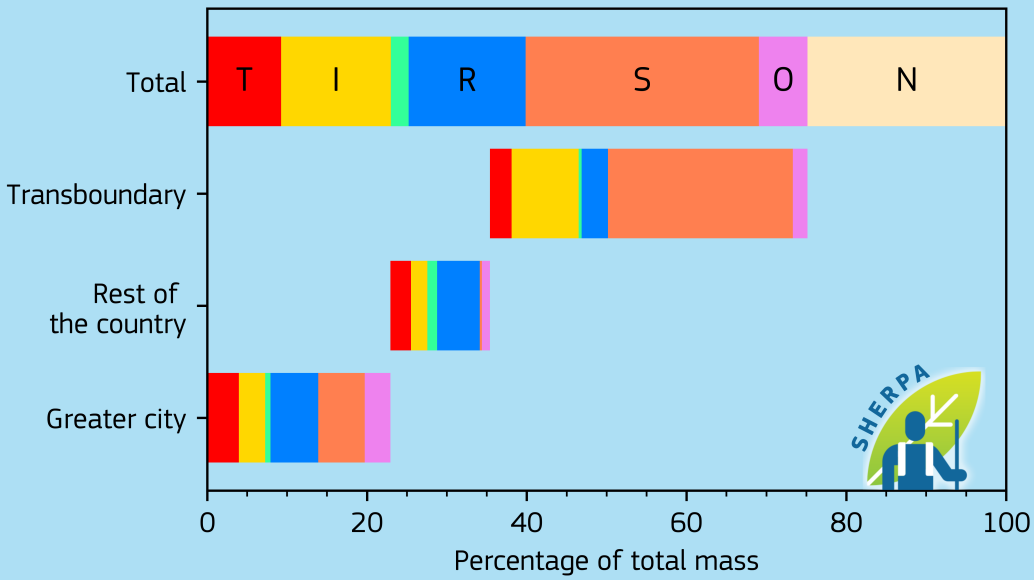
Italy, Palermo



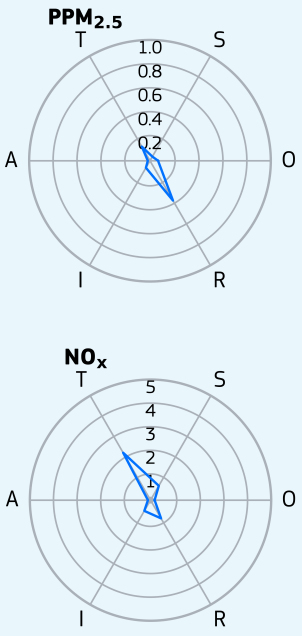
Yearly average urban concentrations (2018)

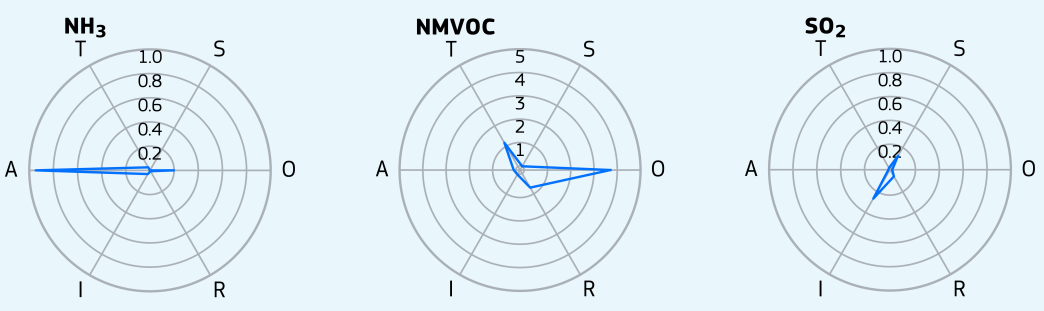


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
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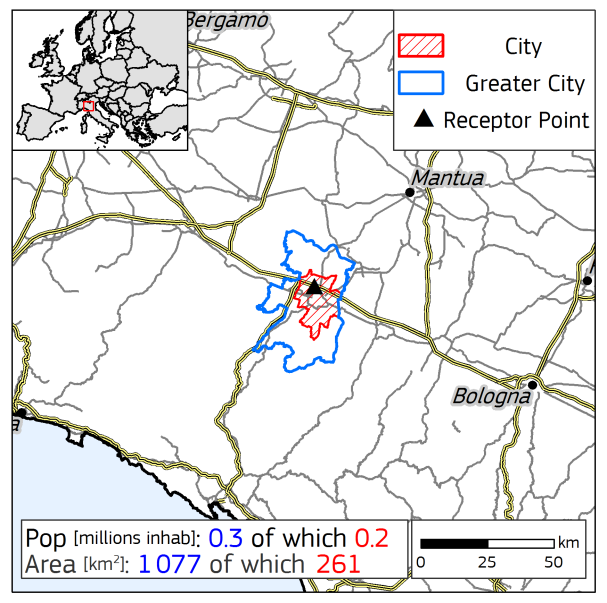
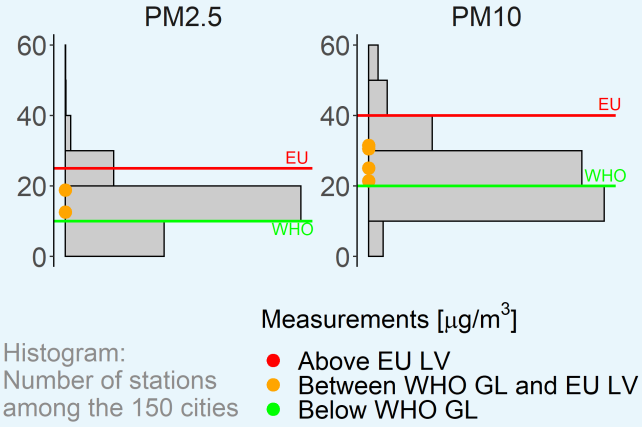
Greater city

Italy, Parma



Yearly average urban concentrations (2018)



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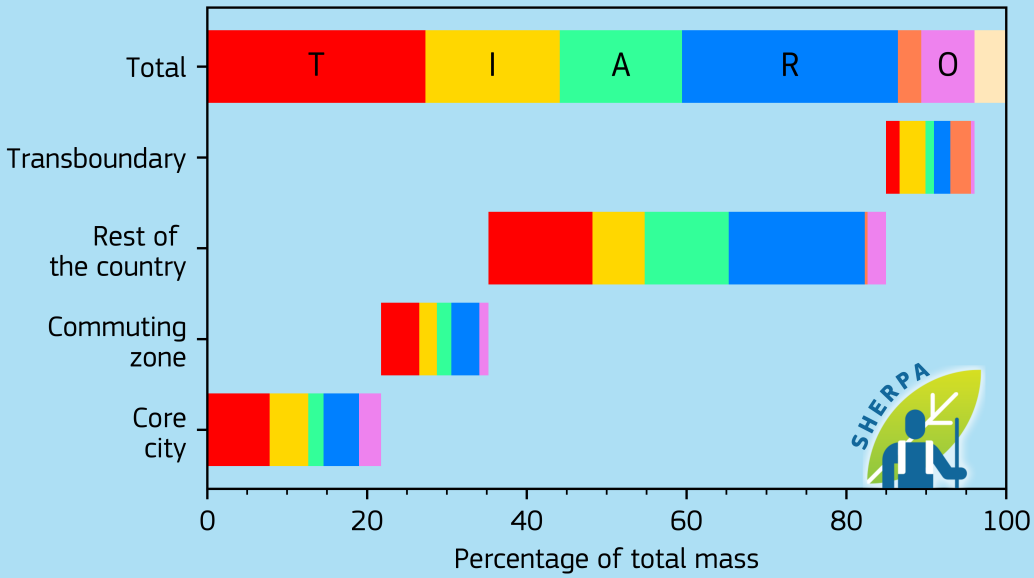
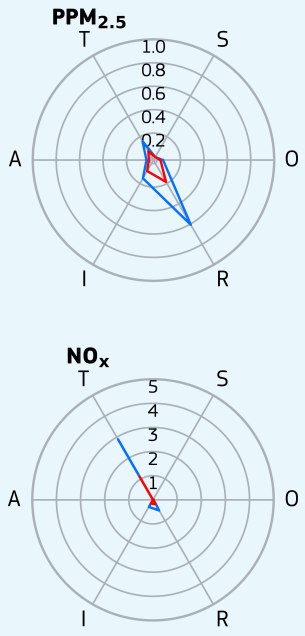
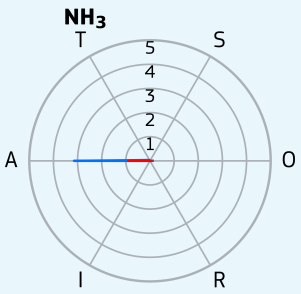
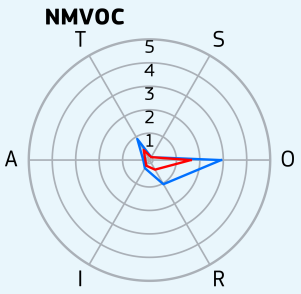
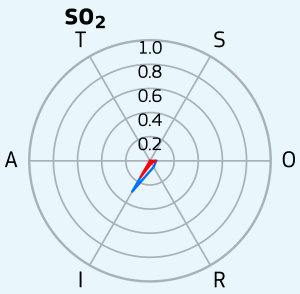


Emissions [kton/year]









- T - Transport
- I - Industry
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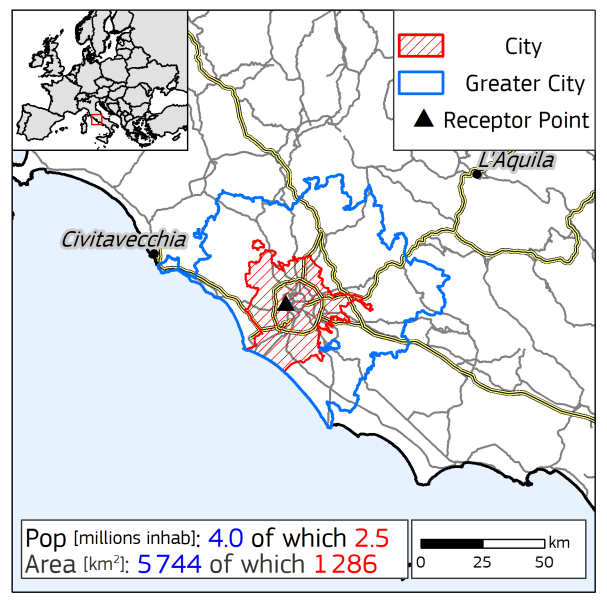
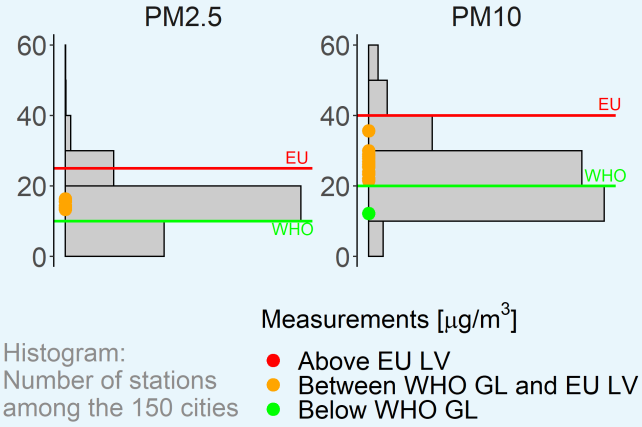
- Greater city
- Core city

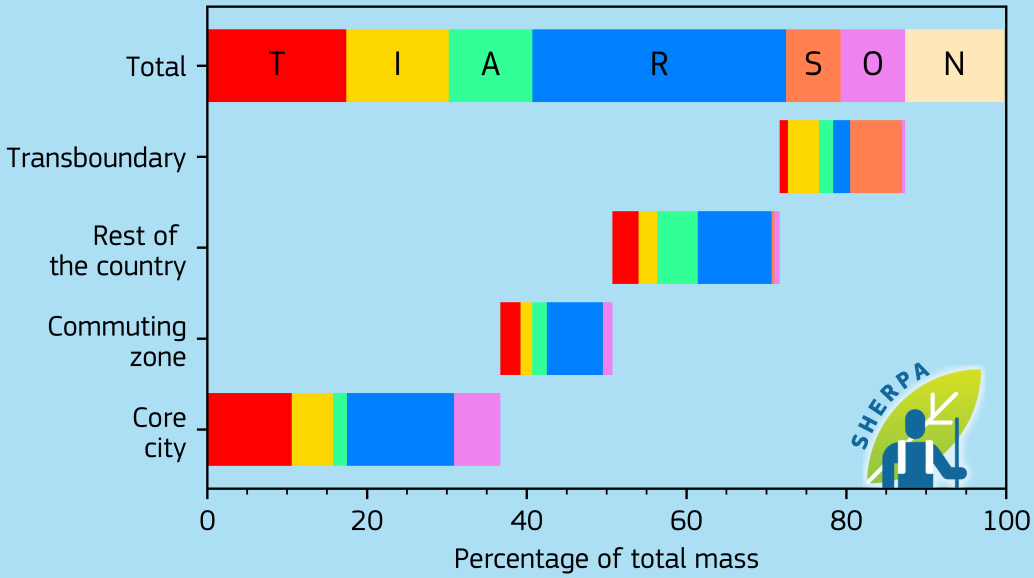
Italy, Rome



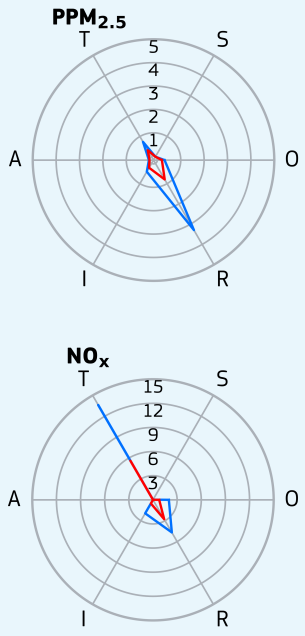
Yearly average urban concentrations (2018)

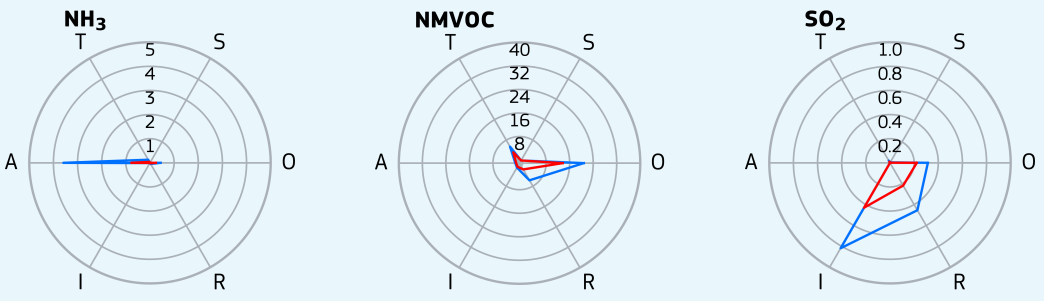


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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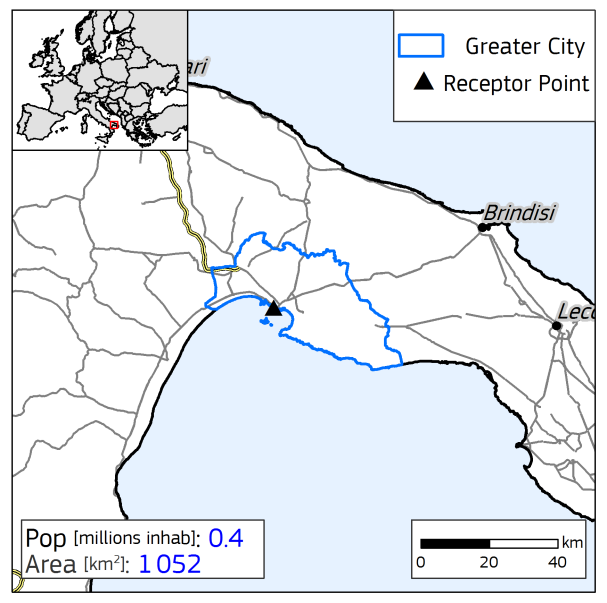
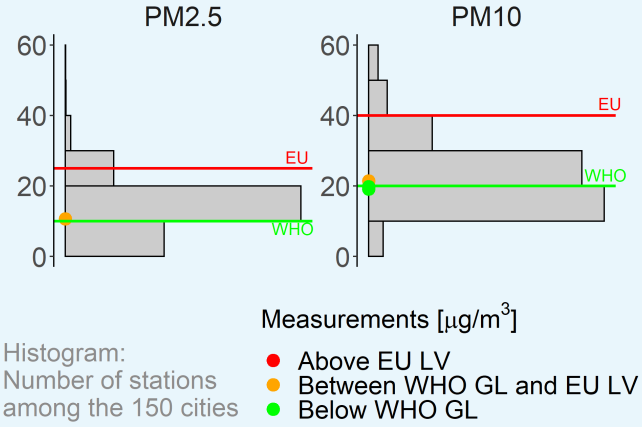
Italy, Taranto



Yearly average urban concentrations (2018)



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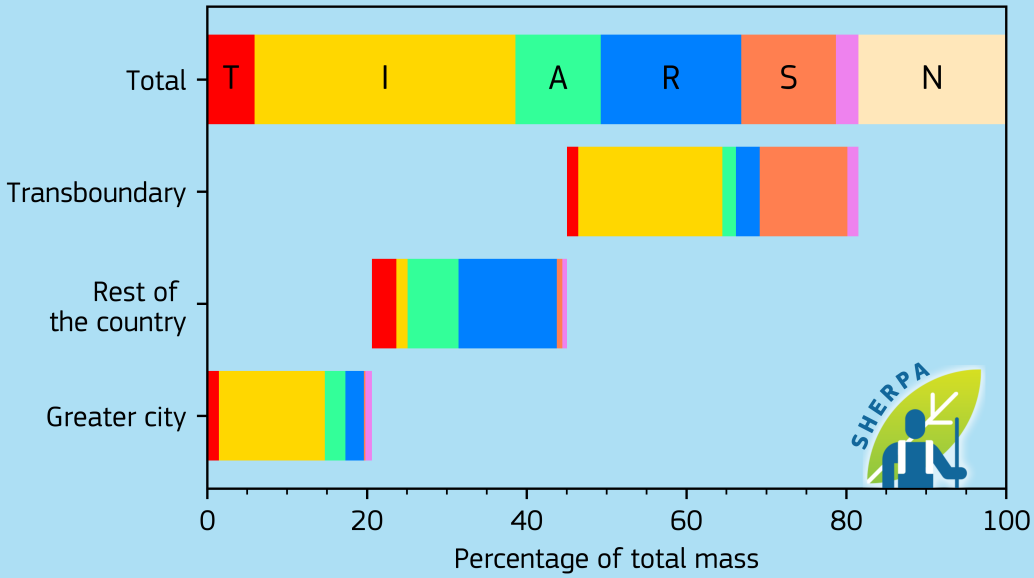
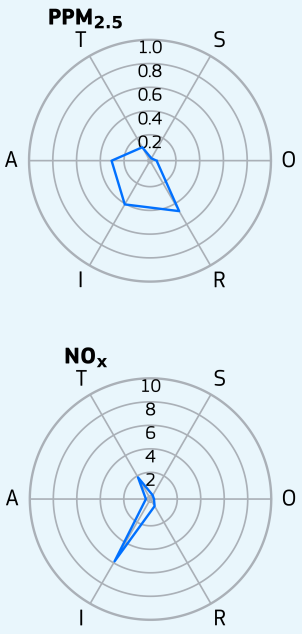
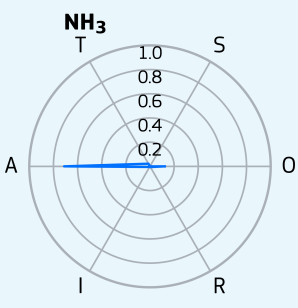
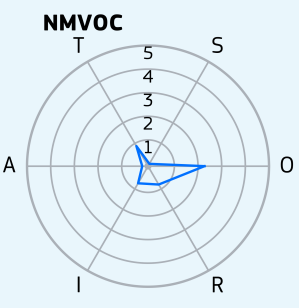
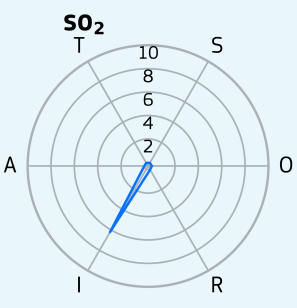


Emissions [kton/year]



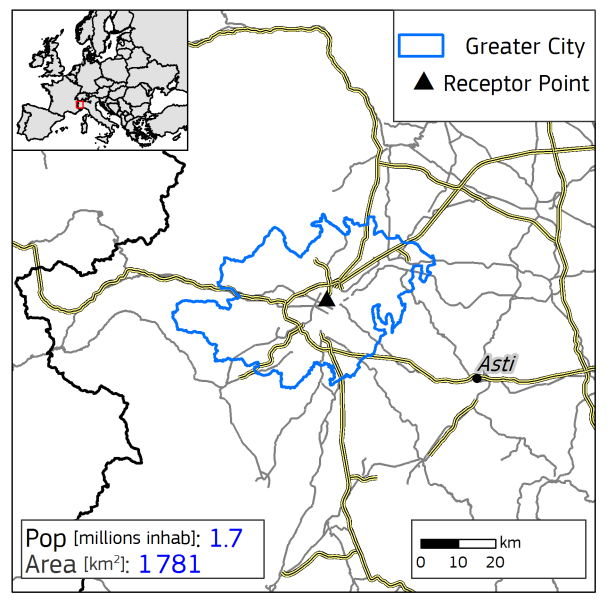




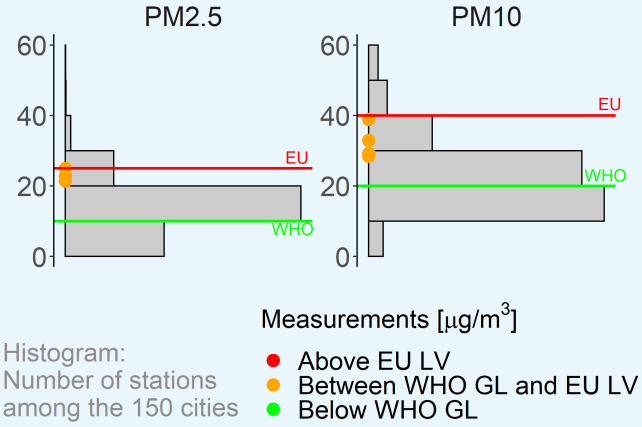


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

Italy, Turin



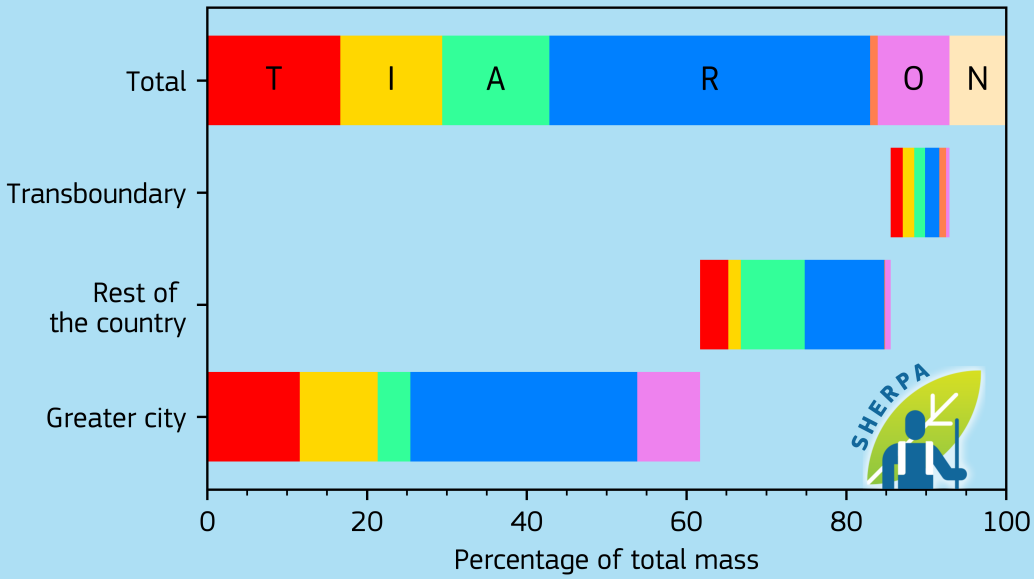
Yearly average urban concentrations (2018)



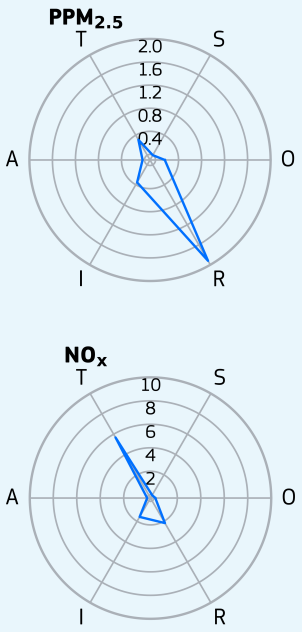
Histogram:
Number of stations
among the 150 cities

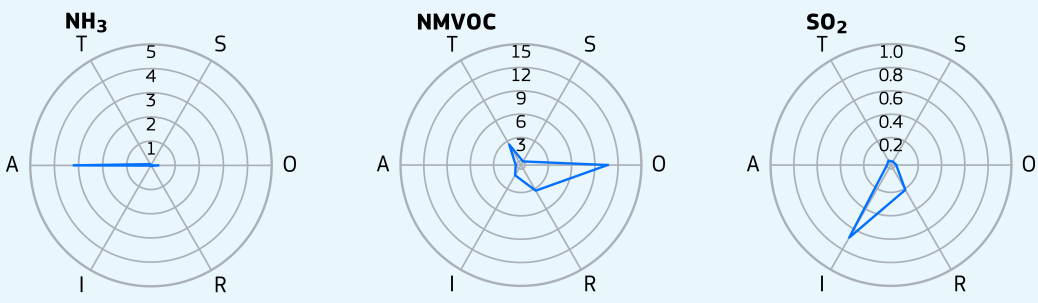
Measurements [µg/m³]
- Above EU LV
- Between WHO GL and EU LV
- Below WHO GL

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



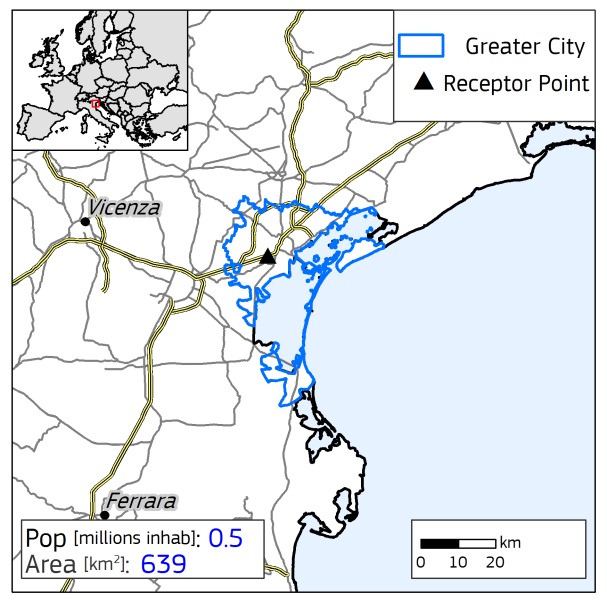
Emissions [kton/year]



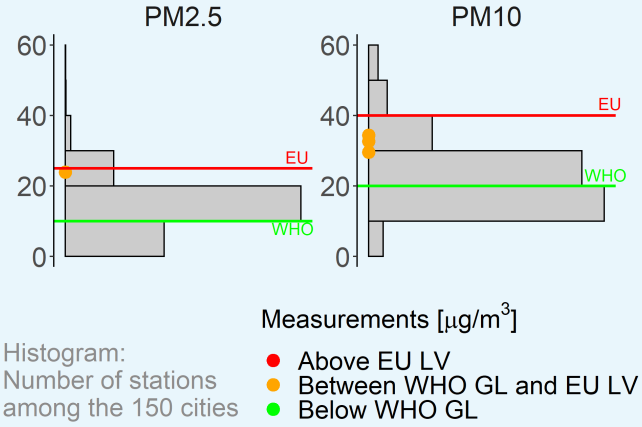


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- Greater city

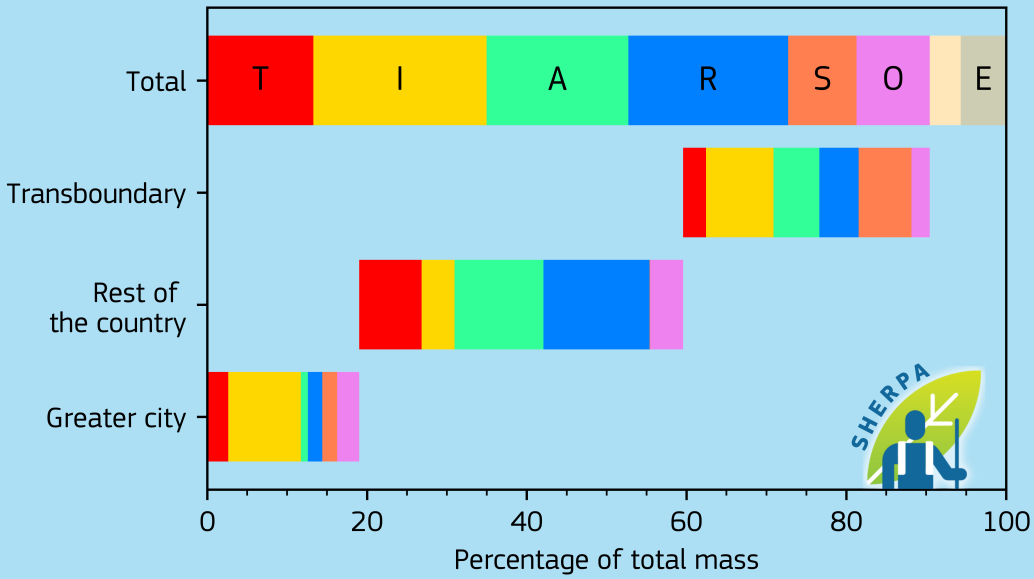
Italy, Venice



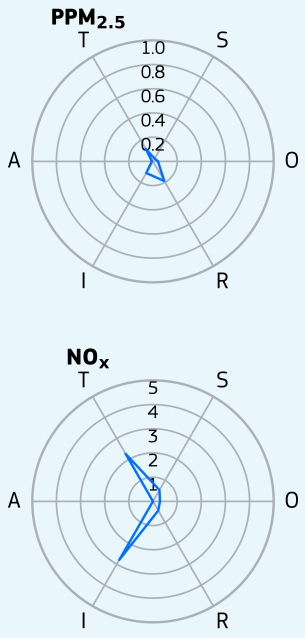
Yearly average urban concentrations (2018)

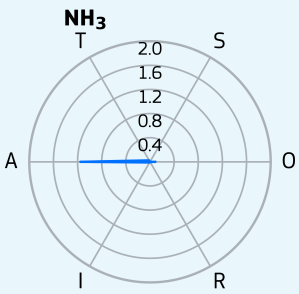


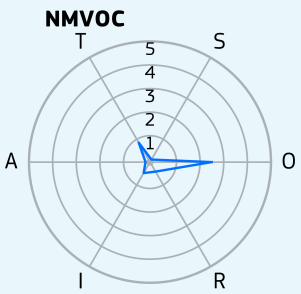
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

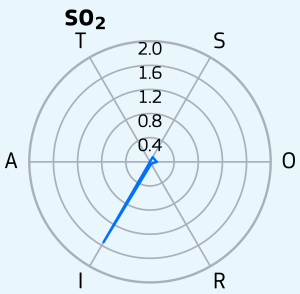


Emissions [kton/year]



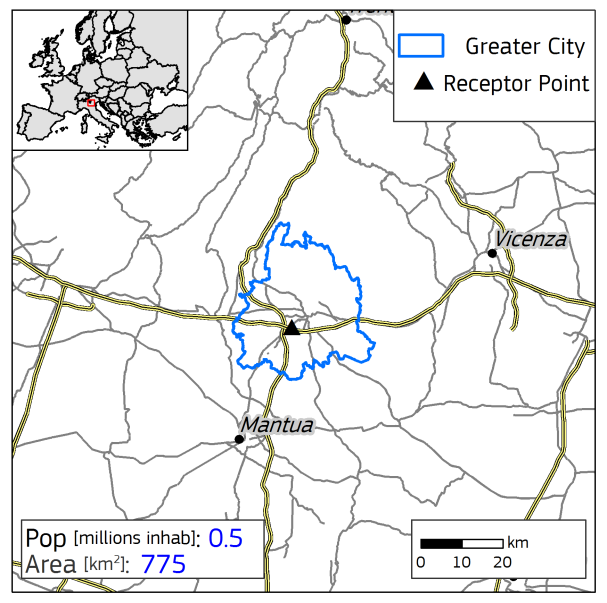




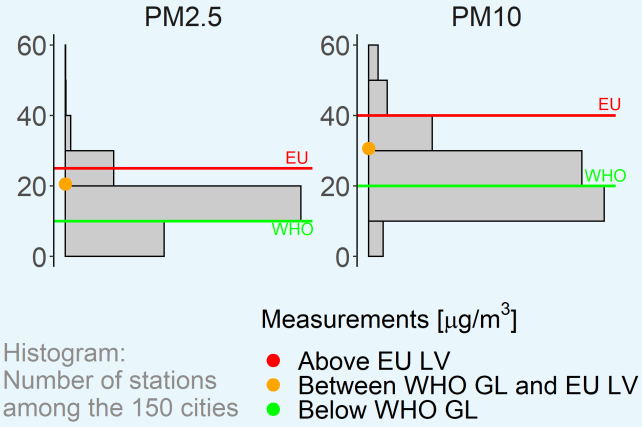


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

Italy, Verona

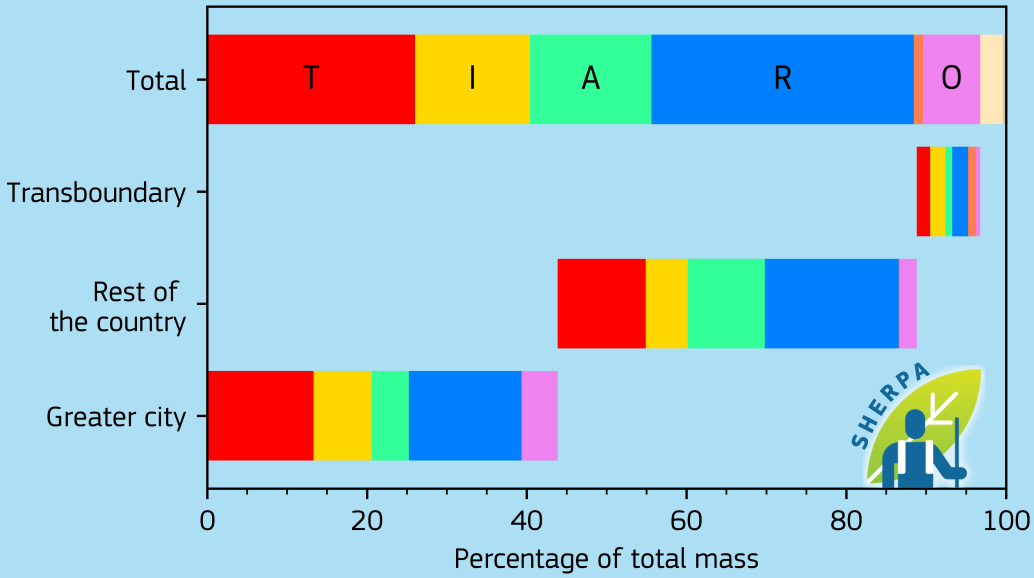


Yearly average urban concentrations (2018)

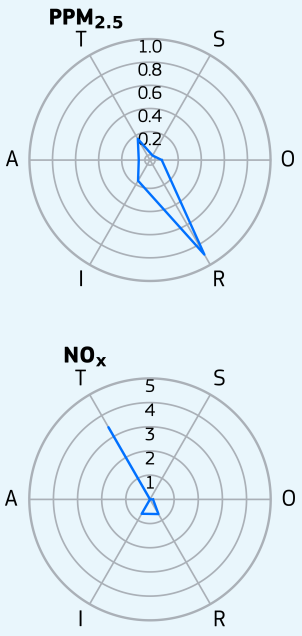


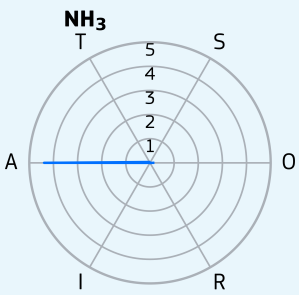
Histogram:
Number of stations
among the 150 cities

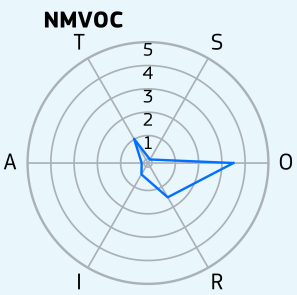
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

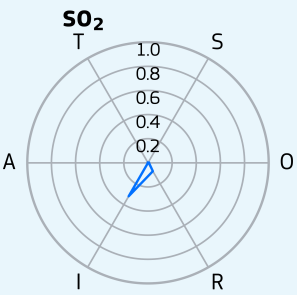


Emissions [kton/year]



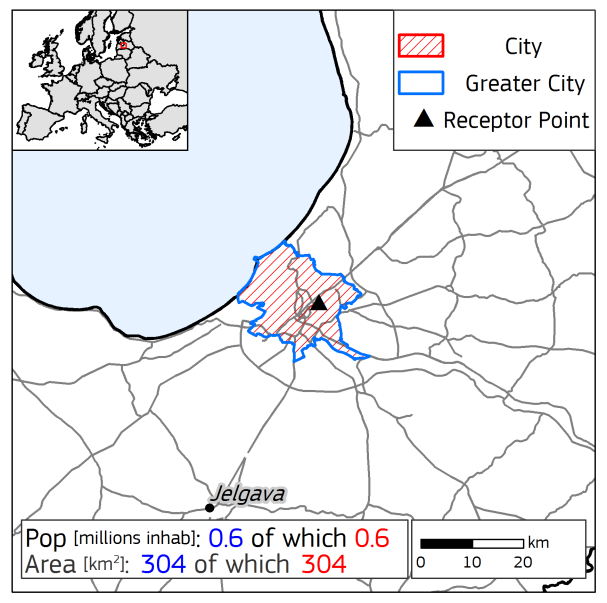




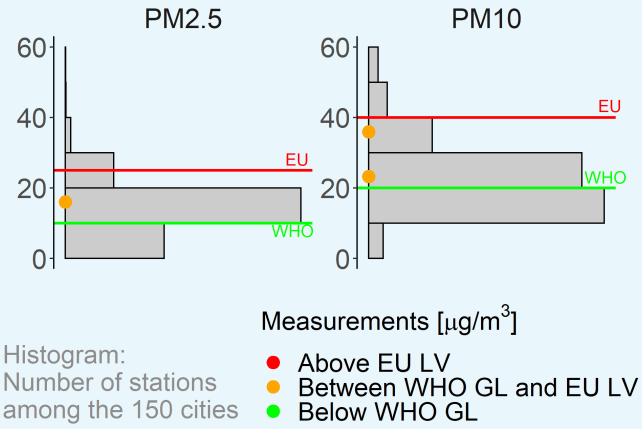


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

Latvia, Riga

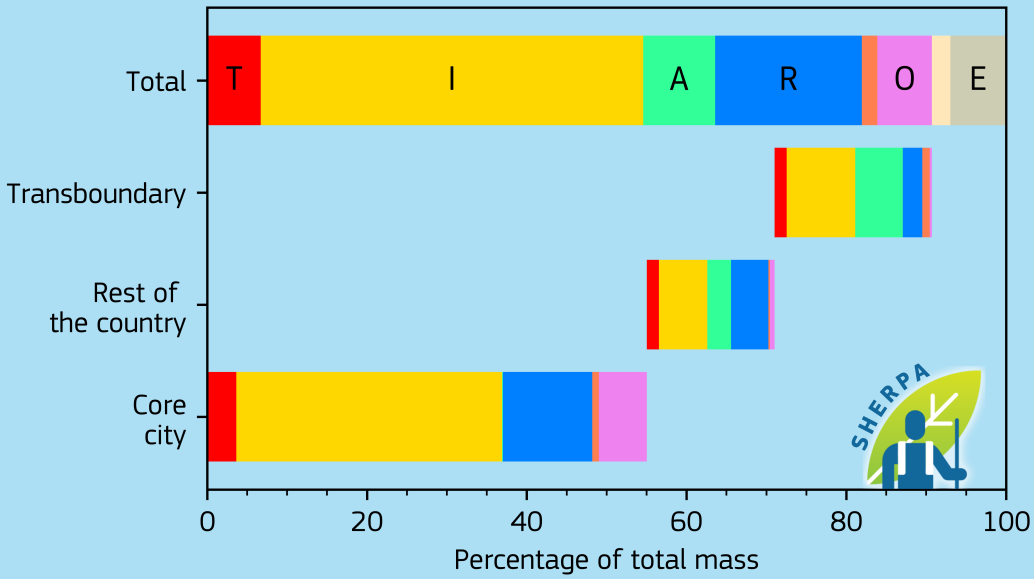


Yearly average urban concentrations (2018)

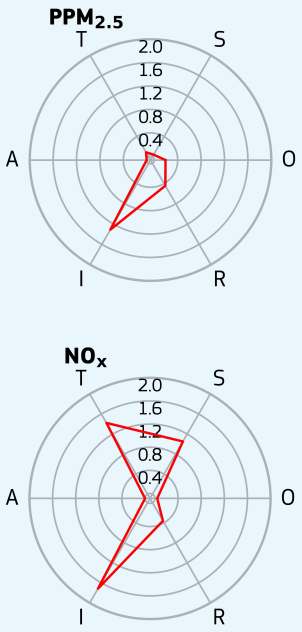


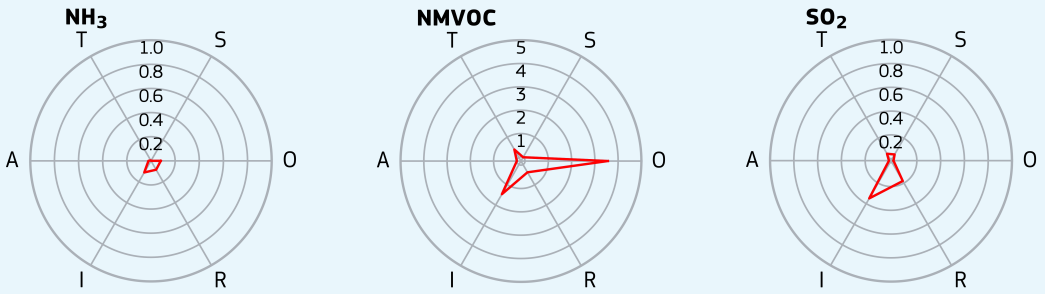
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



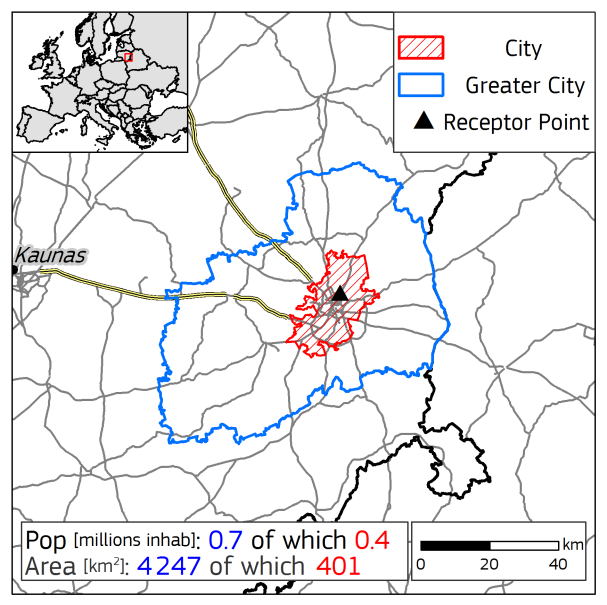
Emissions [kton/year]



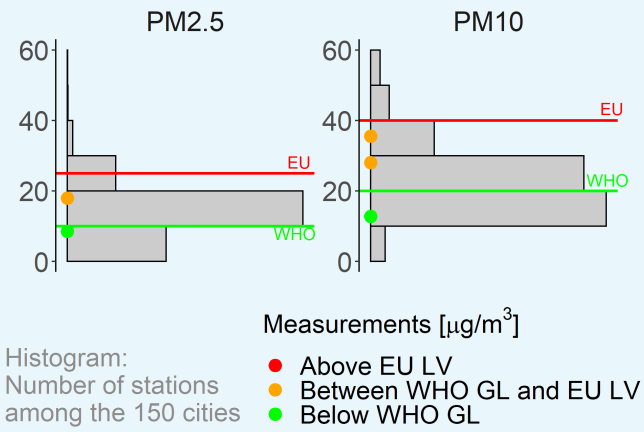


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

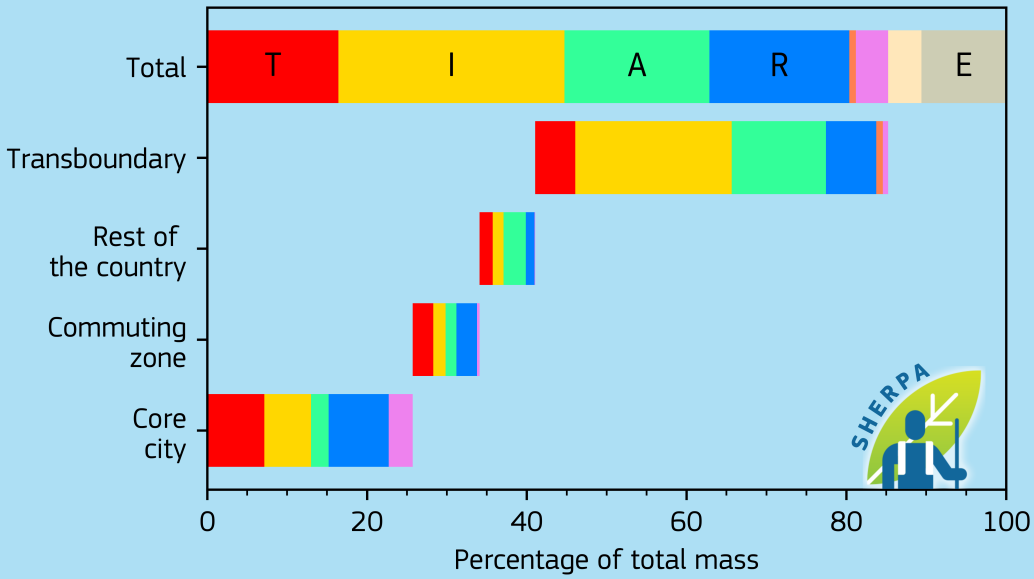
Lithuania, Vilnius



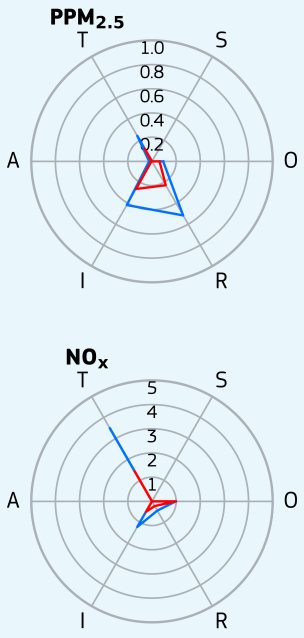
Yearly average urban concentrations (2018)

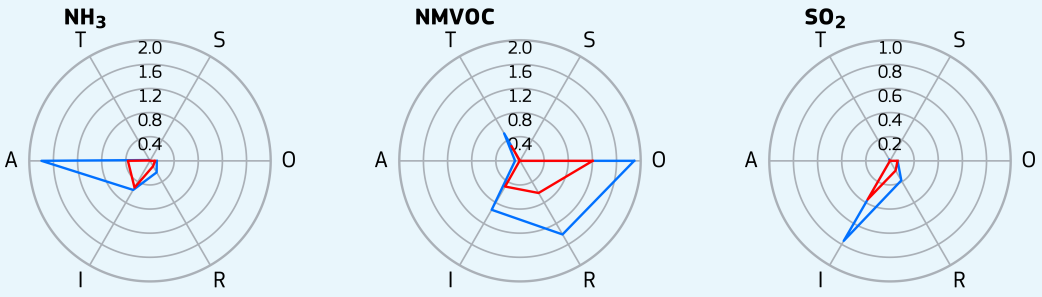


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



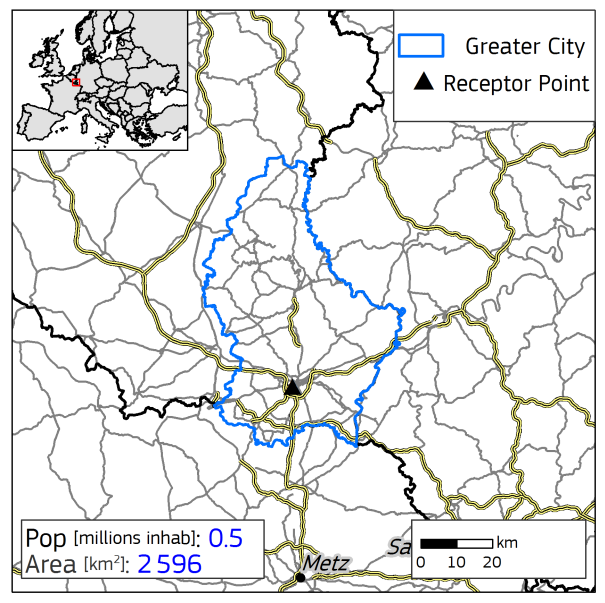
Emissions [kton/year]



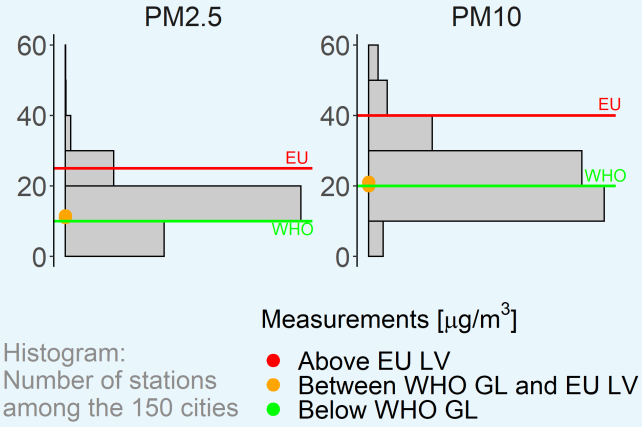


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

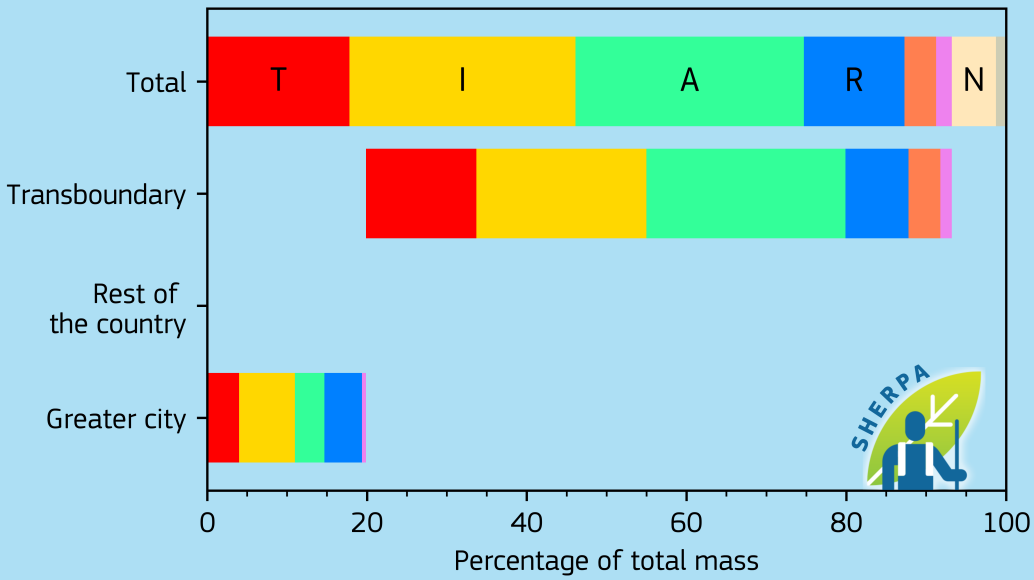
Luxembourg, Luxembourg



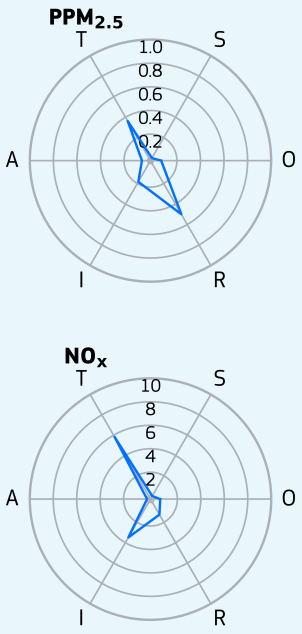
Yearly average urban concentrations (2018)

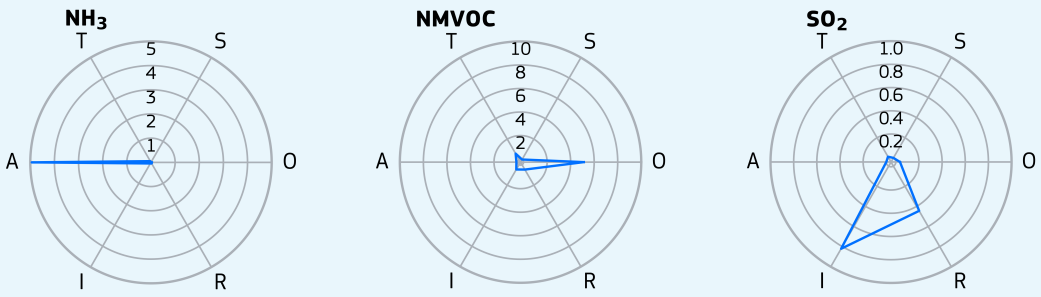


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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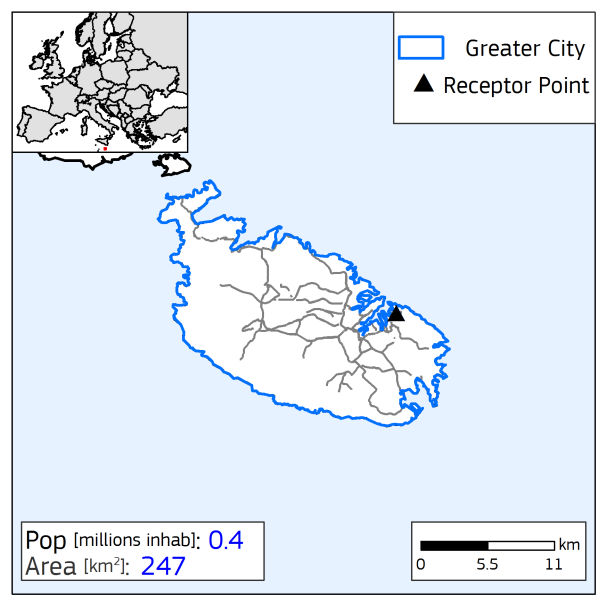
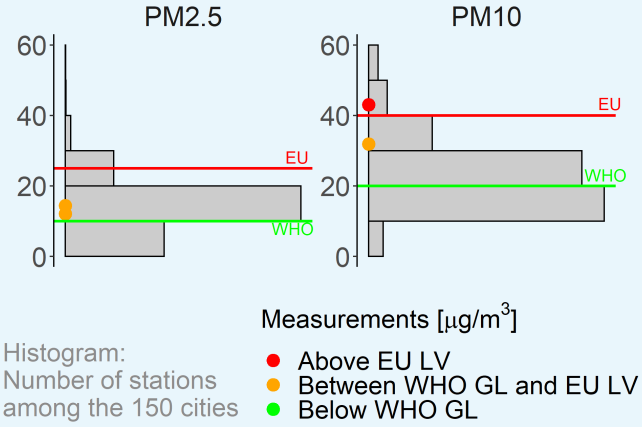
- Greater city

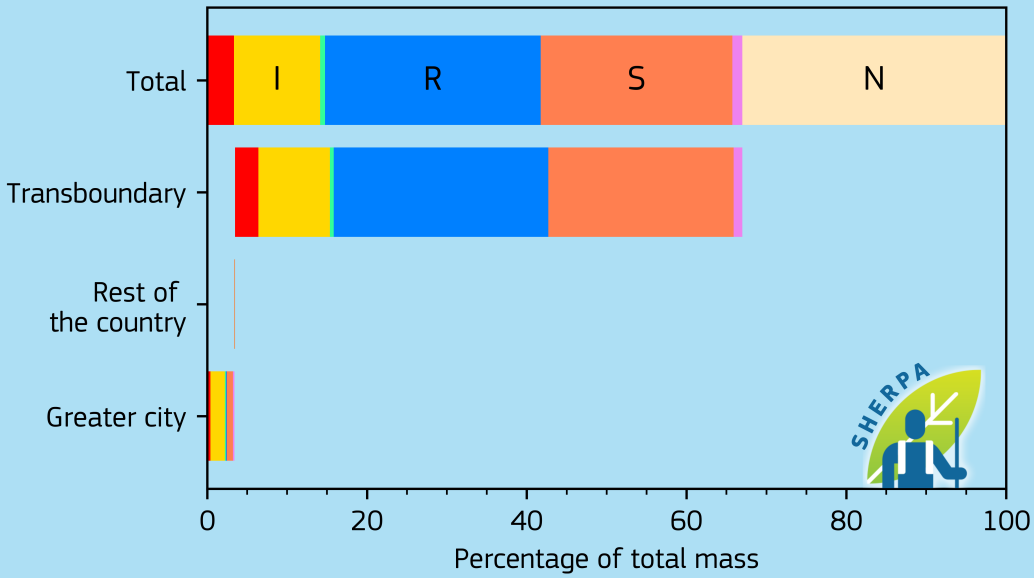
Malta, Valletta



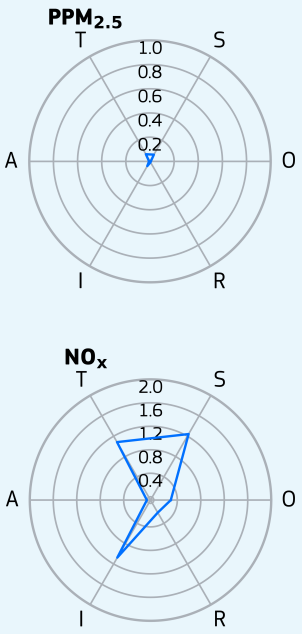
Yearly average urban concentrations (2018)

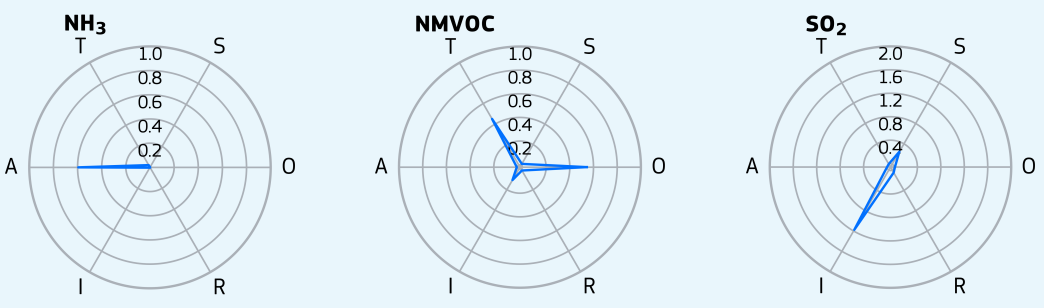


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
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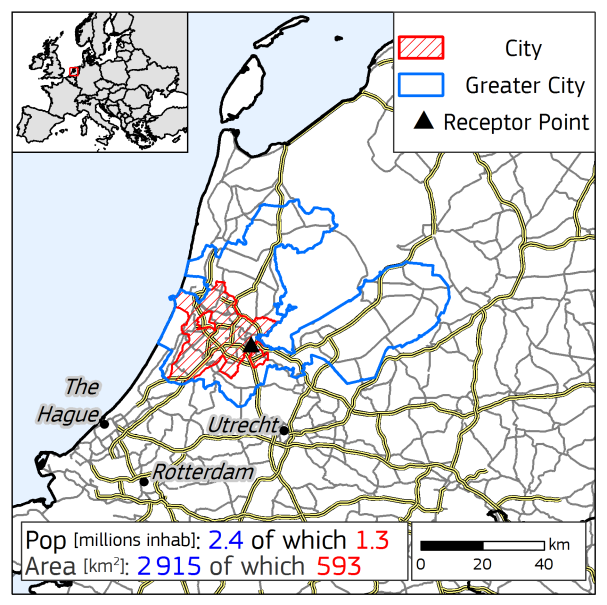
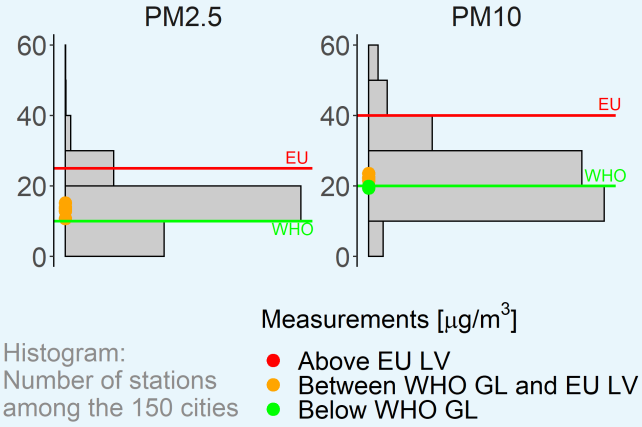
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

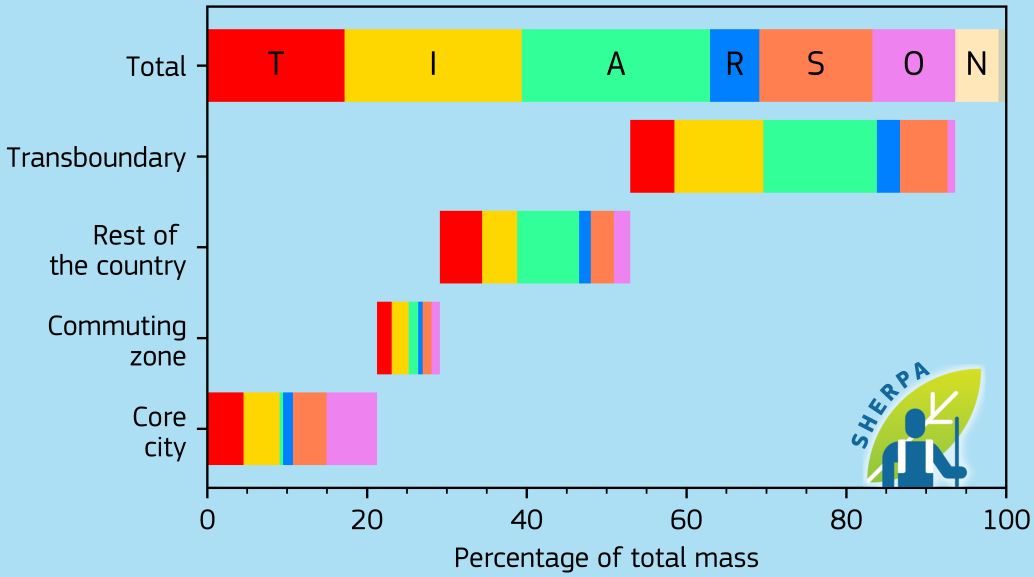
Netherlands, Amsterdam



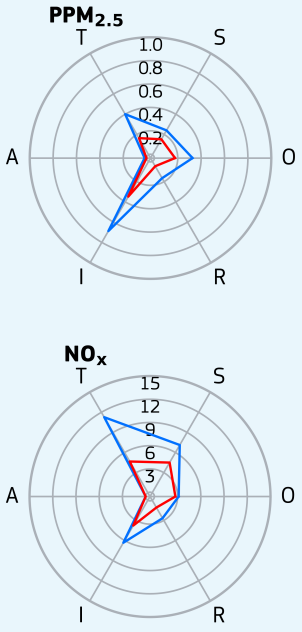
Yearly average urban concentrations (2018)

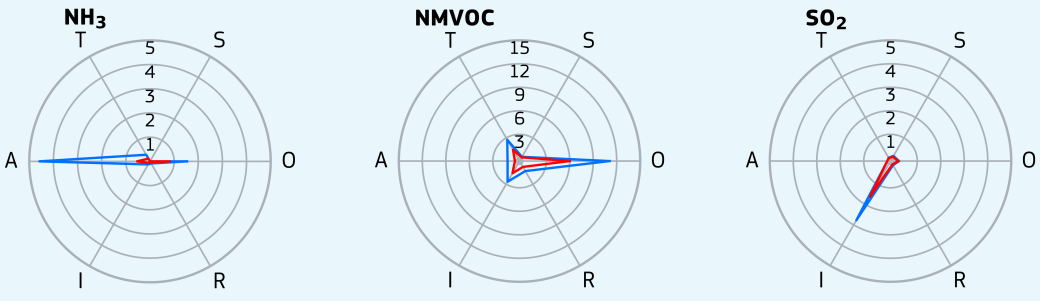


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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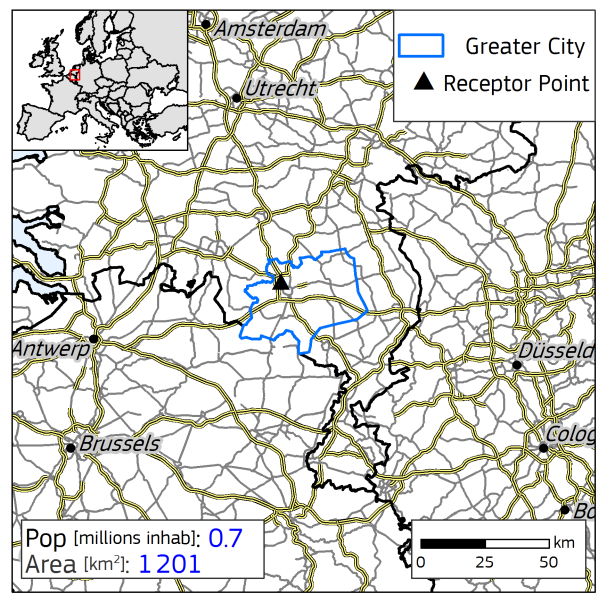
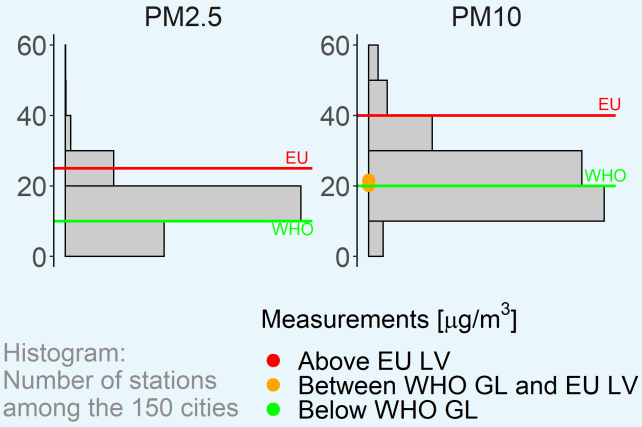
Greater city
Core city

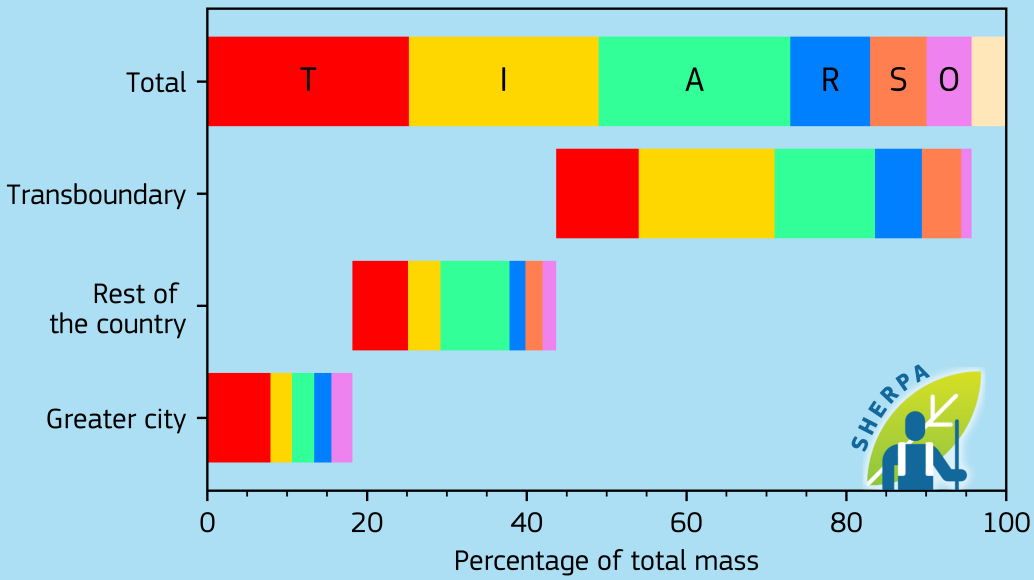
Netherlands, Eindhoven



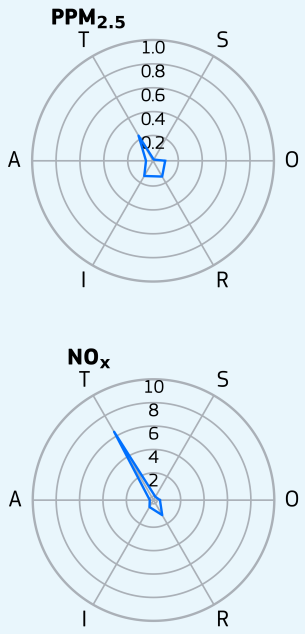
Yearly average urban concentrations (2018)

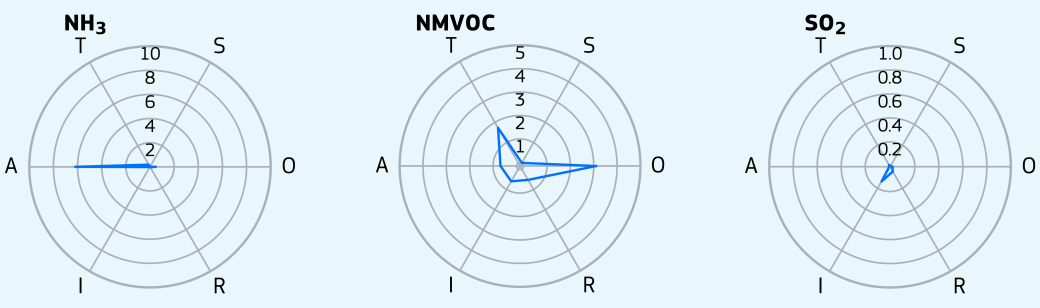


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



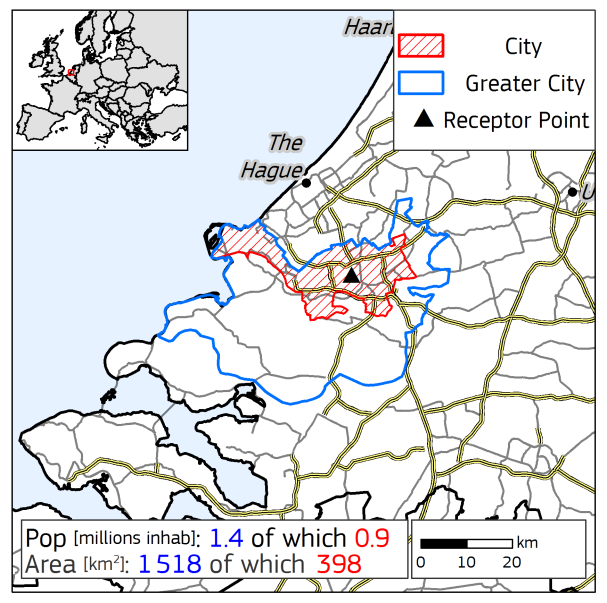
Emissions [kton/year]



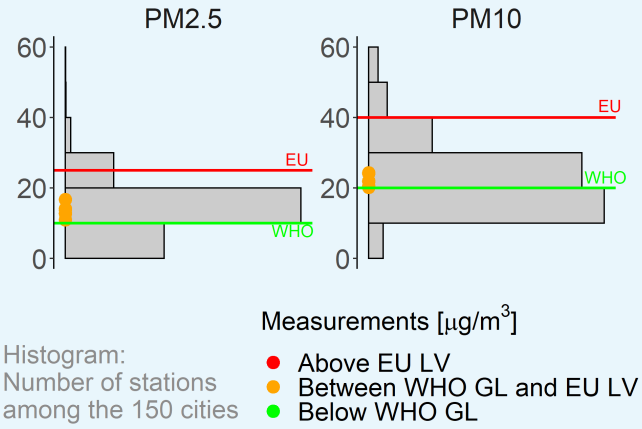


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

Netherlands, Rotterdam

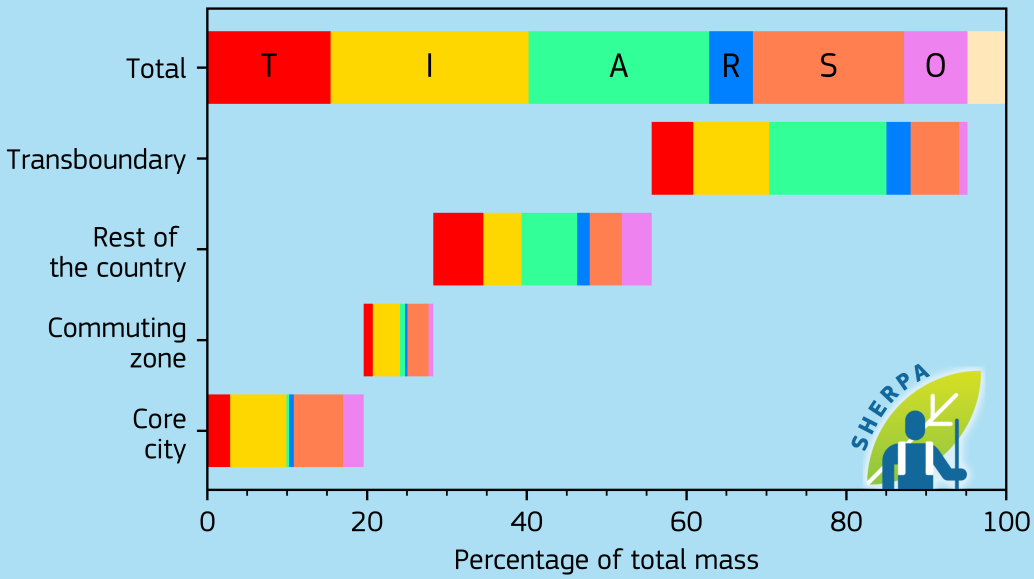


Yearly average urban concentrations (2018)

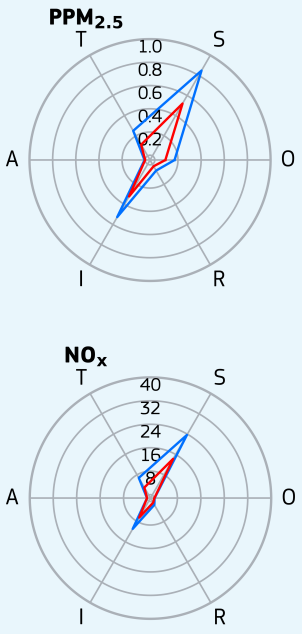


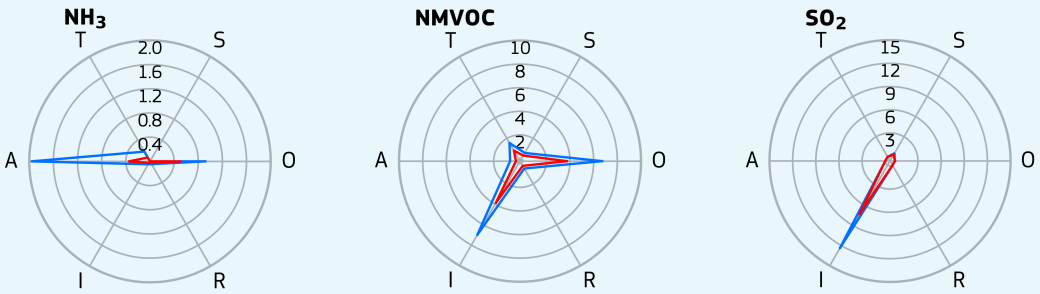
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



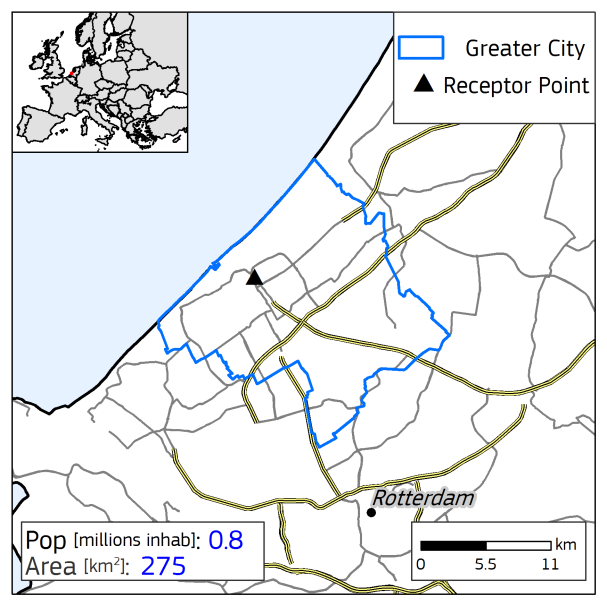
Emissions [kton/year]



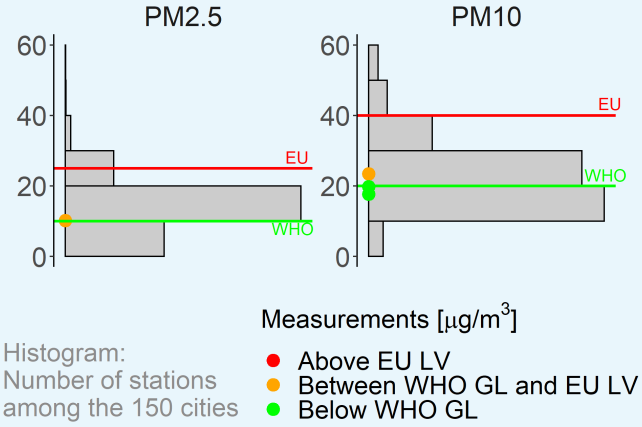


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

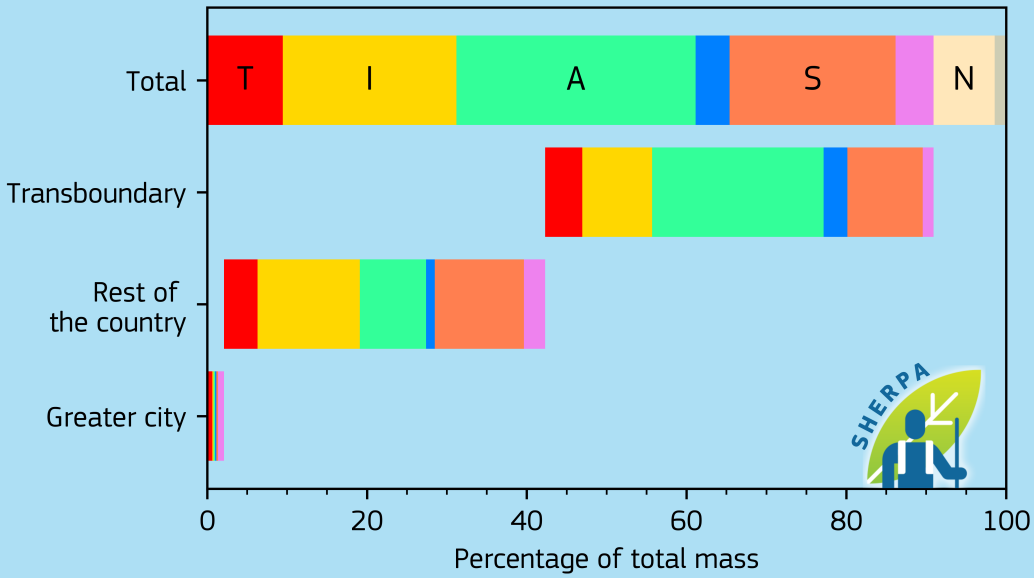
Netherlands, The Hague



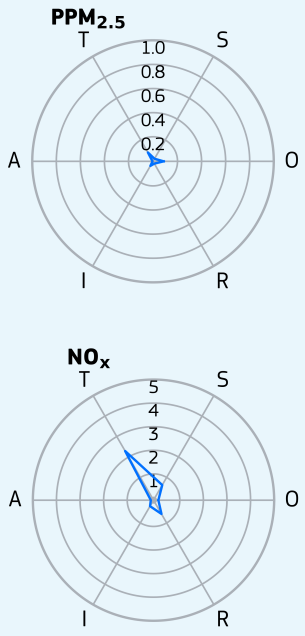
Yearly average urban concentrations (2018)

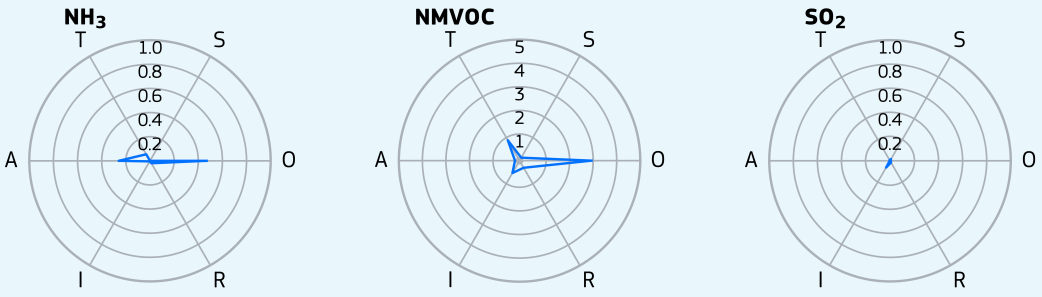


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



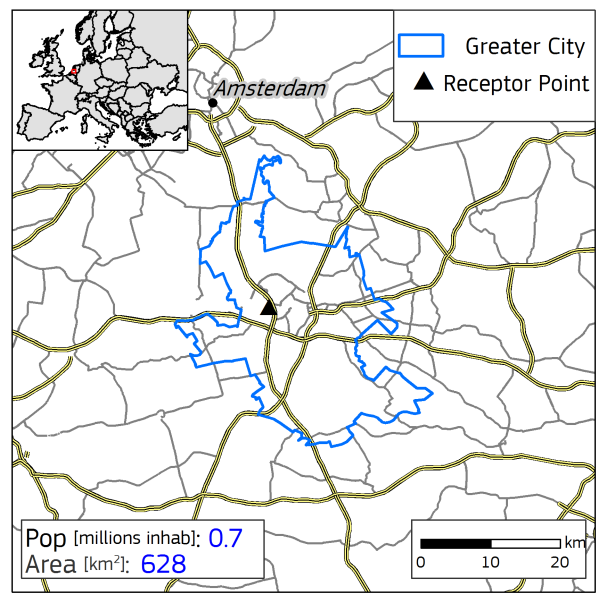
Emissions [kton/year]



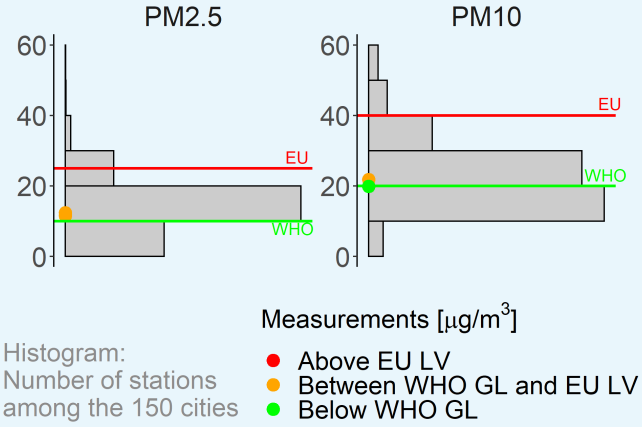


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

Netherlands, Utrecht



Yearly average urban concentrations (2018)



Histogram:
Number of stations
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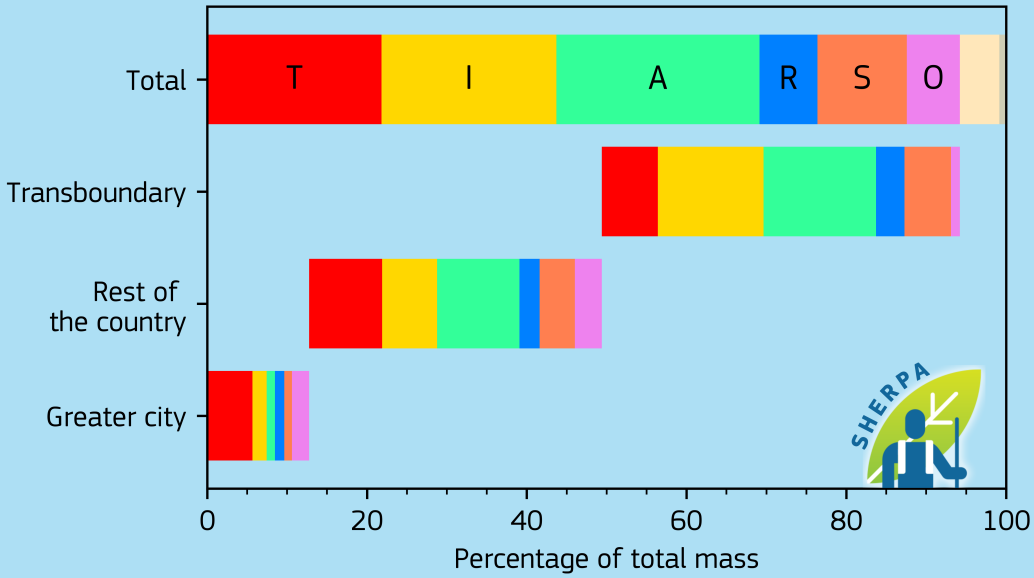
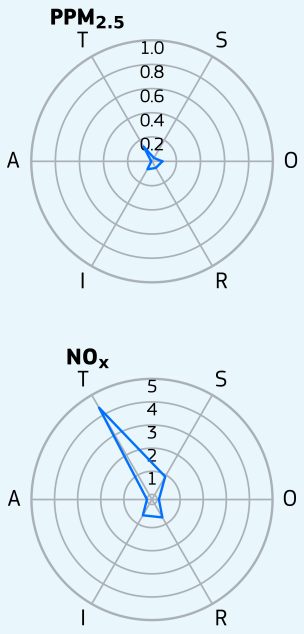
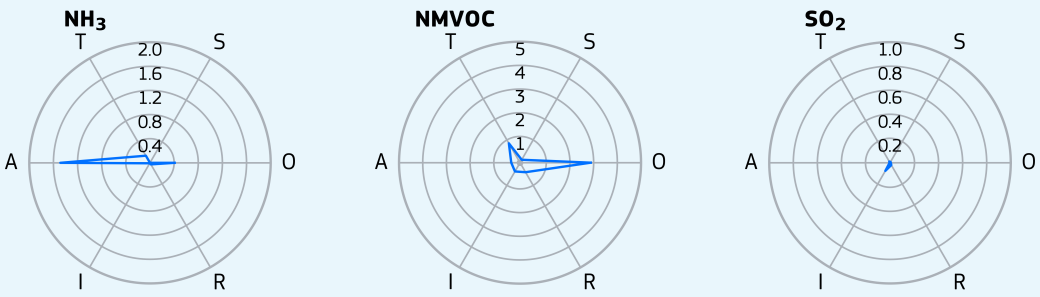


Emissions [kton/year]





- T - Transport
- I - Industry
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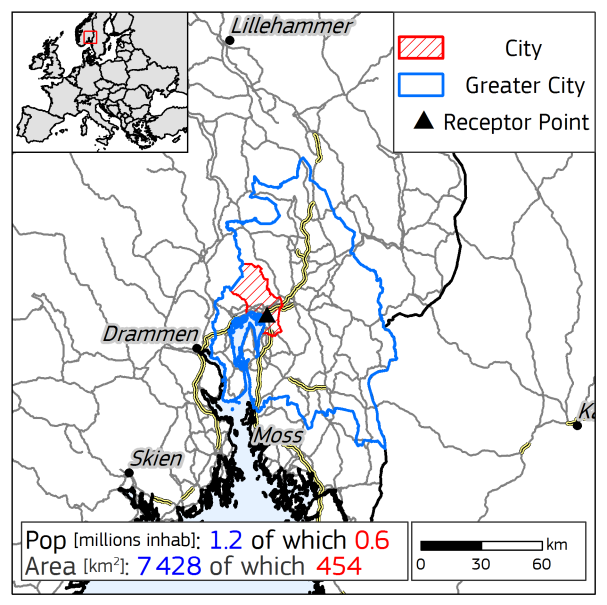
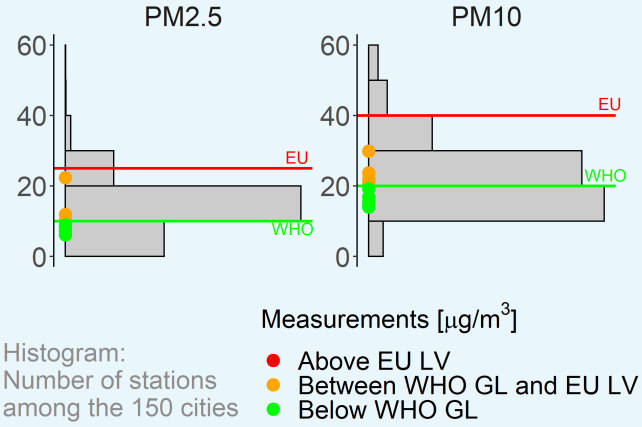
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

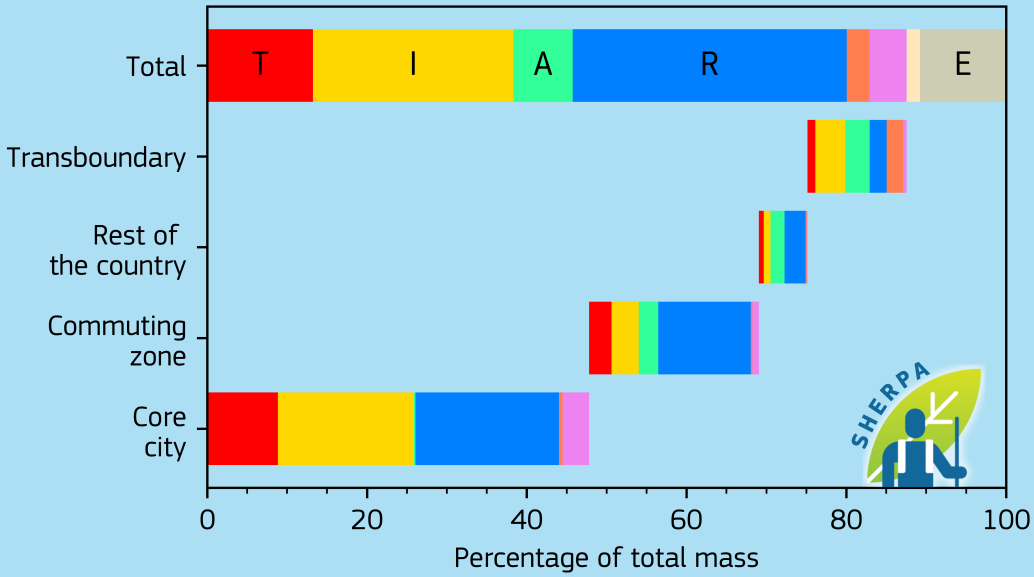
Norway, Oslo



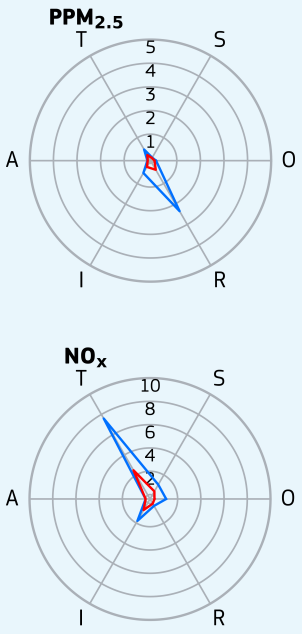
Yearly average urban concentrations (2018)

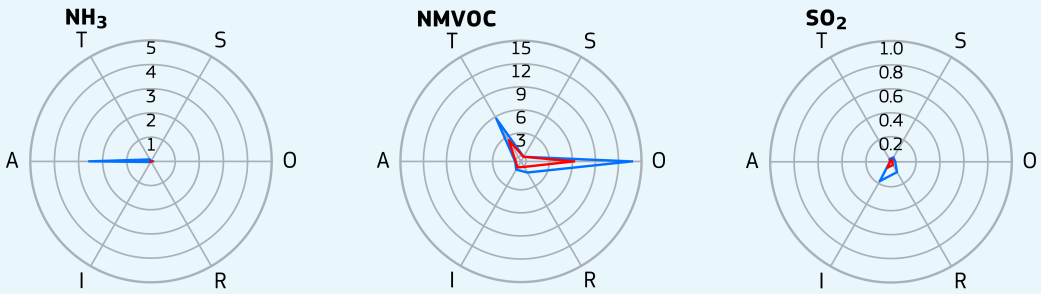


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



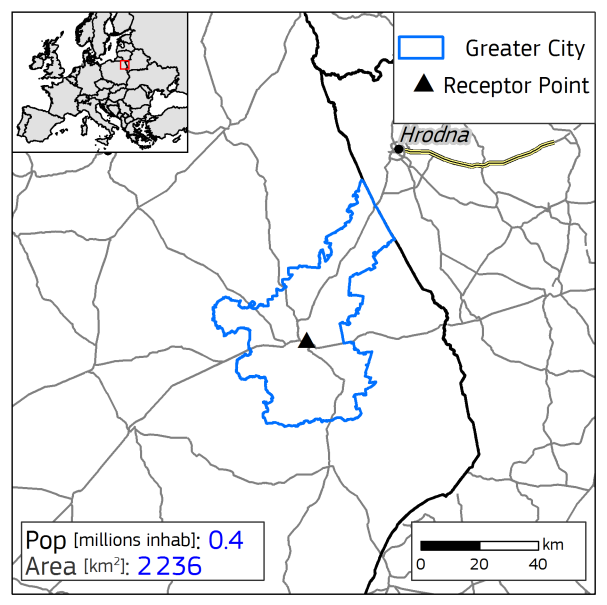
Emissions [kton/year]



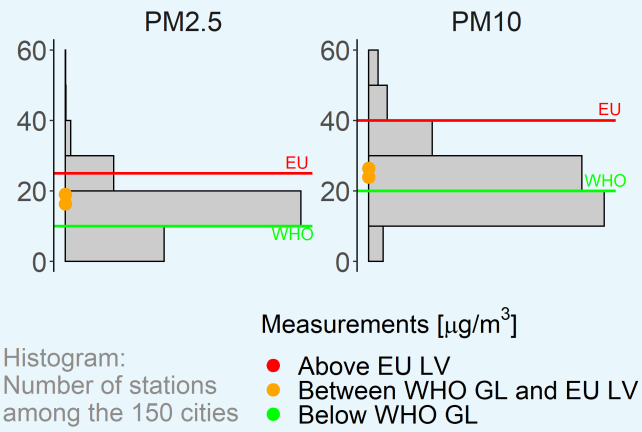


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

Poland, Białystok



Yearly average urban concentrations (2018)



Histogram:
Number of stations
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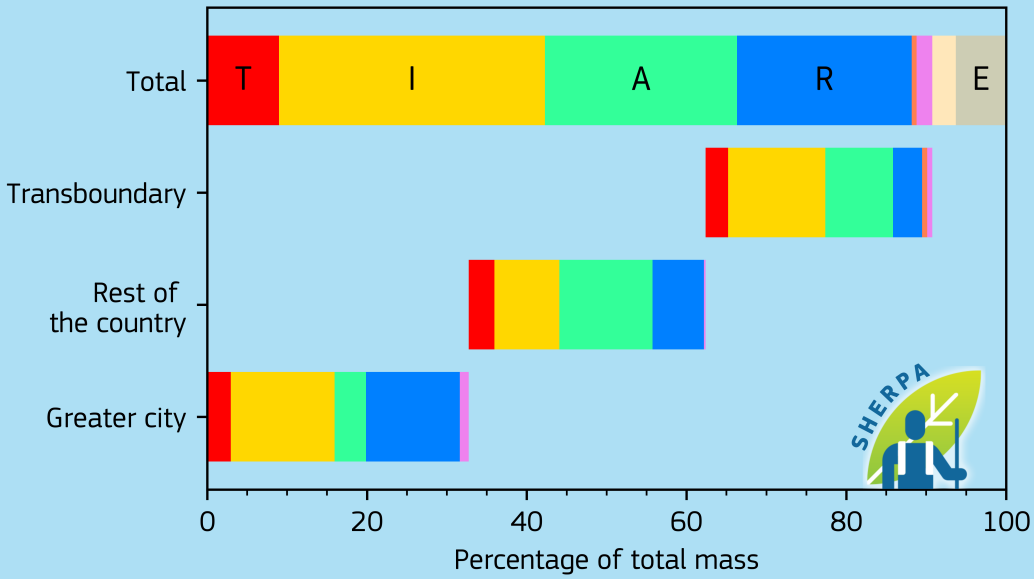
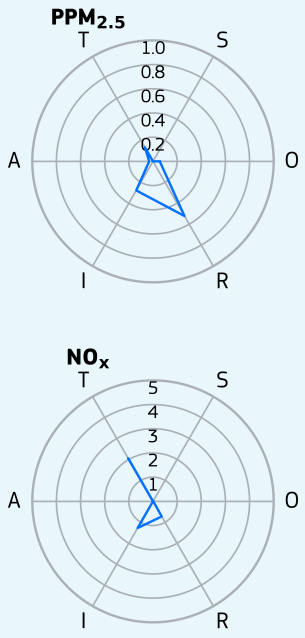
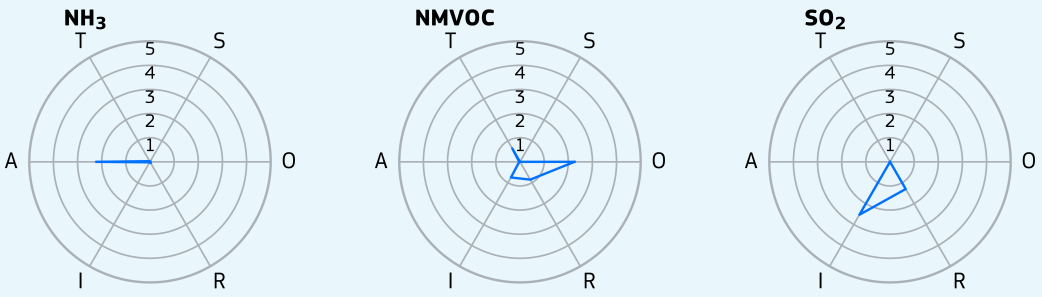
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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- R - Residential
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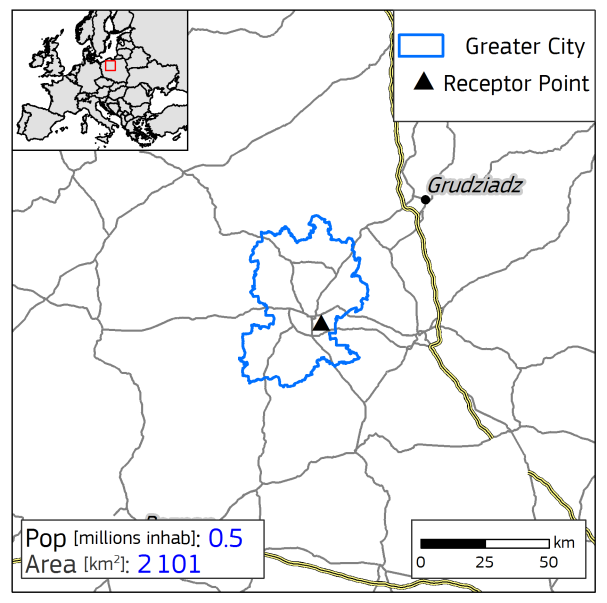
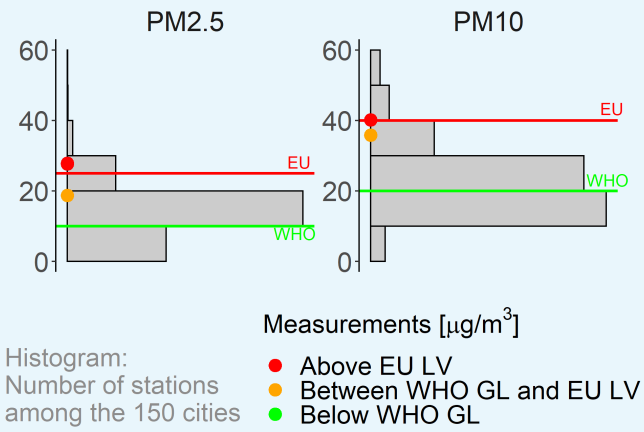
- N - Natural
- E - External
- Greater city

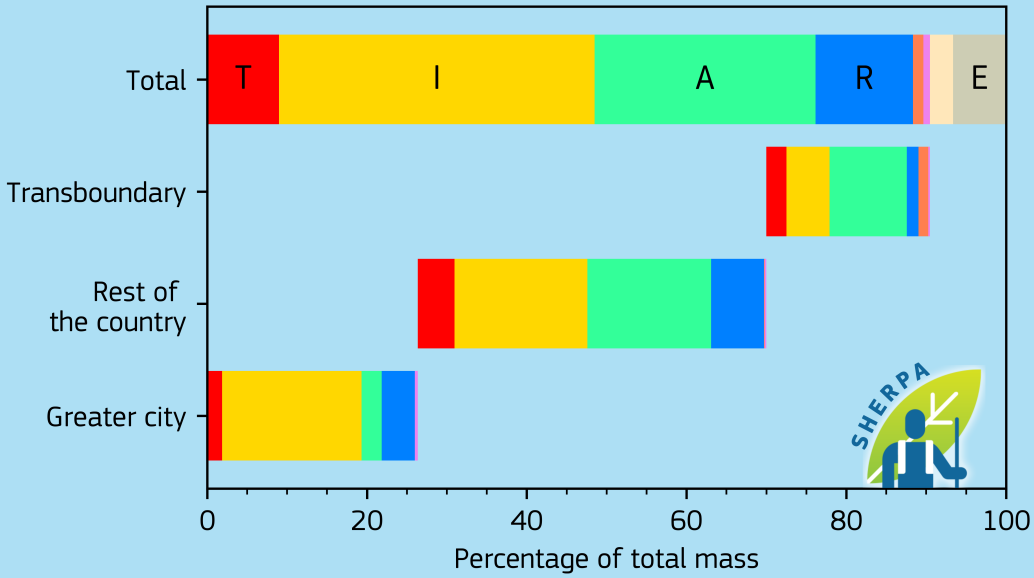
Poland, Bydgoszcz



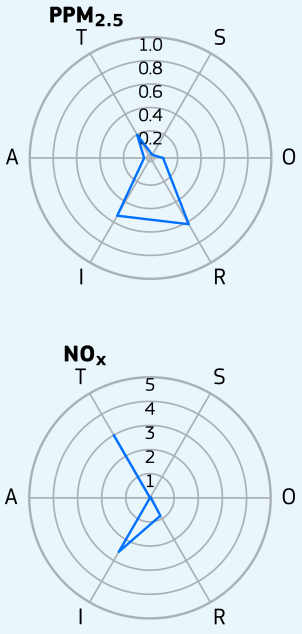
Yearly average urban concentrations (2018)

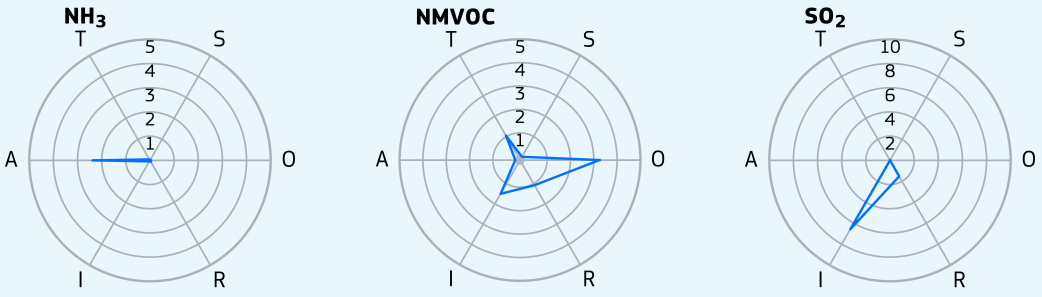


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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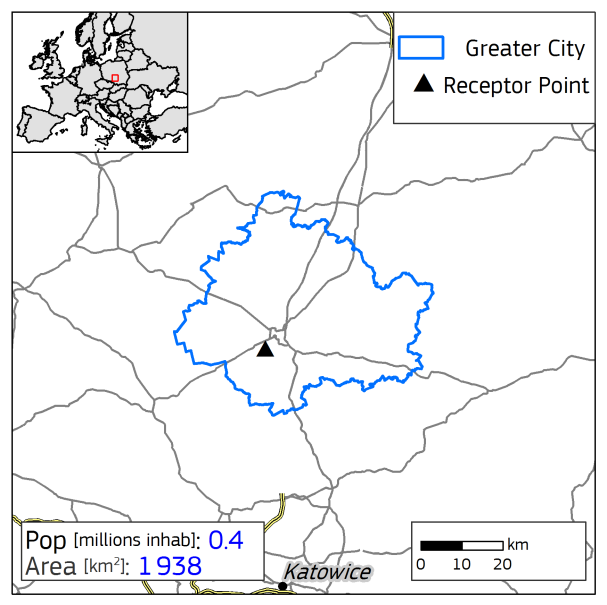
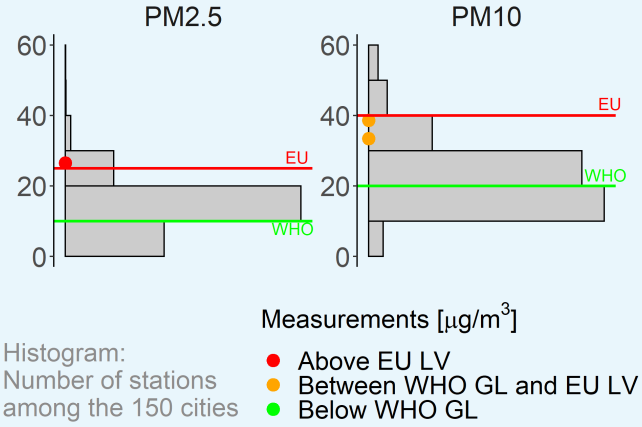
- Greater city

Poland, Częstochowa



Yearly average urban concentrations (2018)



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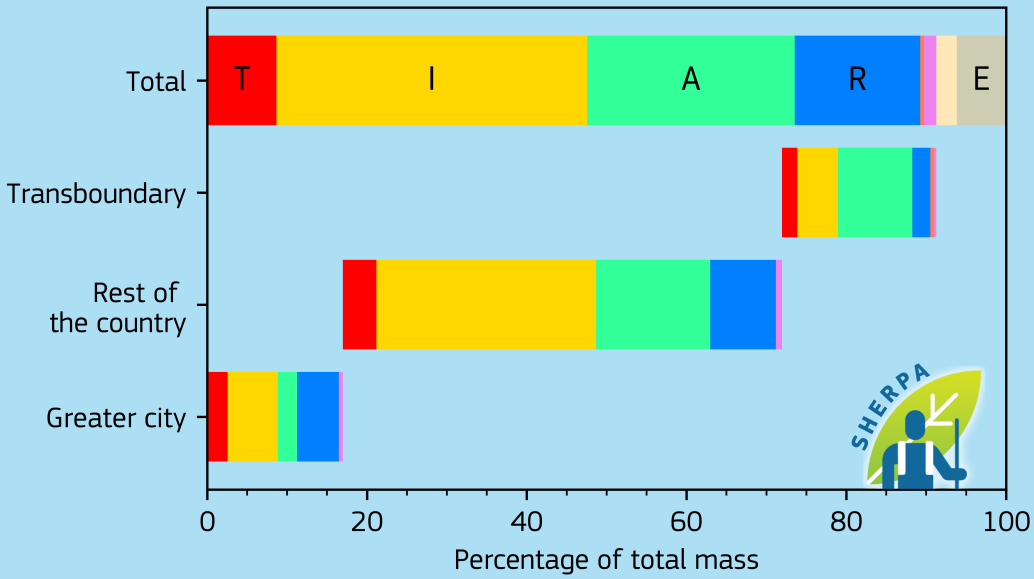
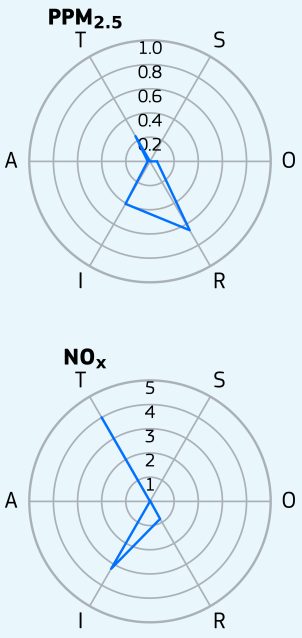
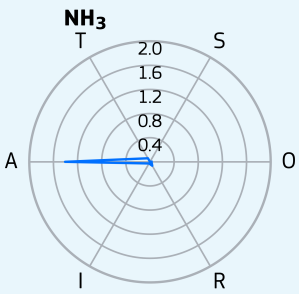
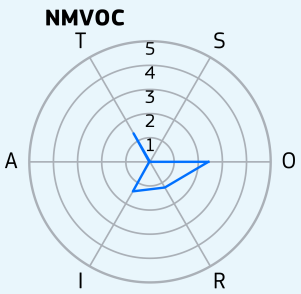
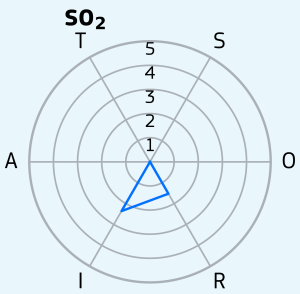


Emissions [kton/year]









- T - Transport
- I - Industry
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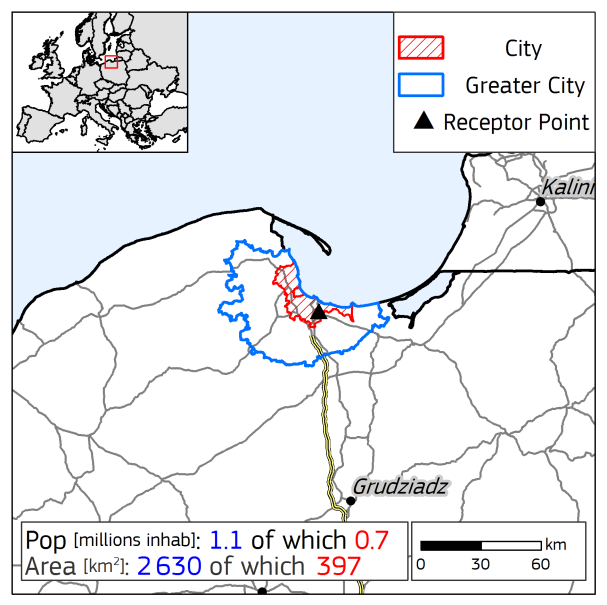
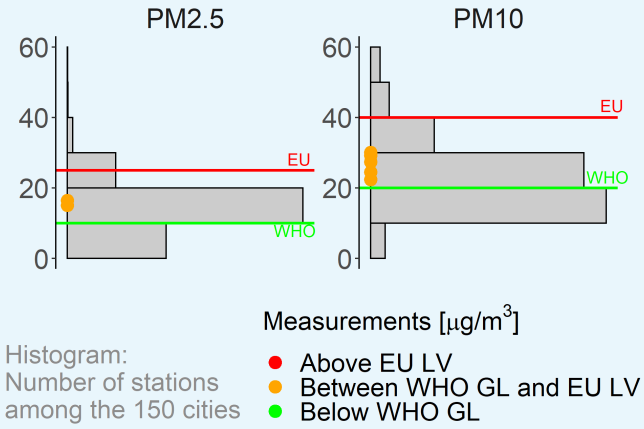
- Greater city

Poland, Gdańsk



Yearly average urban concentrations (2018)



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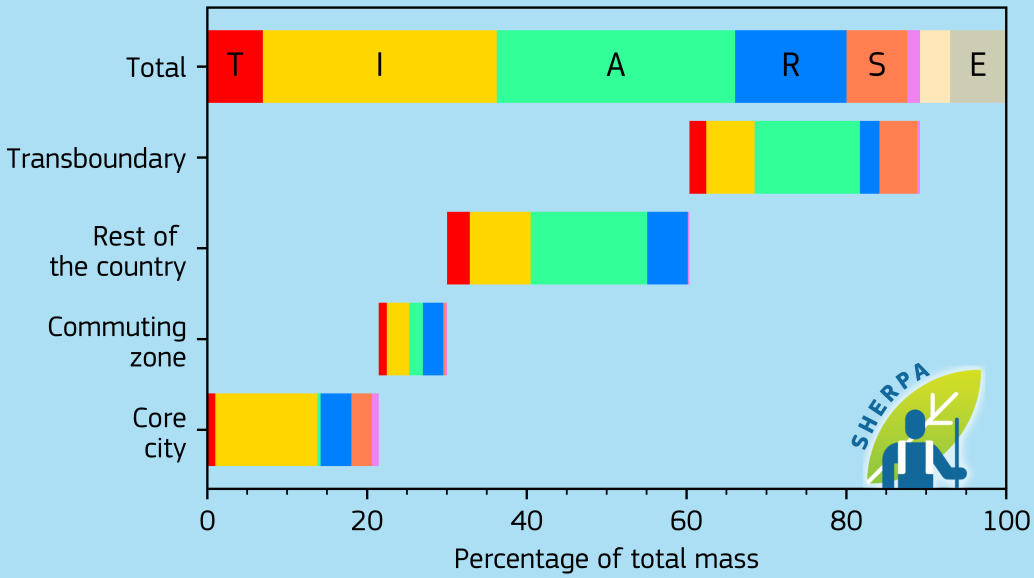
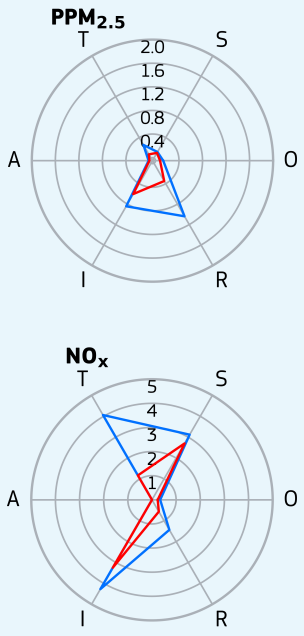
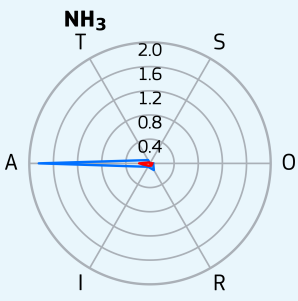
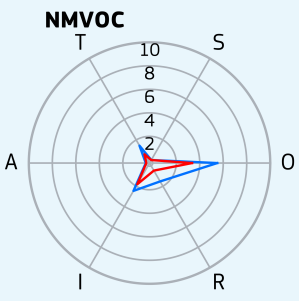
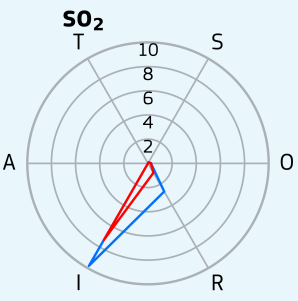


Emissions [kton/year]









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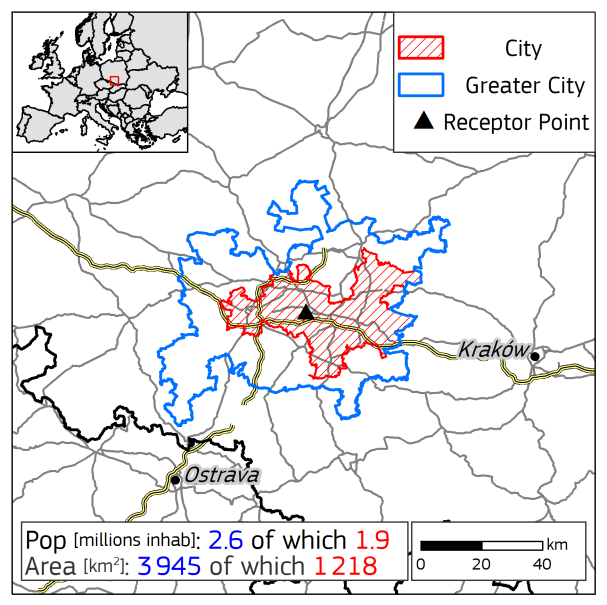
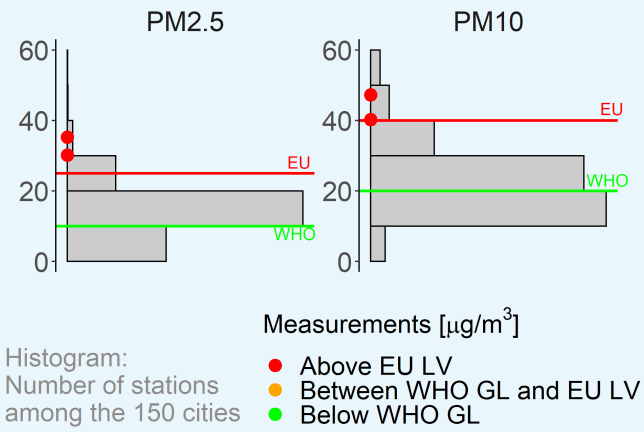
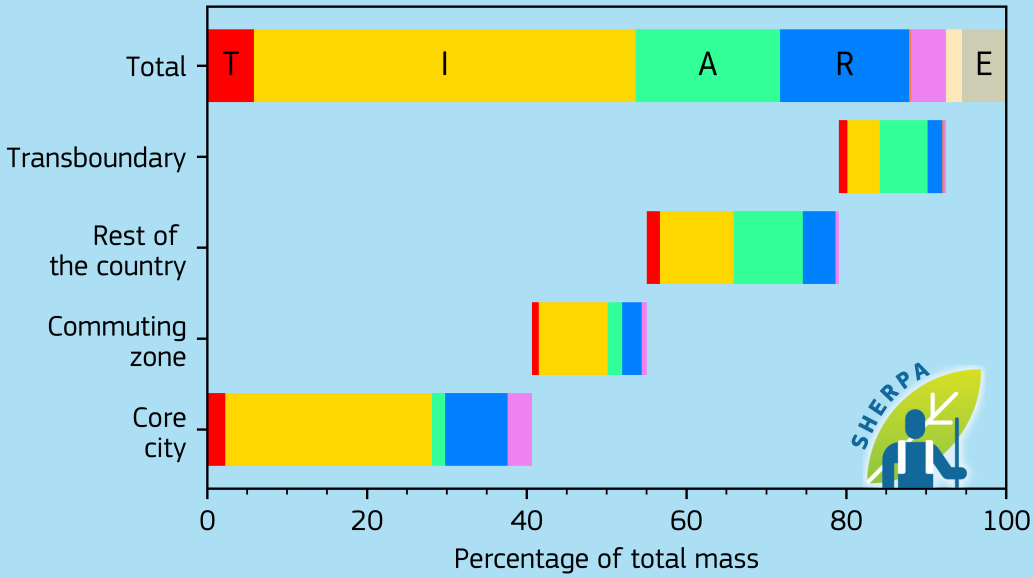
Poland, Katowice



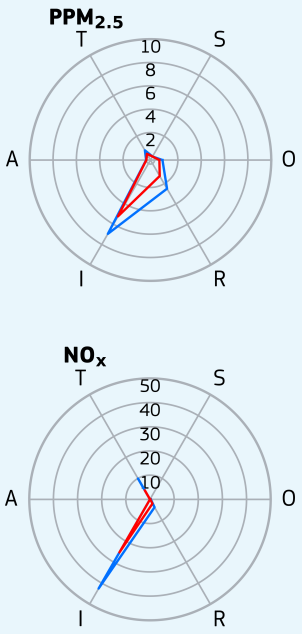
Yearly average urban concentrations (2018)

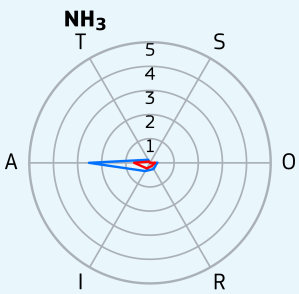


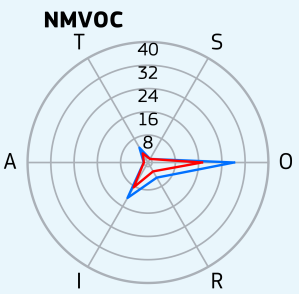
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

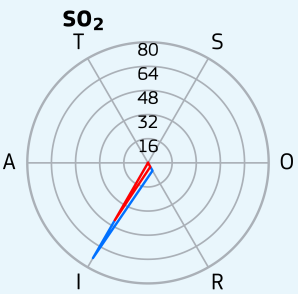


Emissions [kton/year]



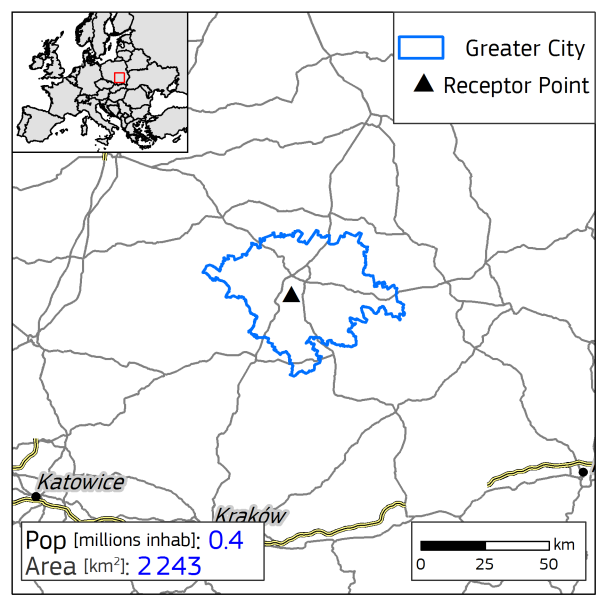




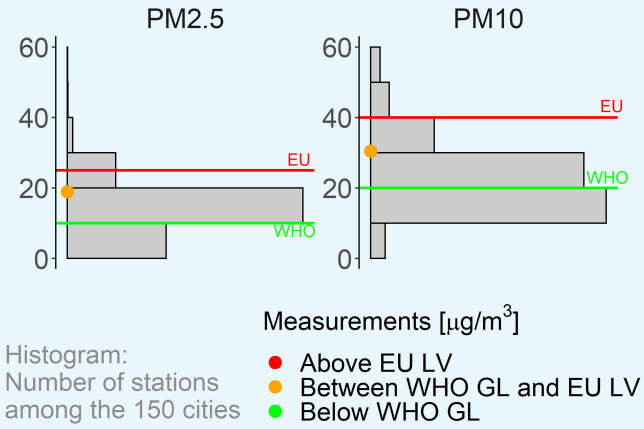


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

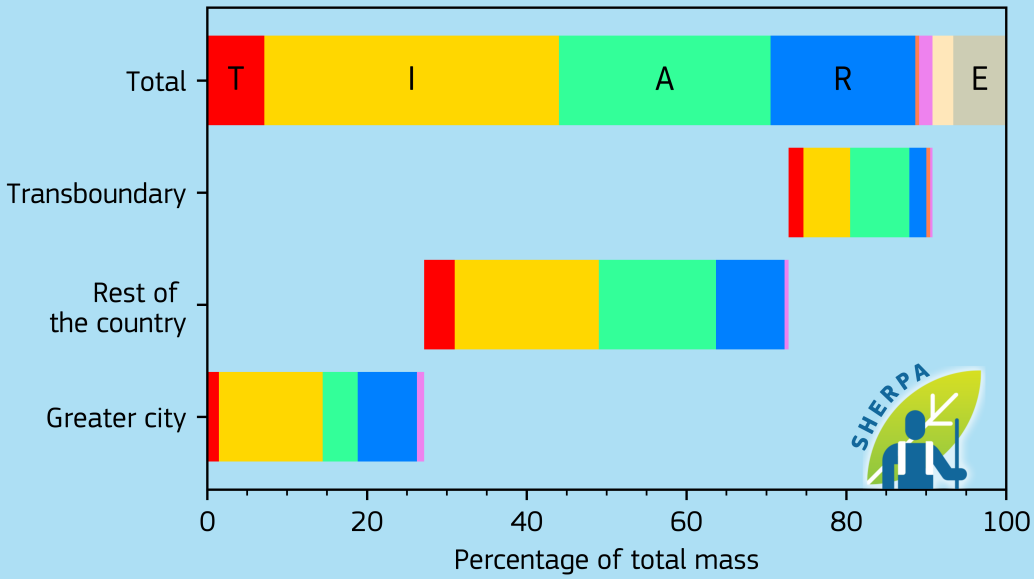
Poland, Kielce



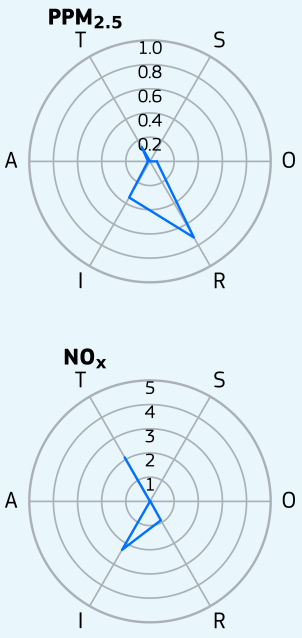
Yearly average urban concentrations (2018)

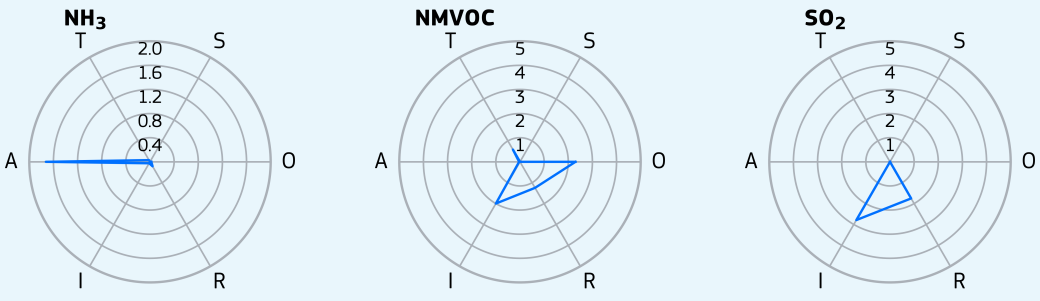


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
- I - Industry
- A - Agriculture
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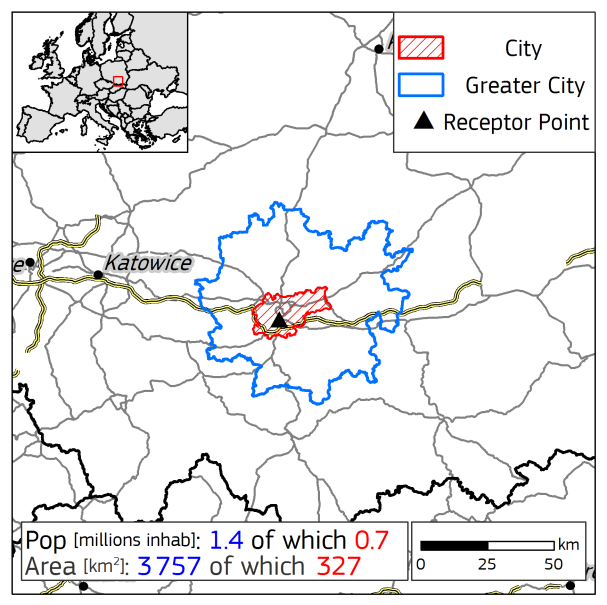
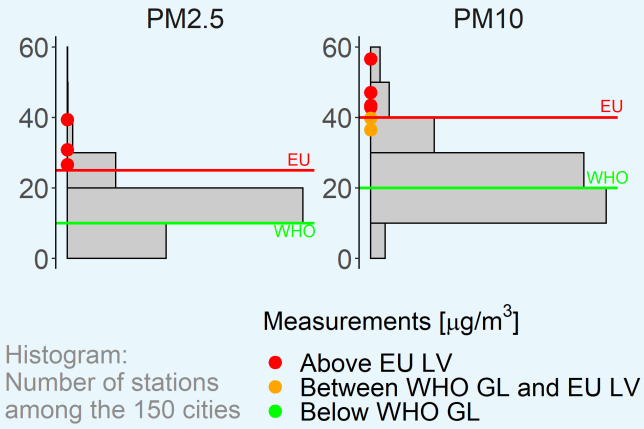
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

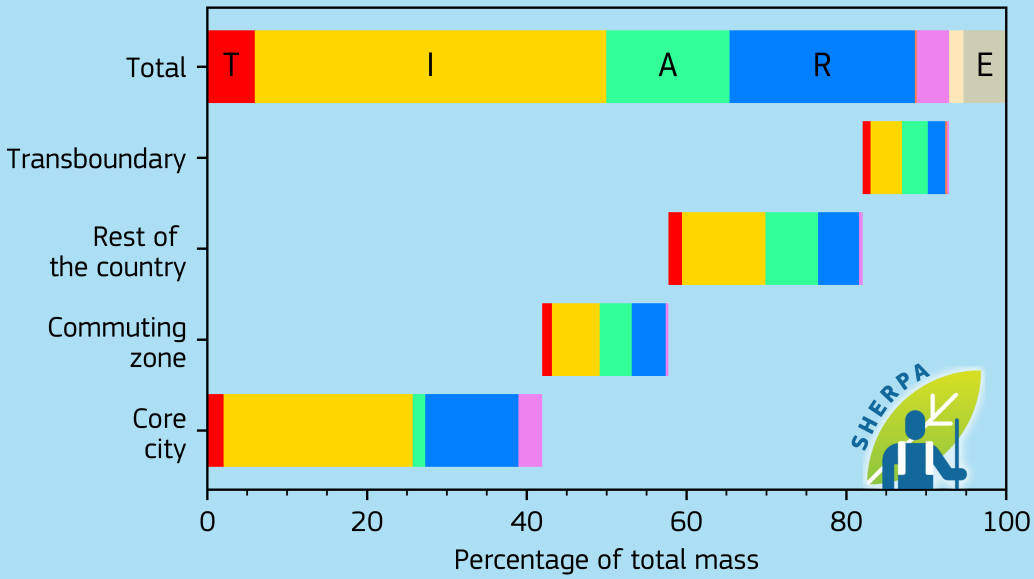
Poland, Kraków



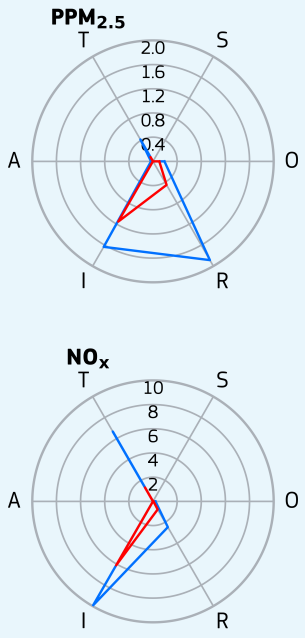
Yearly average urban concentrations (2018)

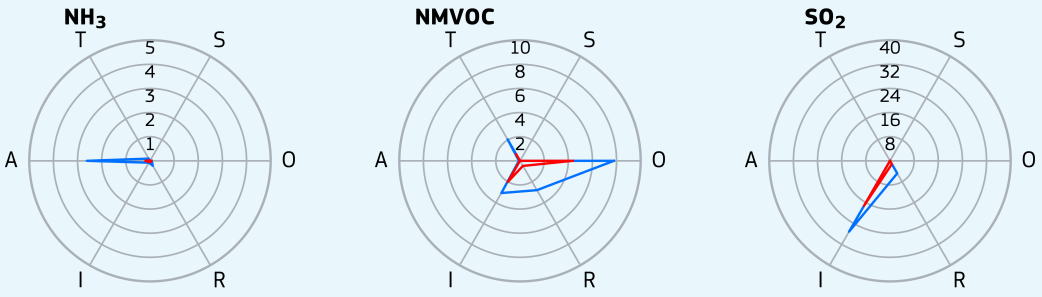


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
I - Industry
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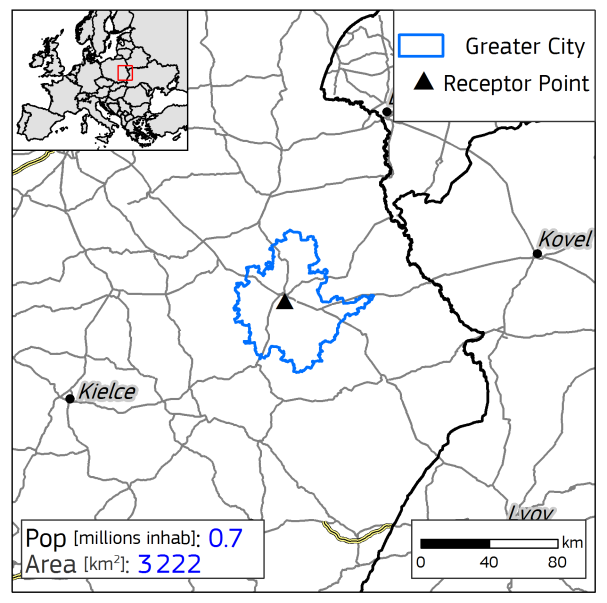
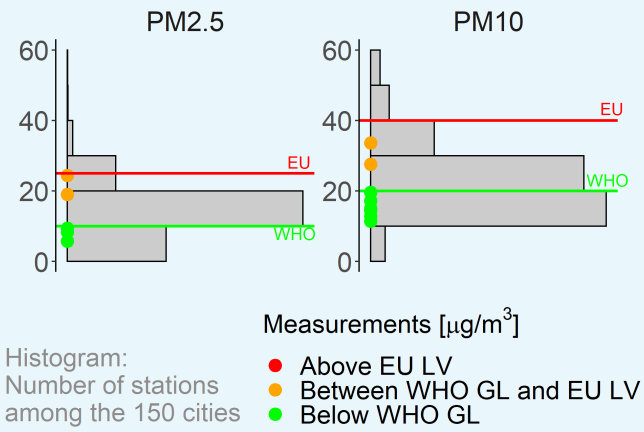
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

Poland, Lublin

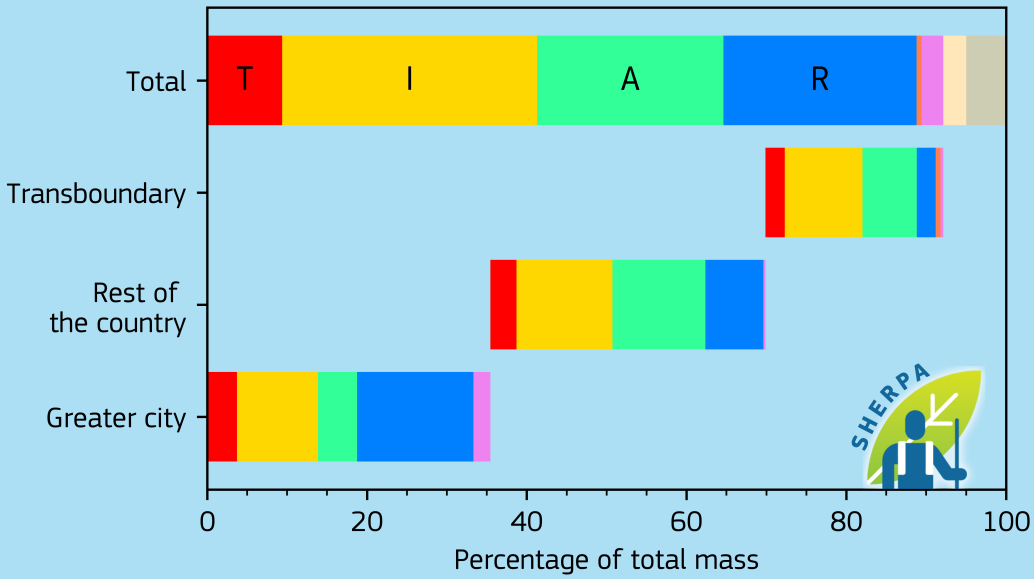


Yearly average urban concentrations (2018)

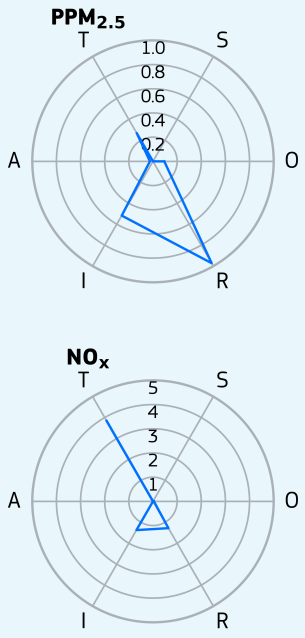


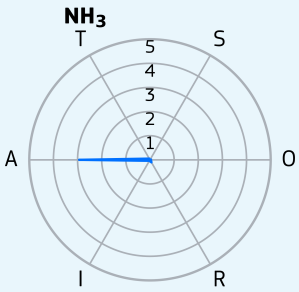
Histogram:
Number of stations
among the 150 cities

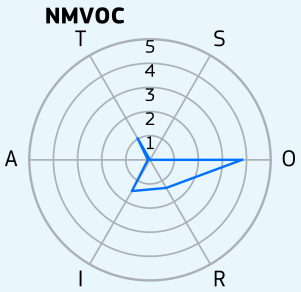
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

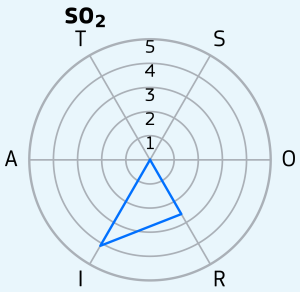


Emissions [kton/year]



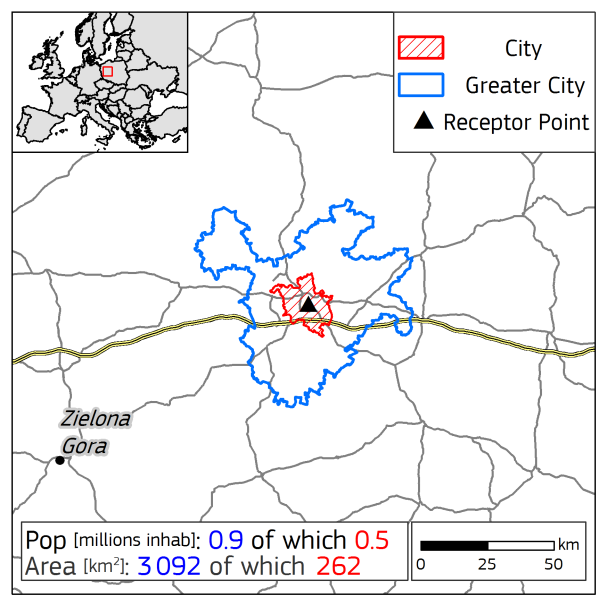




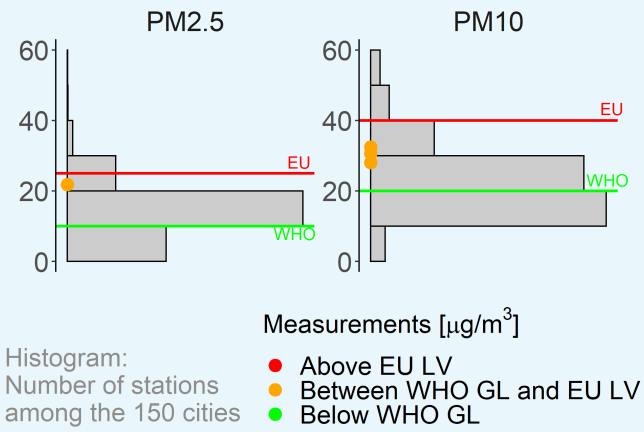


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

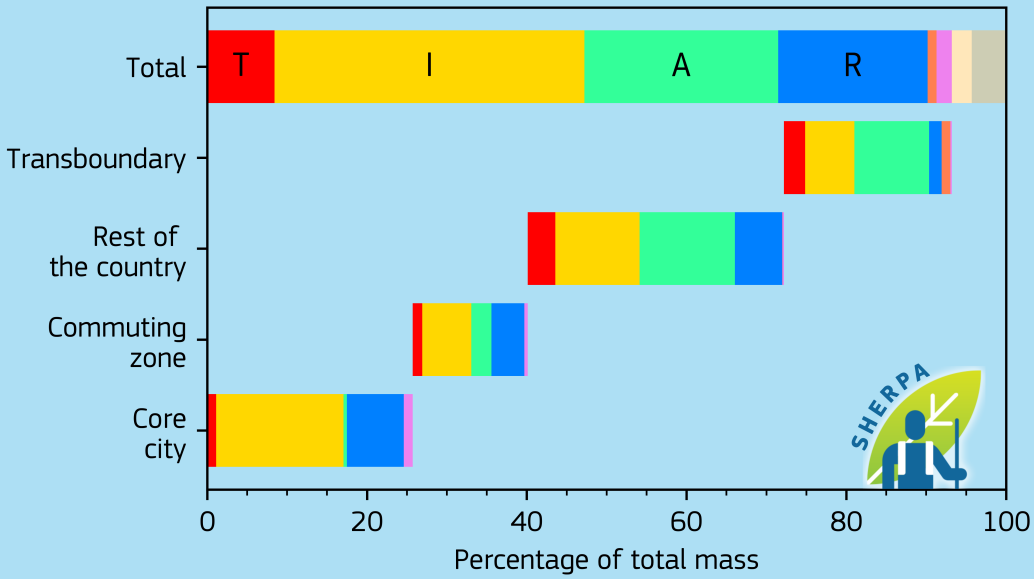
Poland, Poznań



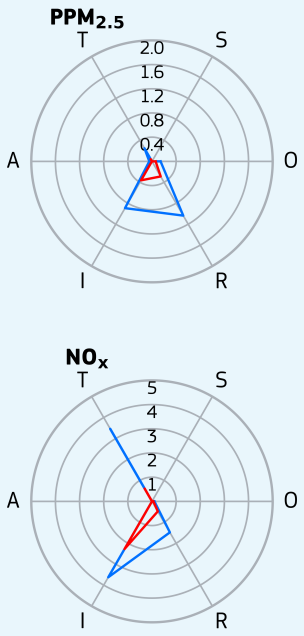
Yearly average urban concentrations (2018)

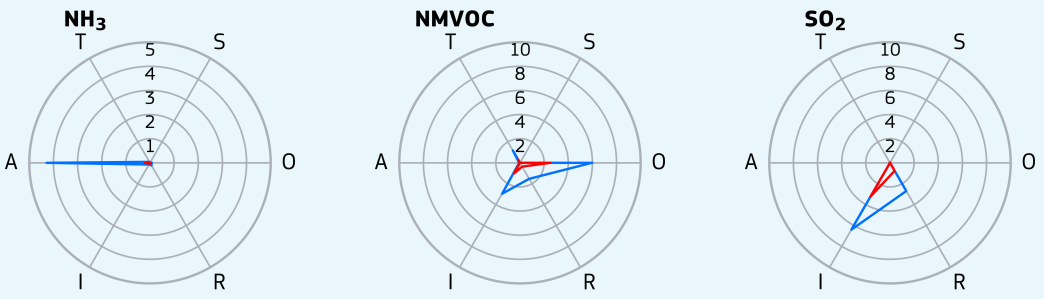


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
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A - Agriculture
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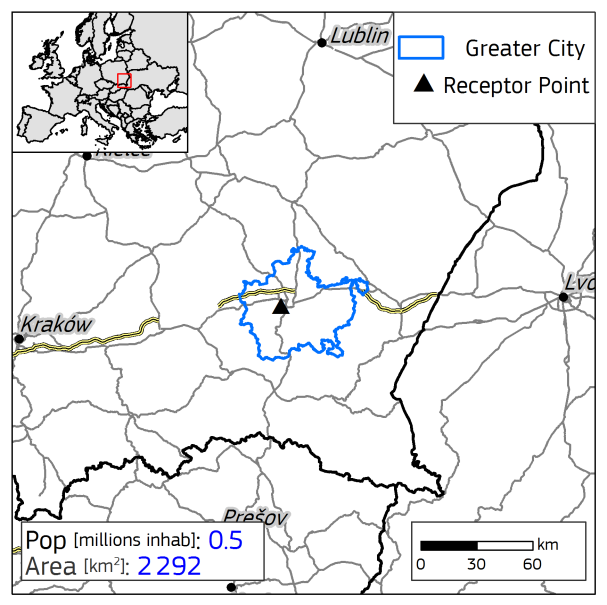
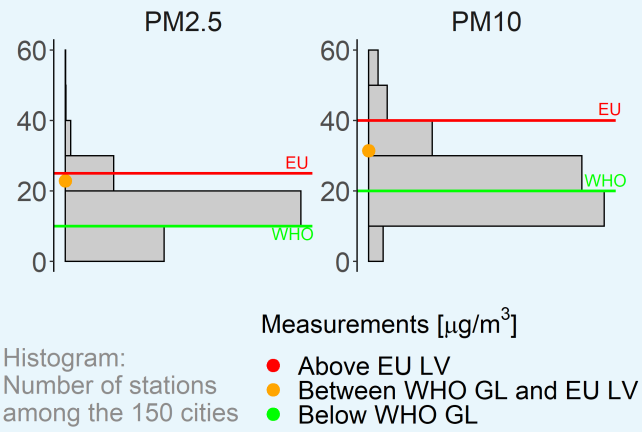
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

Poland, Rzeszów



Yearly average urban concentrations (2018)



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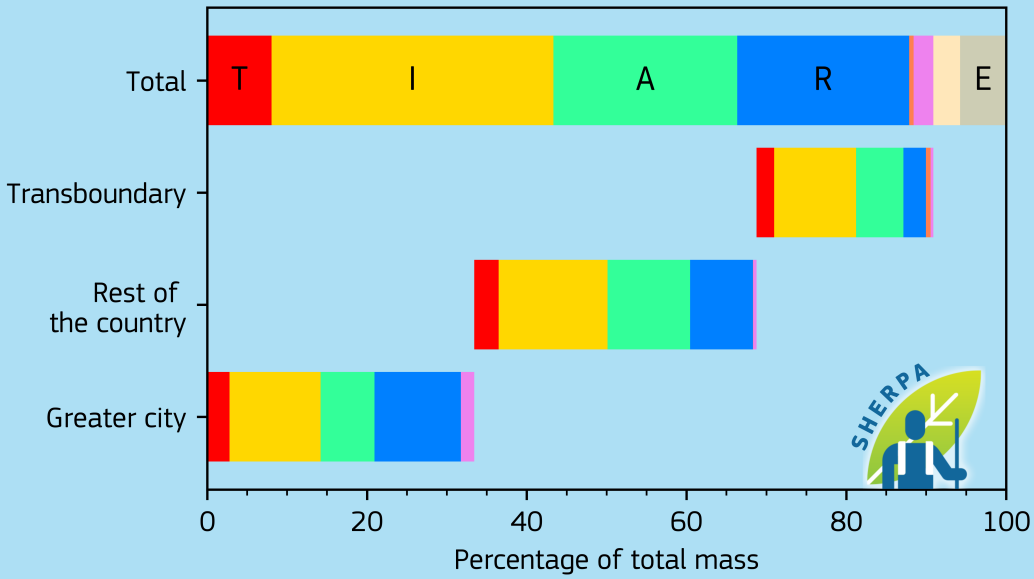
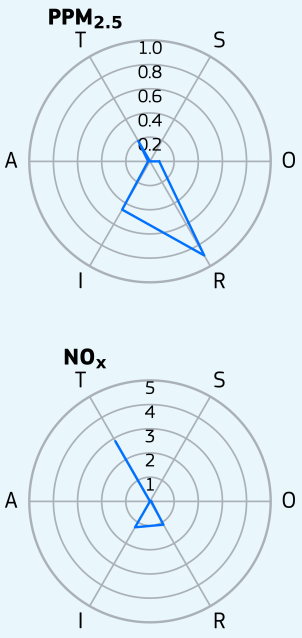
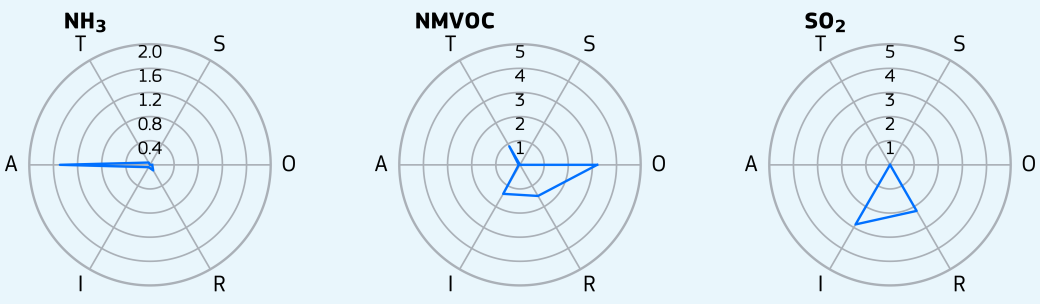


Emissions [kton/year]





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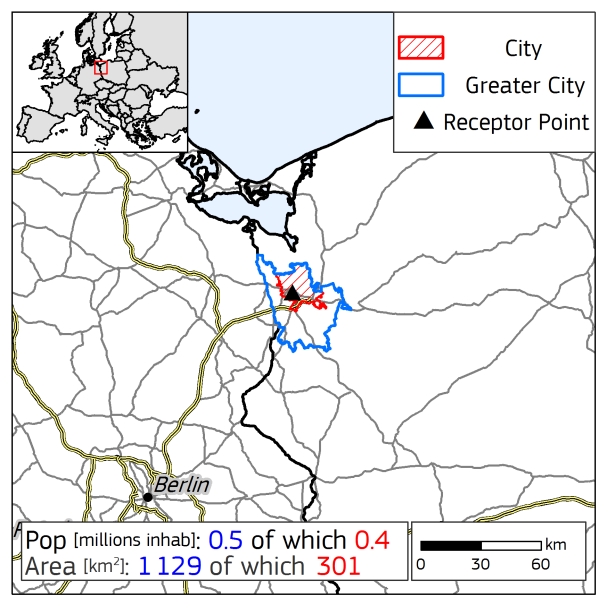
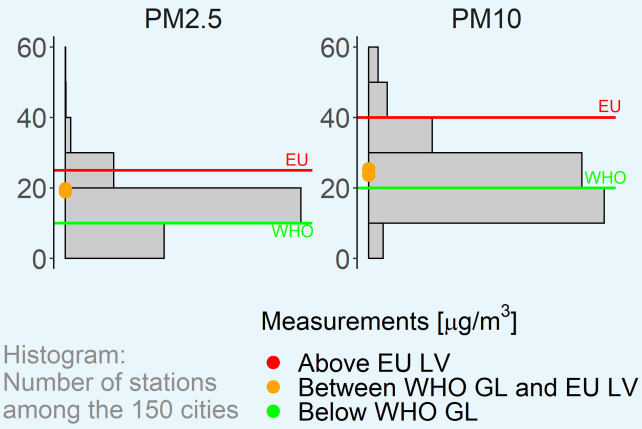
- Greater city

Poland, Szczecin



Yearly average urban concentrations (2018)



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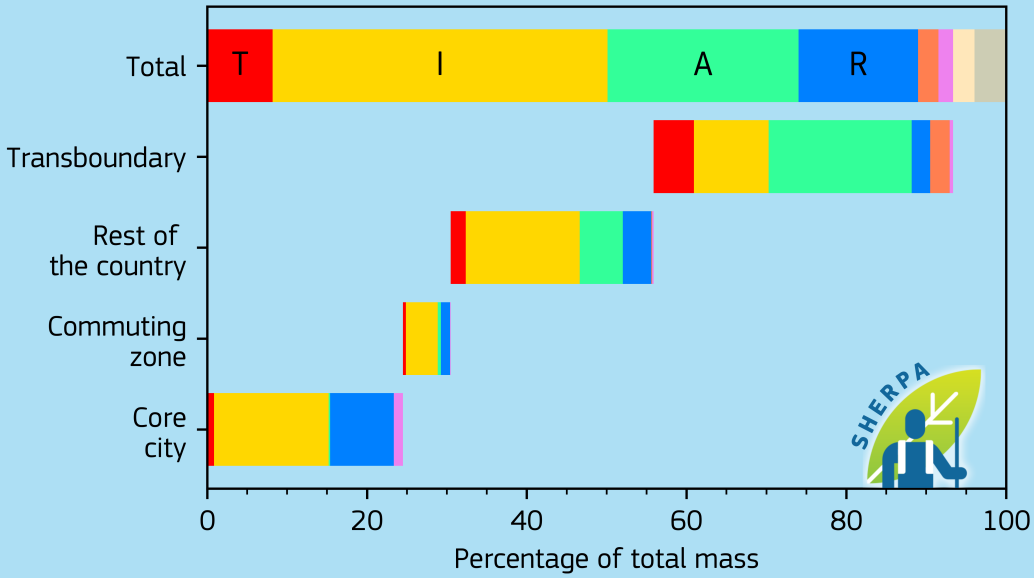
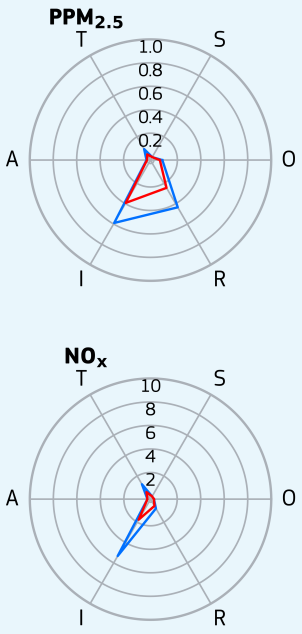
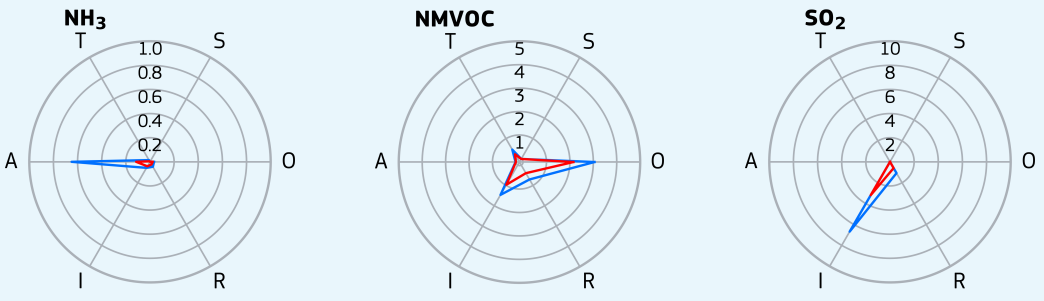


Emissions [kton/year]





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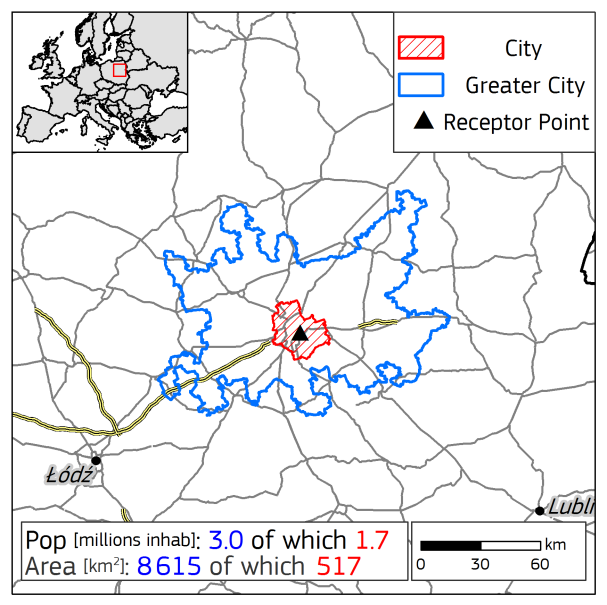
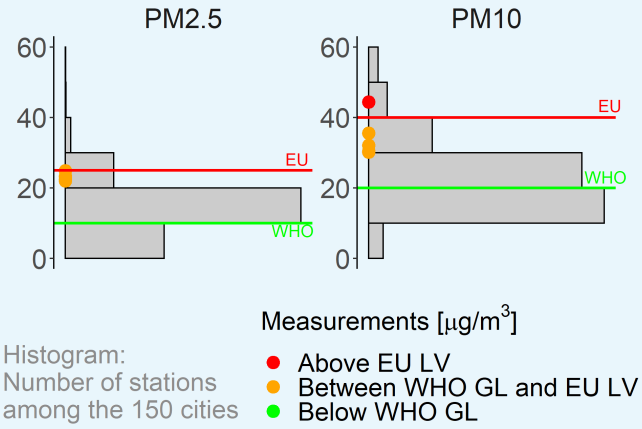
Poland, Warsaw



Yearly average urban concentrations (2018)



Histogram:
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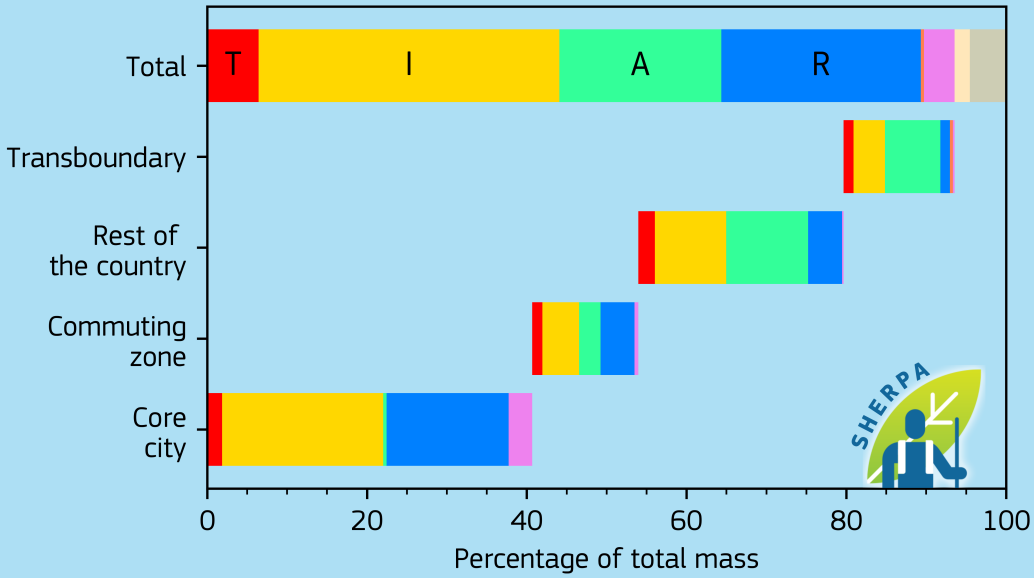
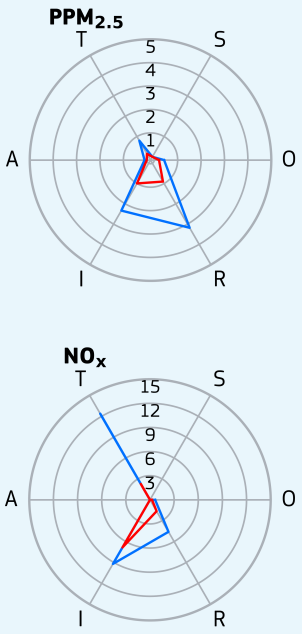
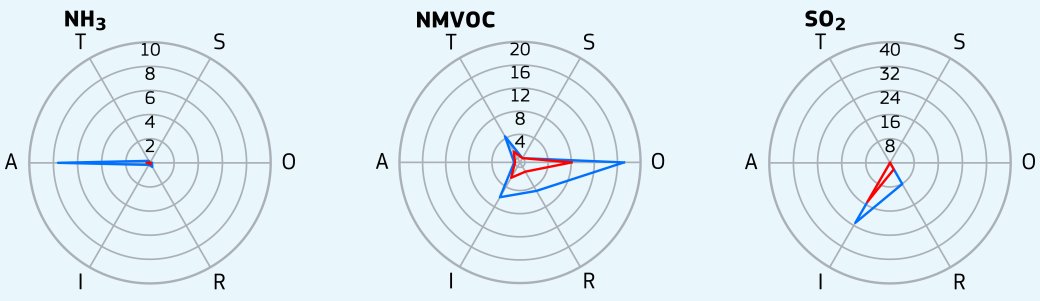


Emissions [kton/year]





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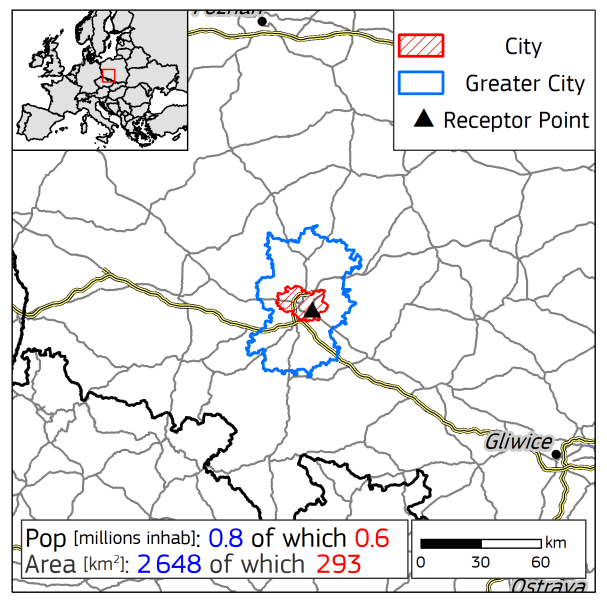
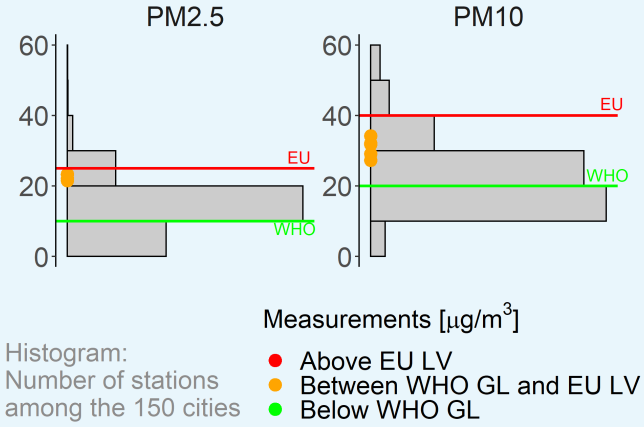
Poland, Wrocław



Yearly average urban concentrations (2018)



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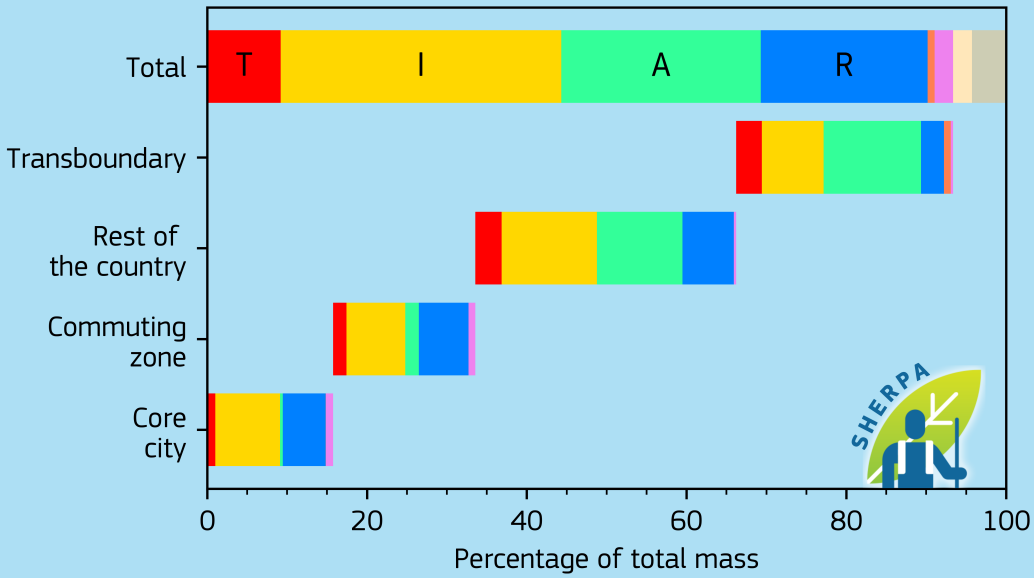
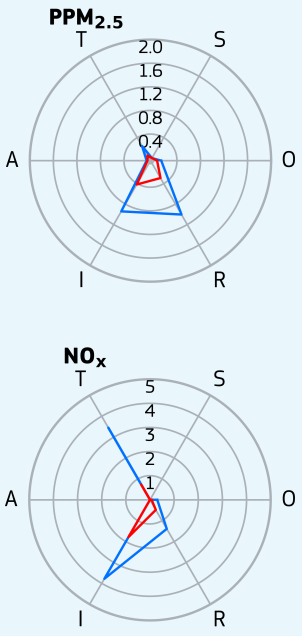
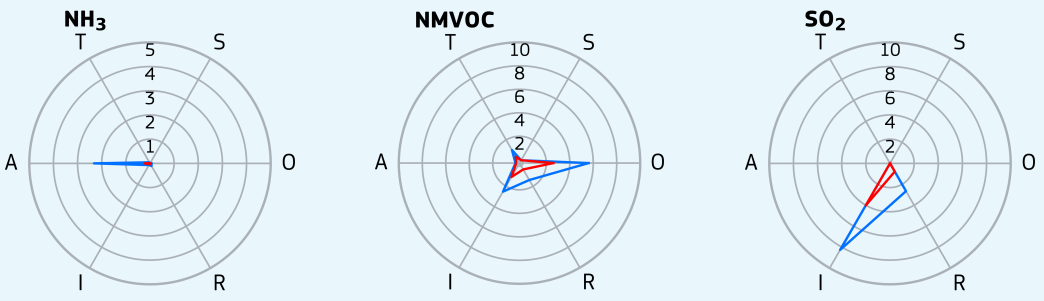


Emissions [kton/year]





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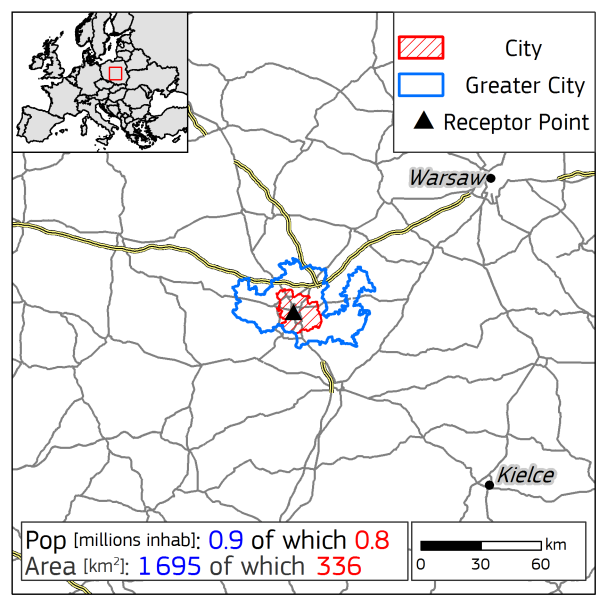
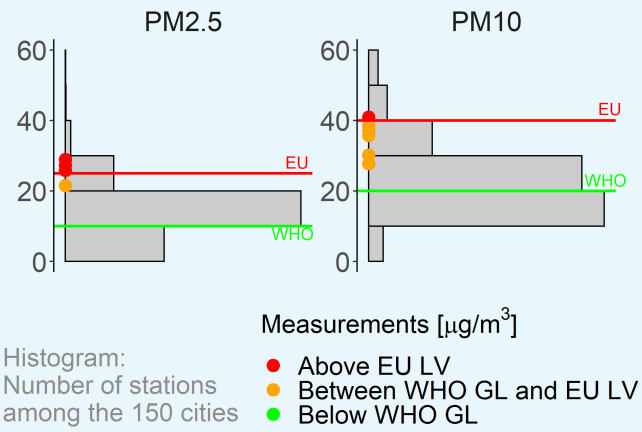
Poland, Łódź



Yearly average urban concentrations (2018)



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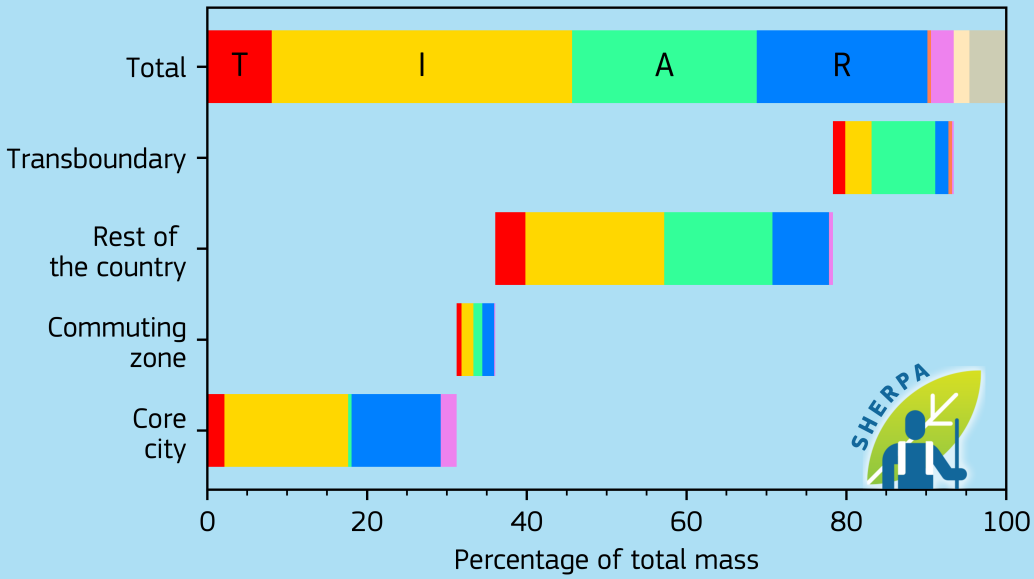
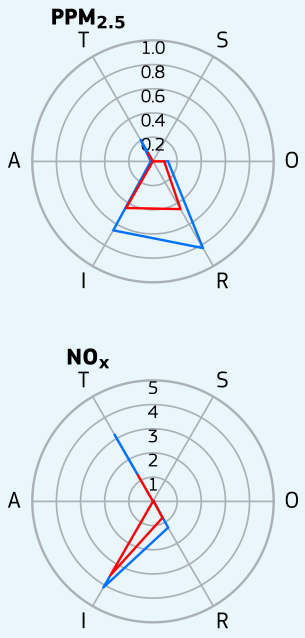
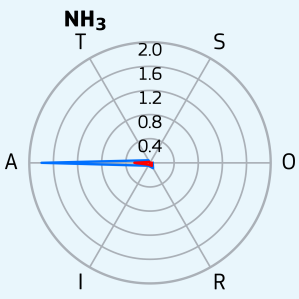
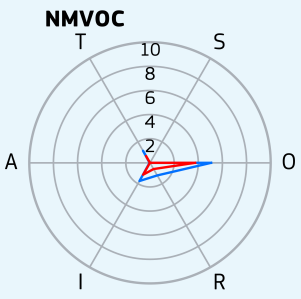
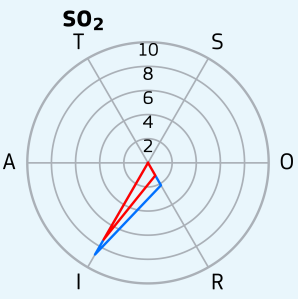


Emissions [kton/year]



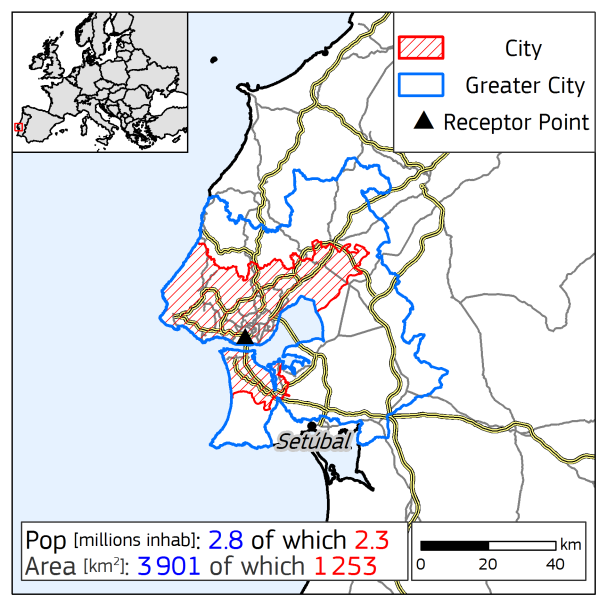




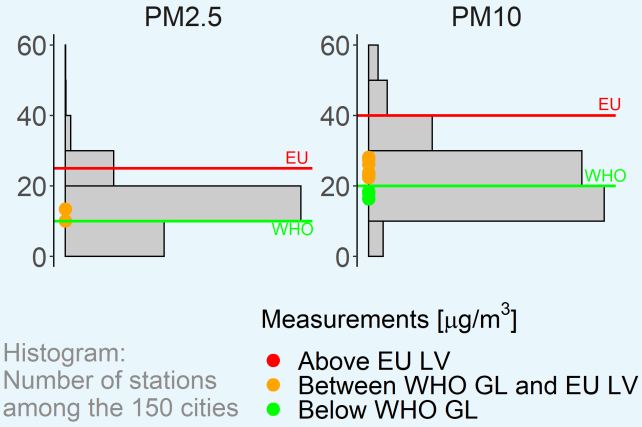


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

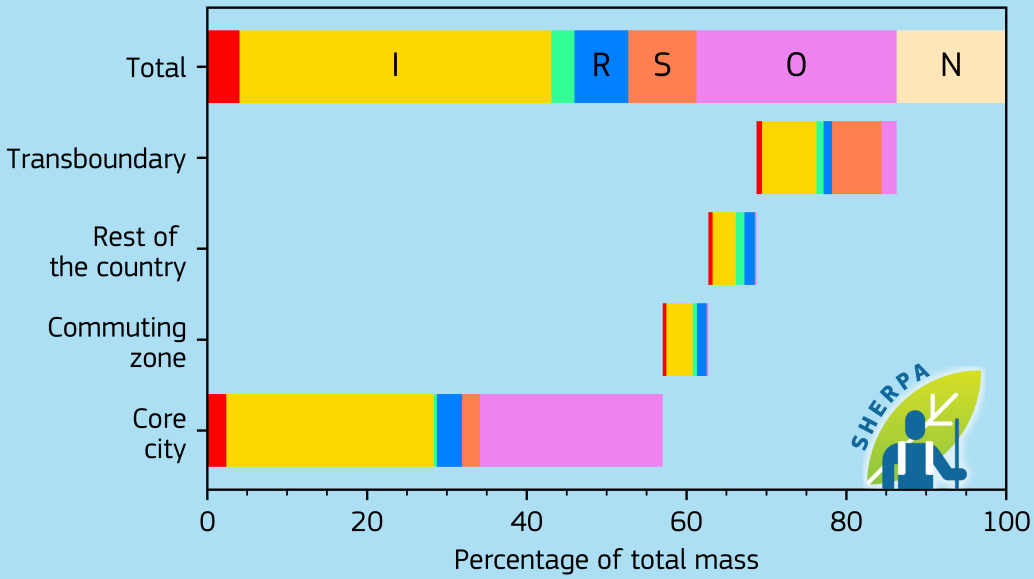
Portugal, Lisbon



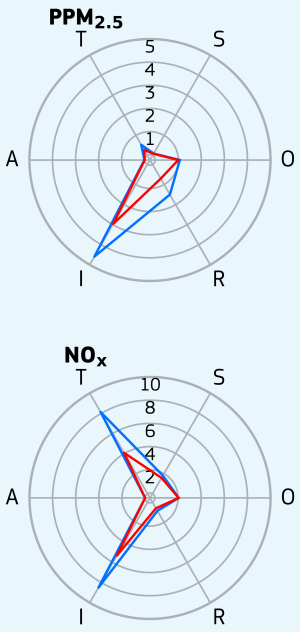
Yearly average urban concentrations (2018)

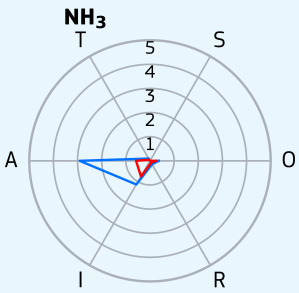


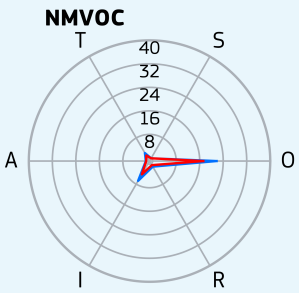
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

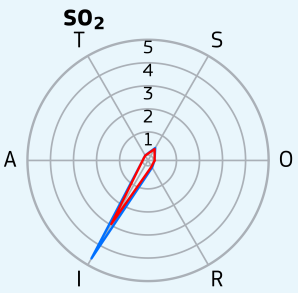


Emissions [kton/year]



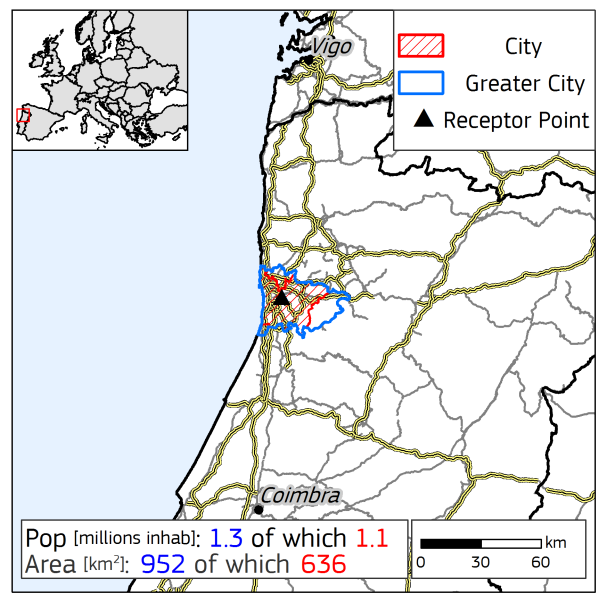




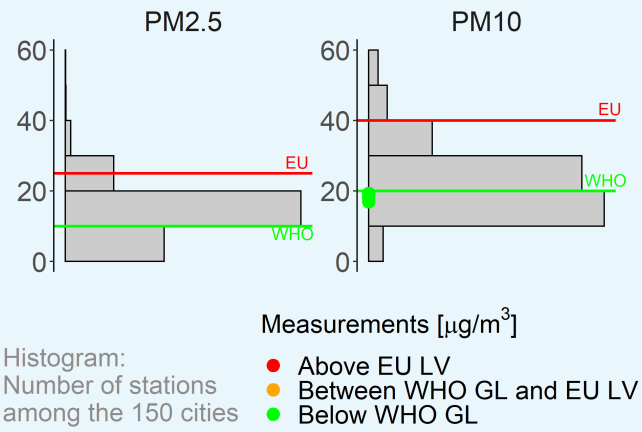


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city
Core city

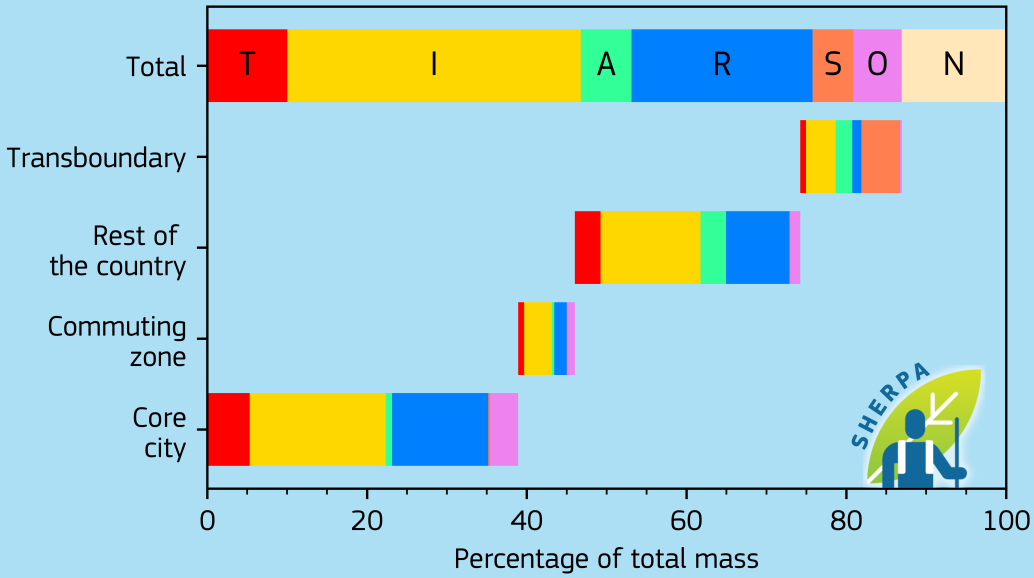
Portugal, Porto



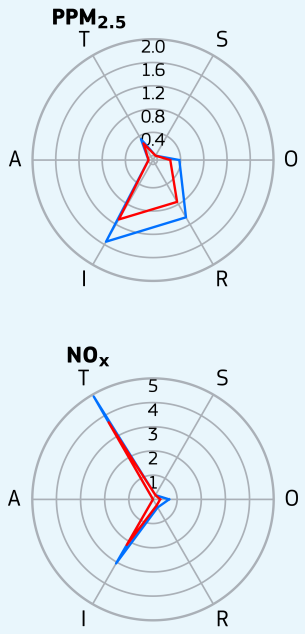
Yearly average urban concentrations (2018)

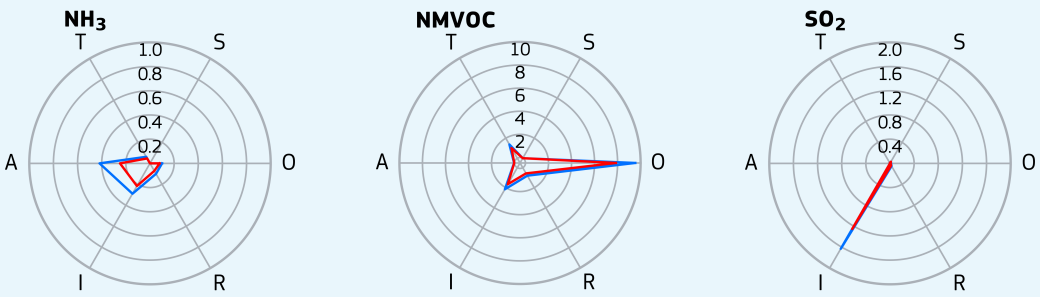


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



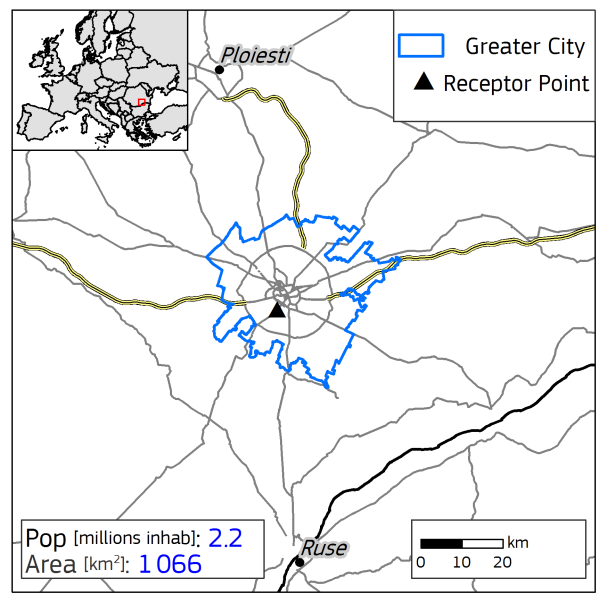
Emissions [kton/year]



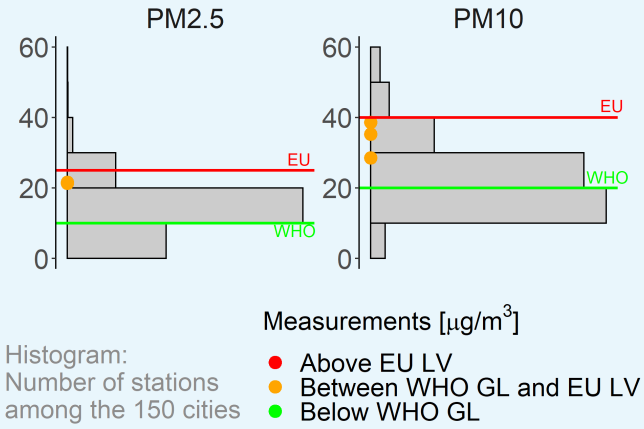


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- Greater city
- Core city

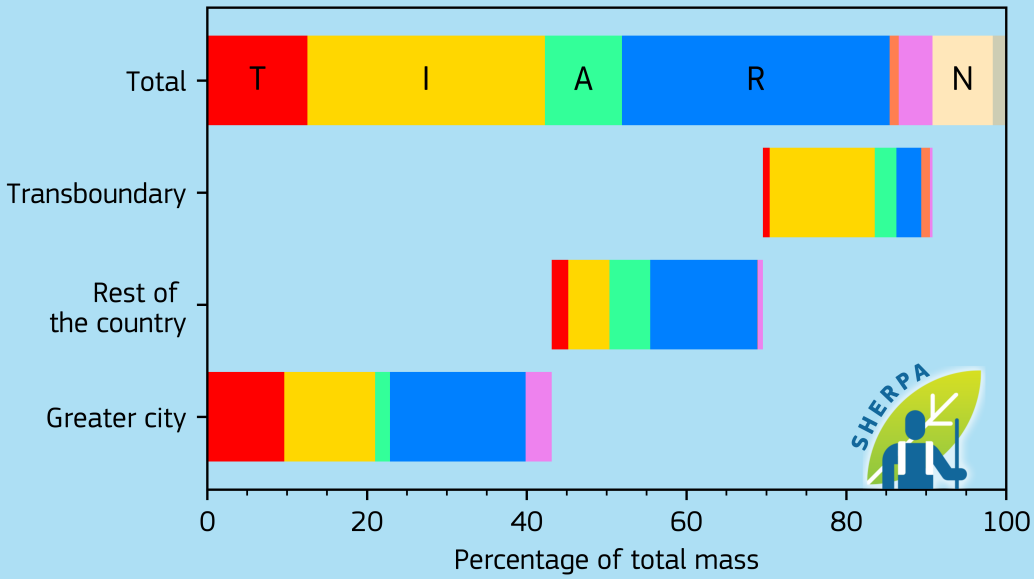
Romania, Bucharest



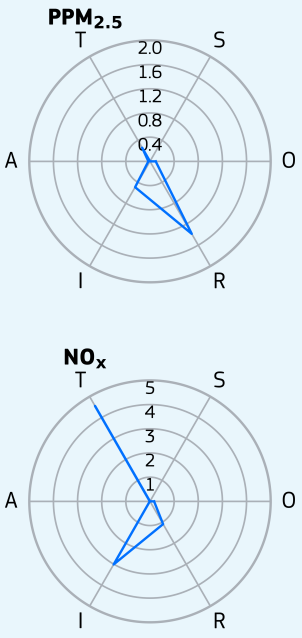
Yearly average urban concentrations (2018)

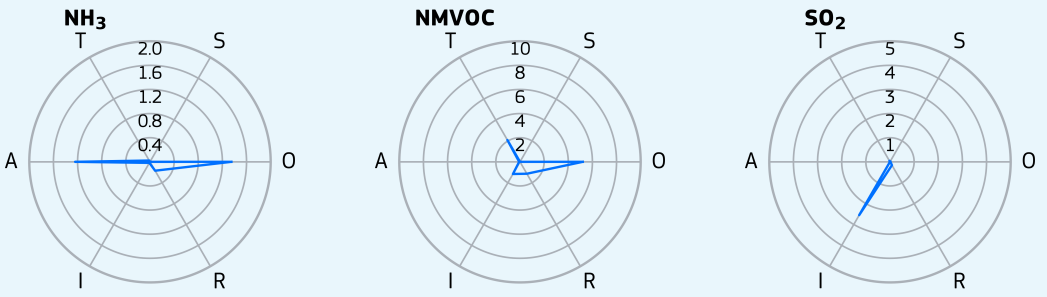


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





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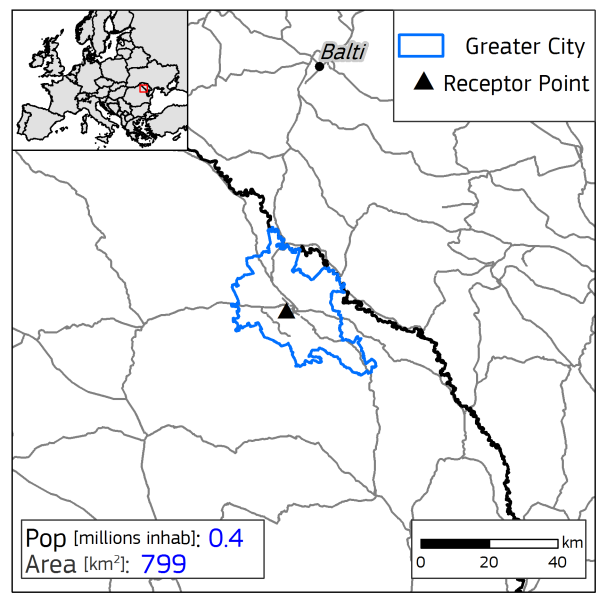
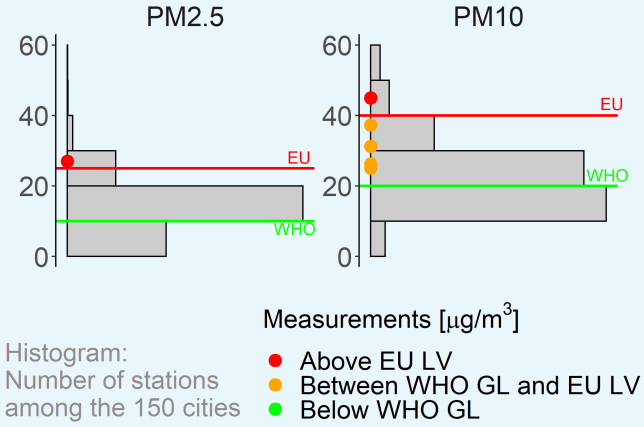
- E - External
- Greater city

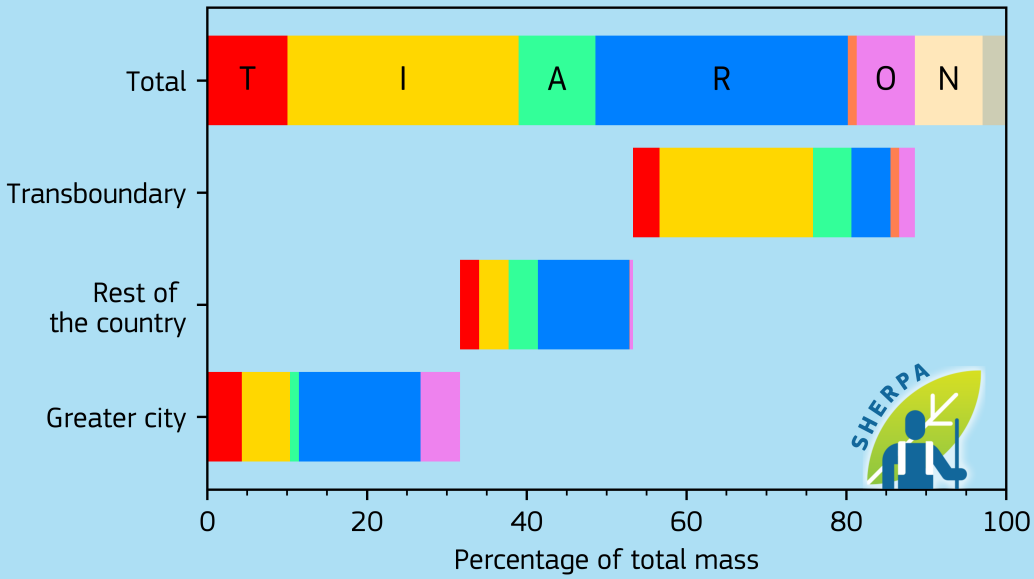
Romania, Iaşi



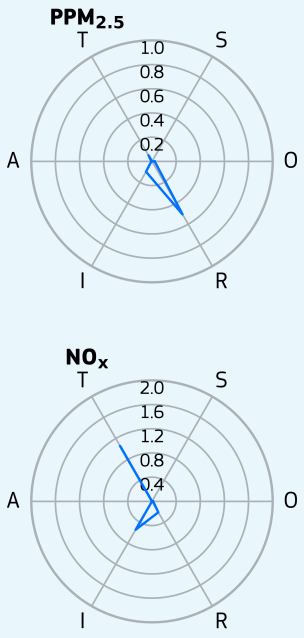
Yearly average urban concentrations (2018)

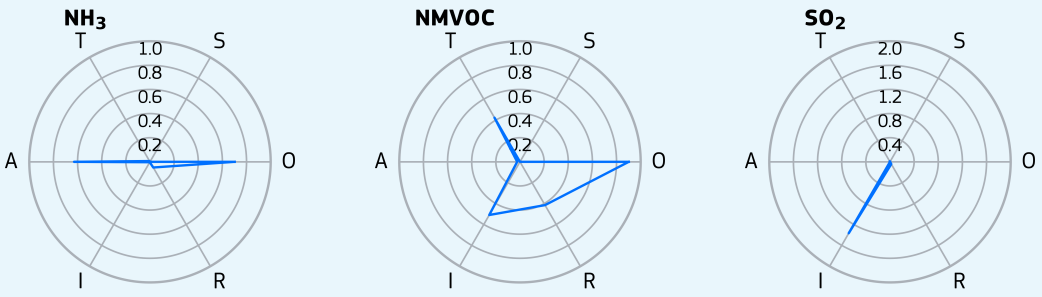


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



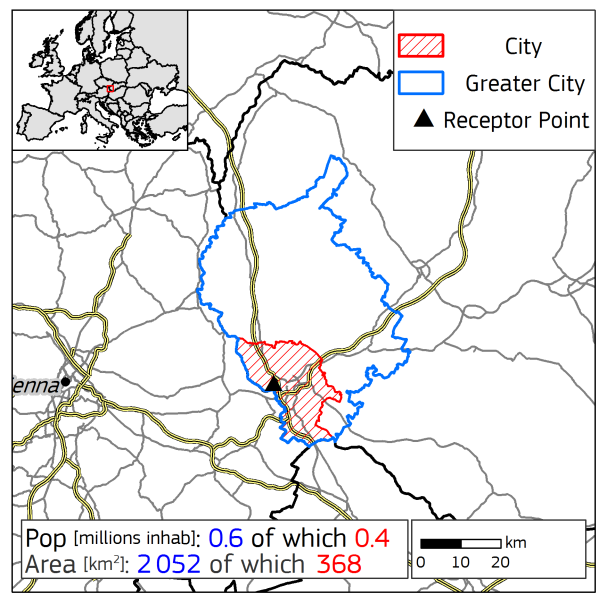
Emissions [kton/year]



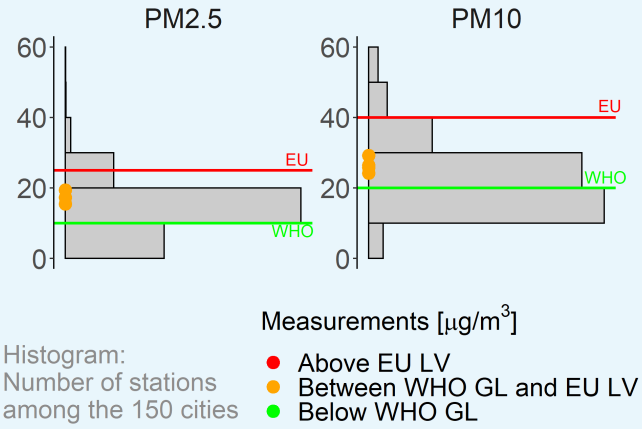


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

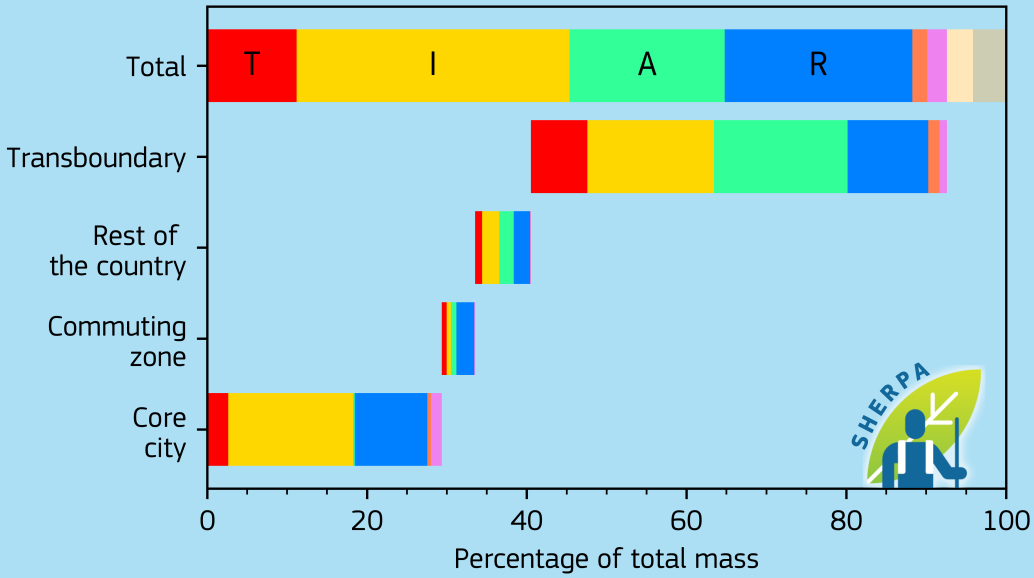
Slovakia, Bratislava



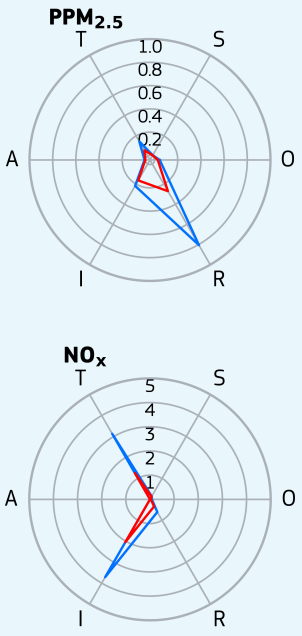
Yearly average urban concentrations (2018)

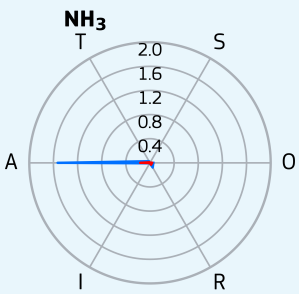


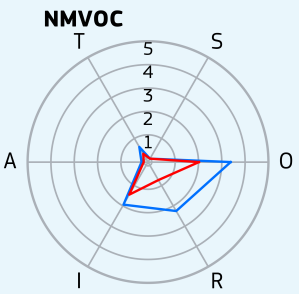
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

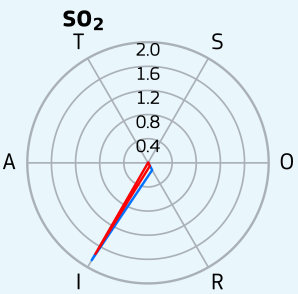


Emissions [kton/year]



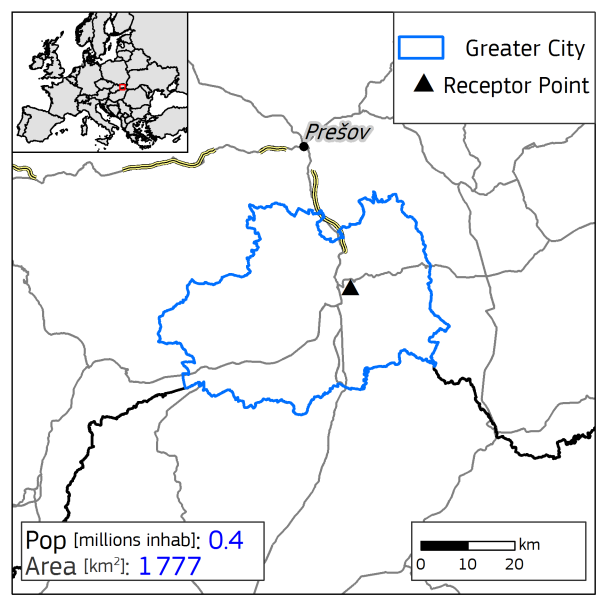




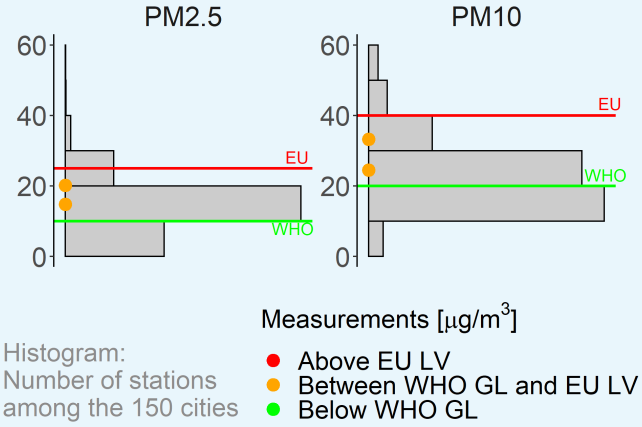


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

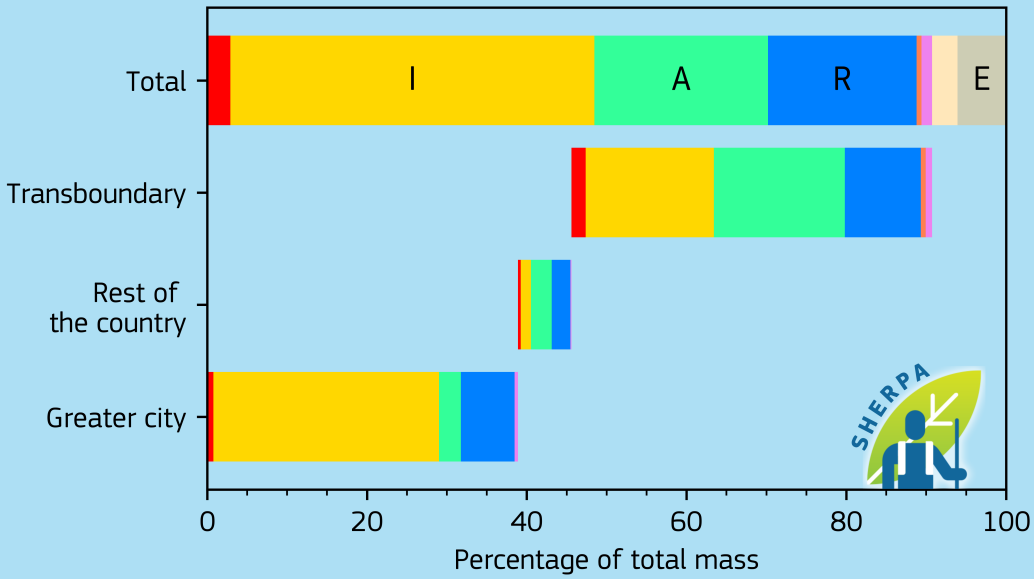
Slovakia, Košice



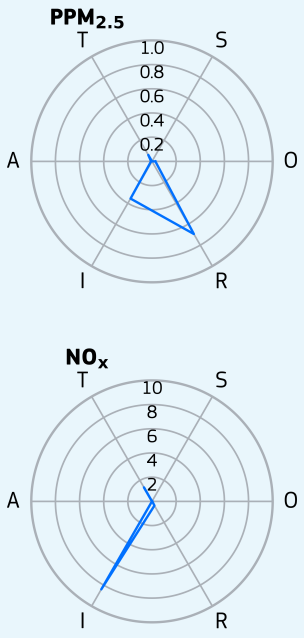
Yearly average urban concentrations (2018)

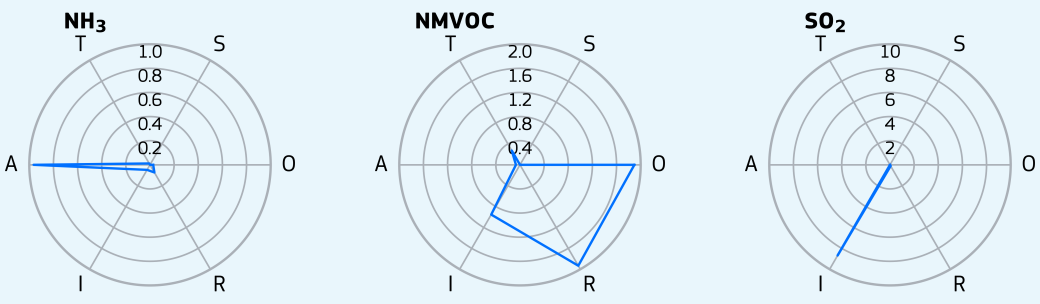


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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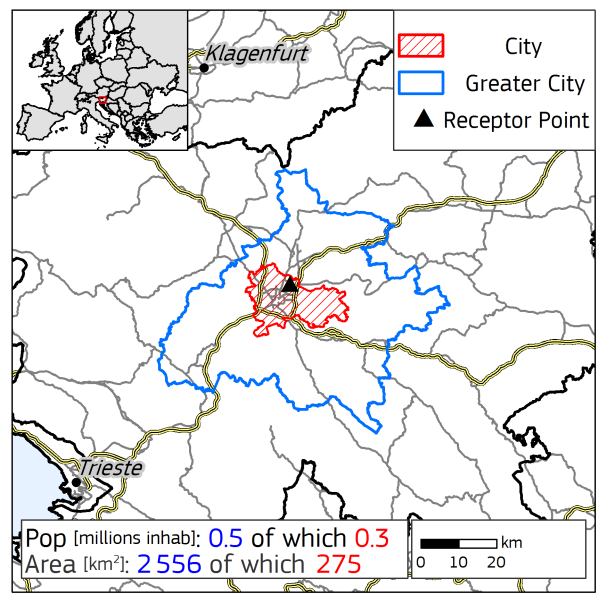
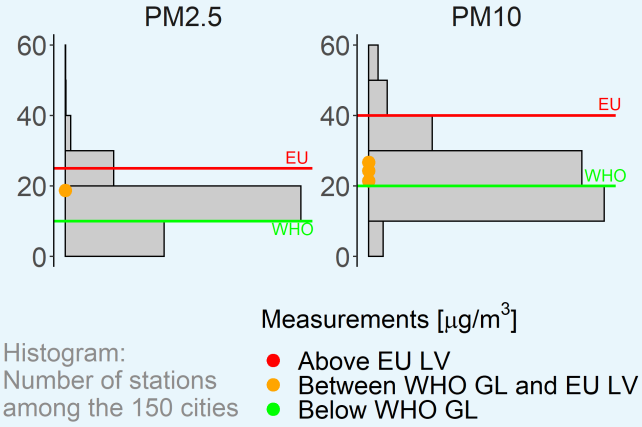
- Greater city

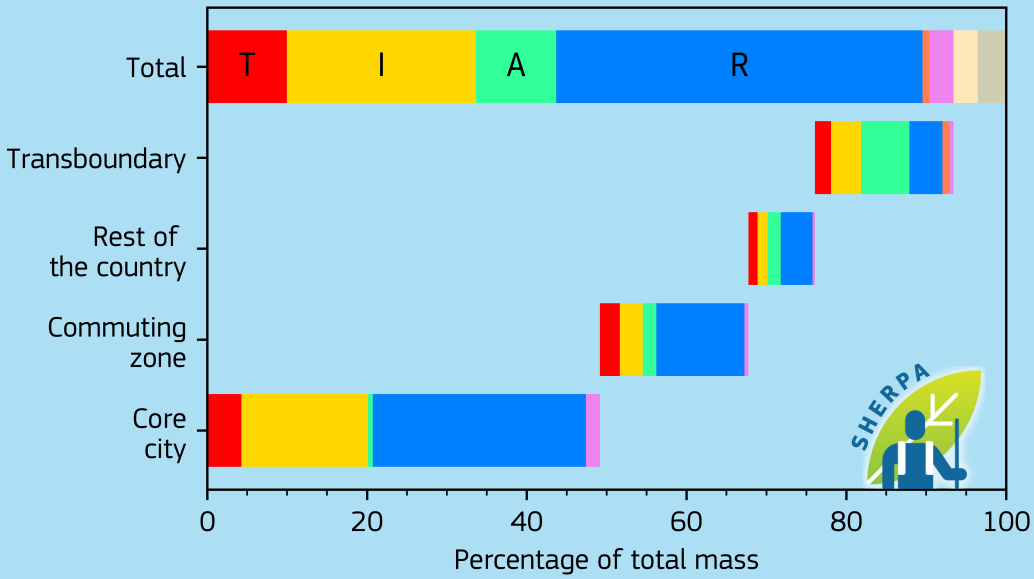
Slovenia, Ljubljana



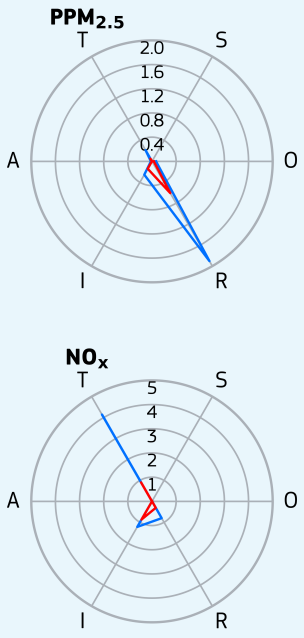
Yearly average urban concentrations (2018)

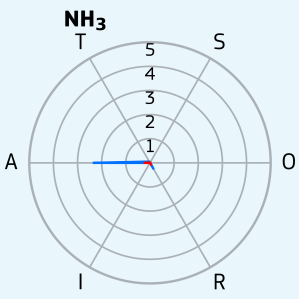


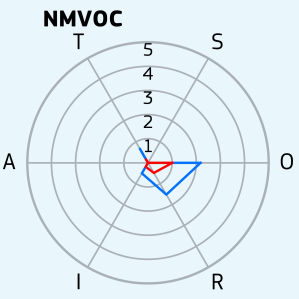
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

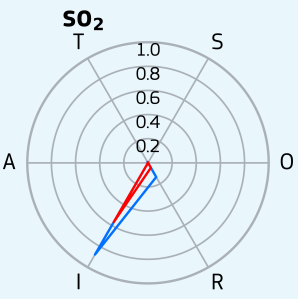


Emissions [kton/year]









T - Transport
I - Industry
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S - Shipping
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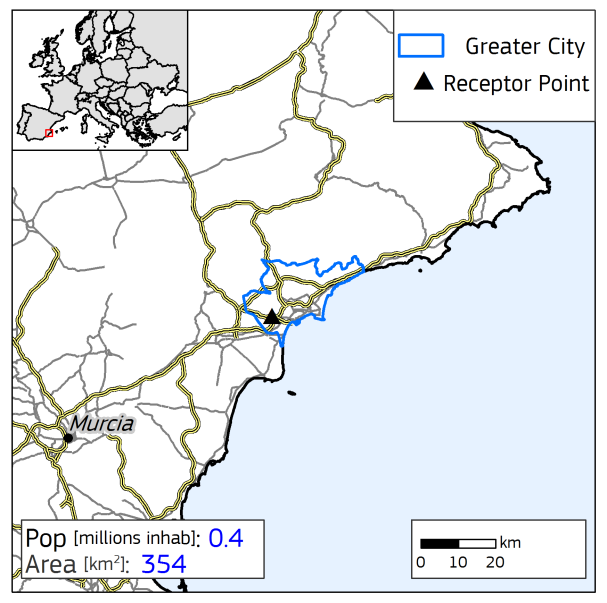
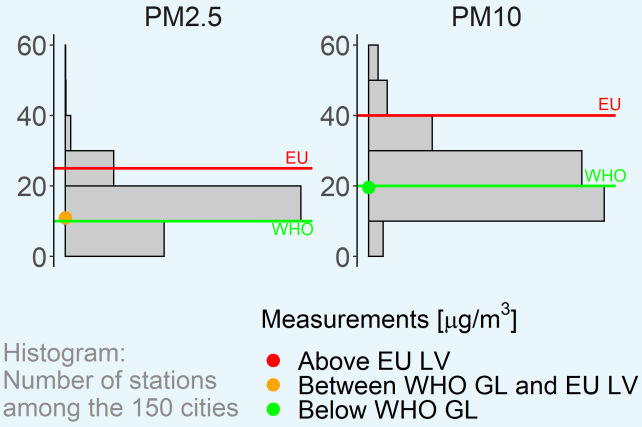
N - Natural
E - External
Greater city
Core city

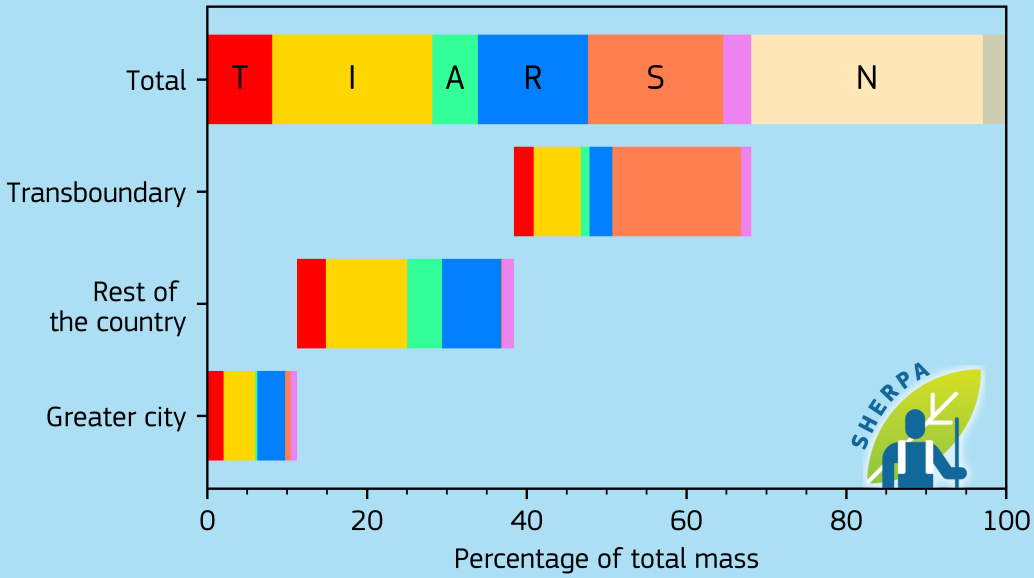
Spain, Alicante



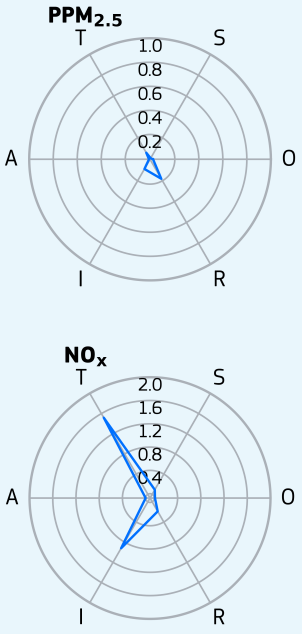
Yearly average urban concentrations (2018)

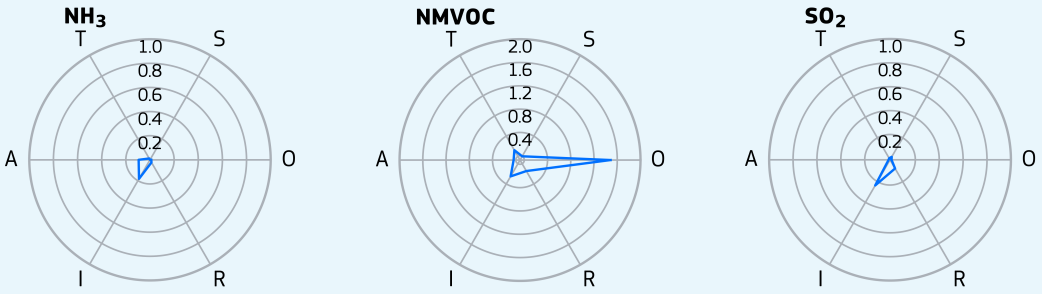


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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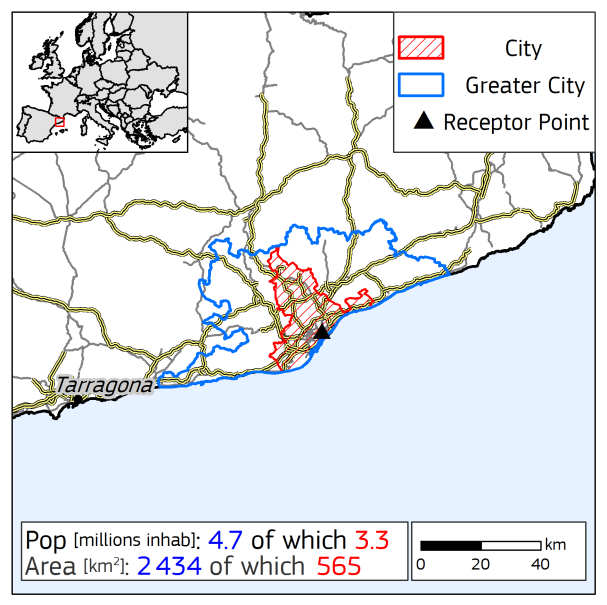
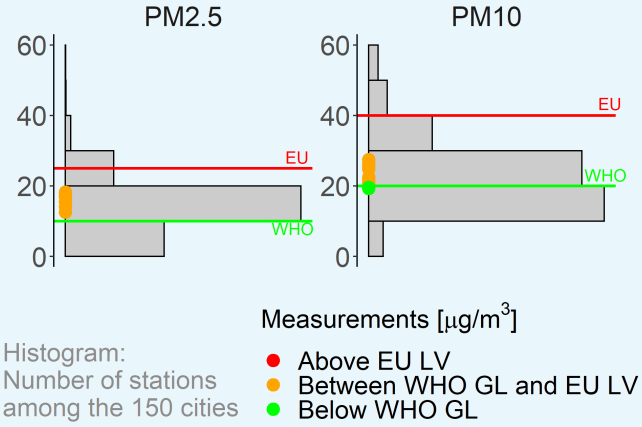
- Greater city

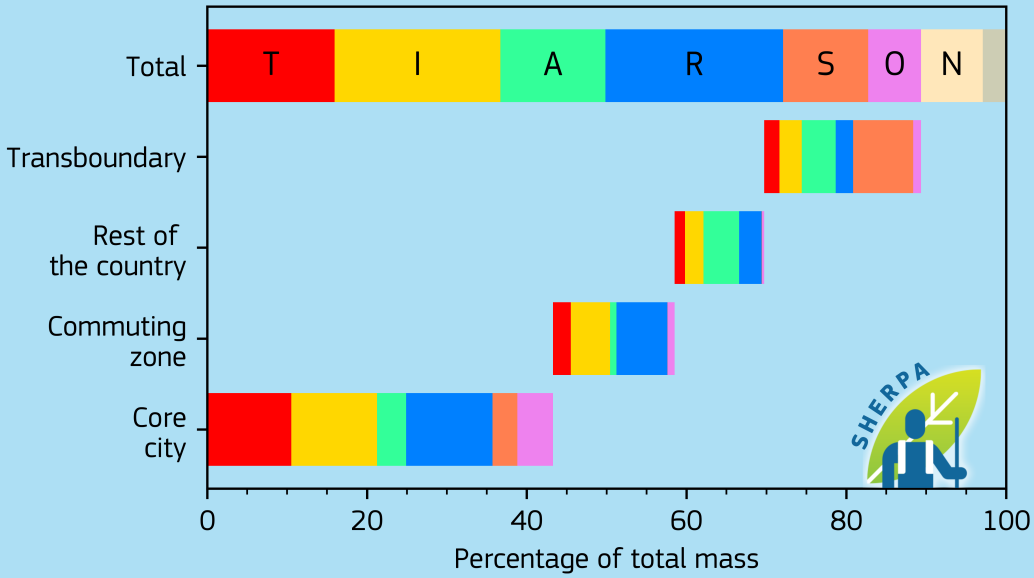
Spain, Barcelona



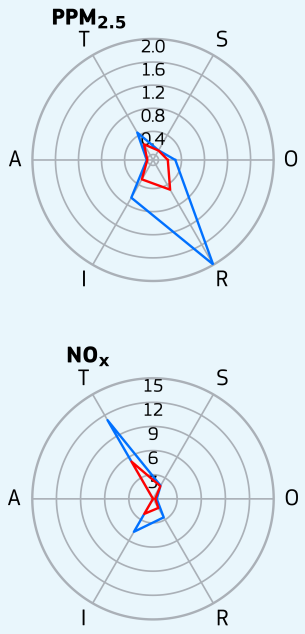
Yearly average urban concentrations (2018)

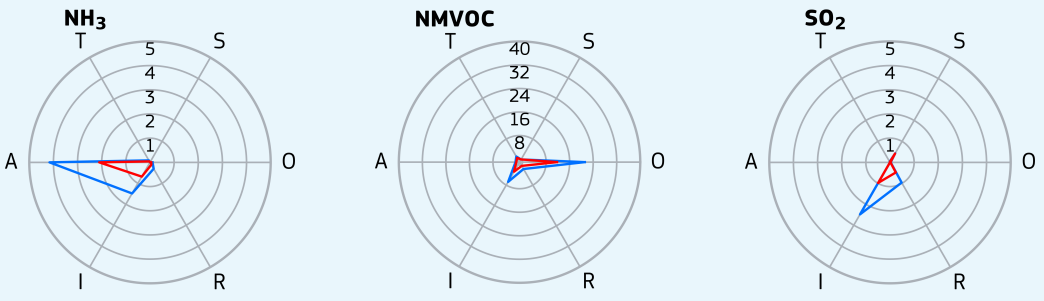


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



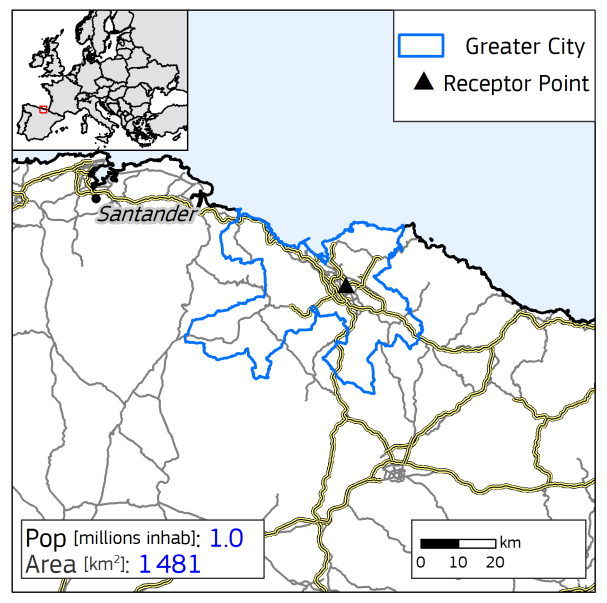
Emissions [kton/year]



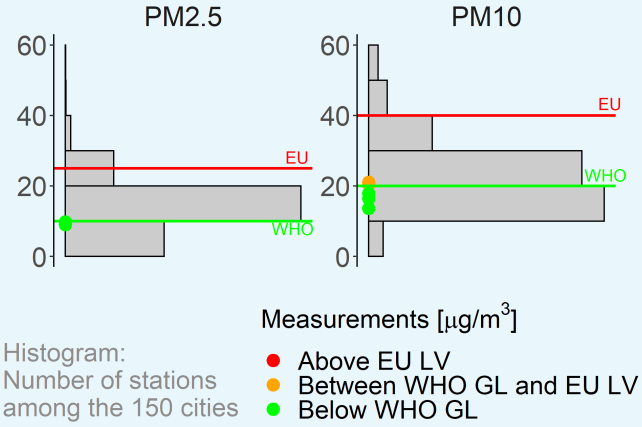


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

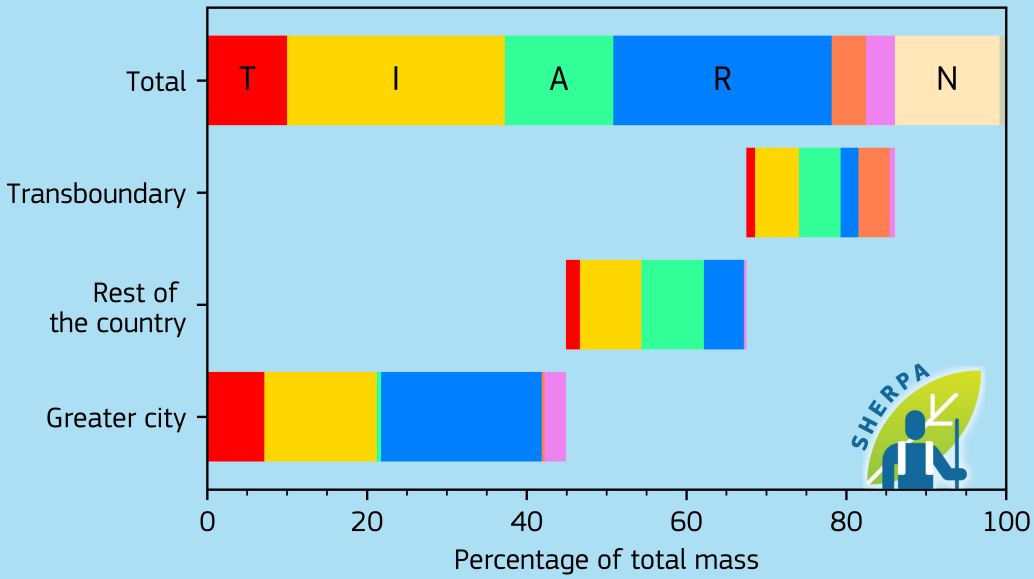
Spain, Bilbao



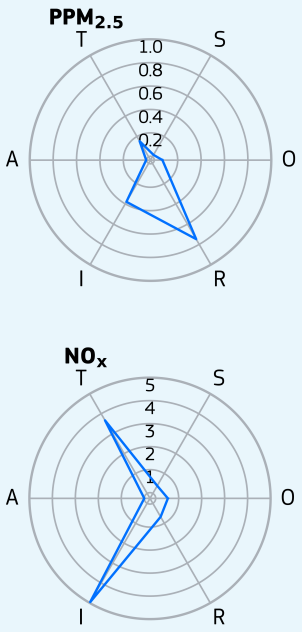
Yearly average urban concentrations (2018)

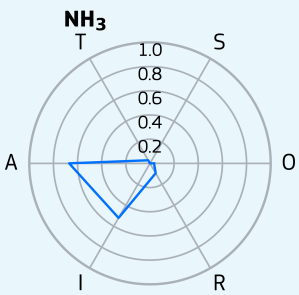


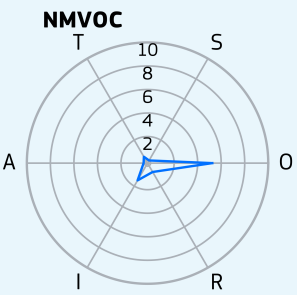
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

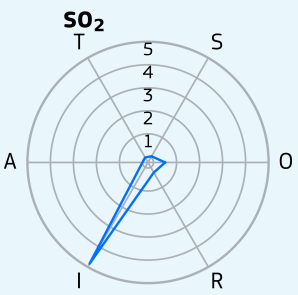


Emissions [kton/year]



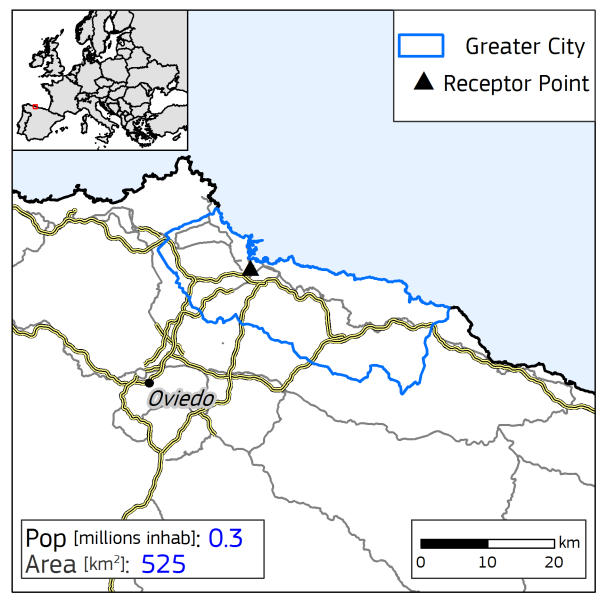




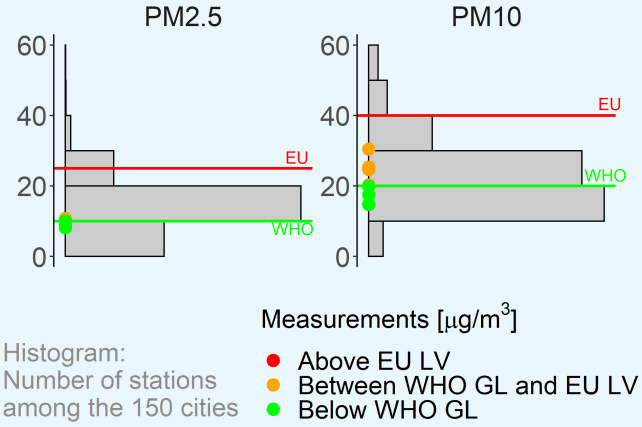


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

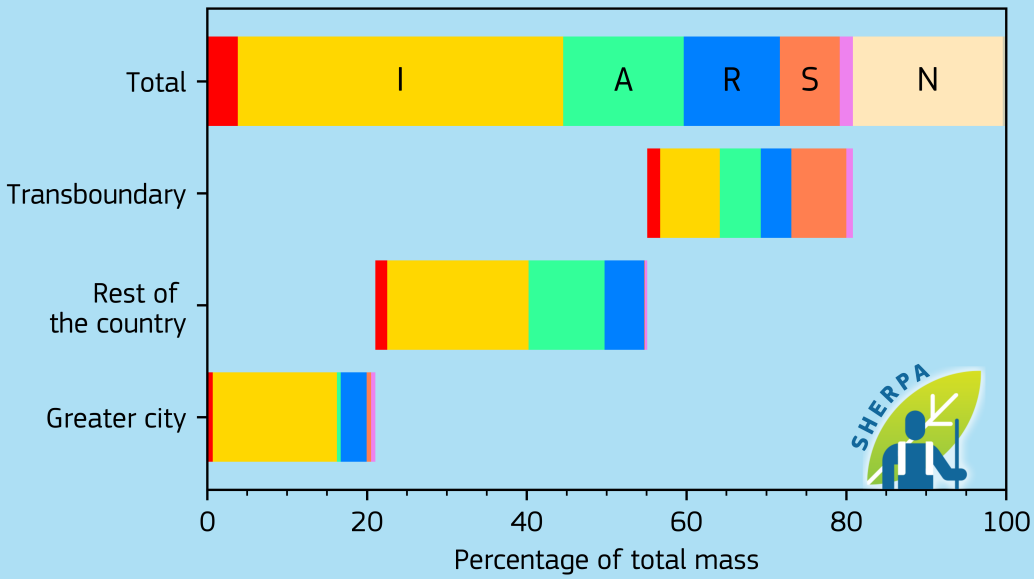
Spain, Gijón



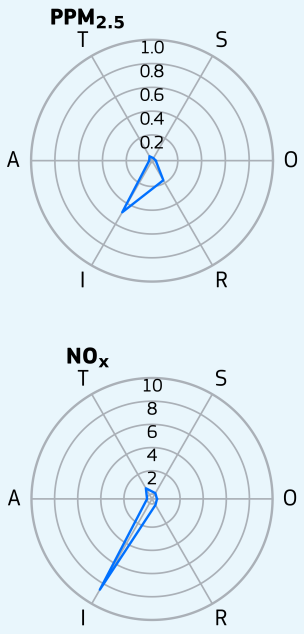
Yearly average urban concentrations (2018)

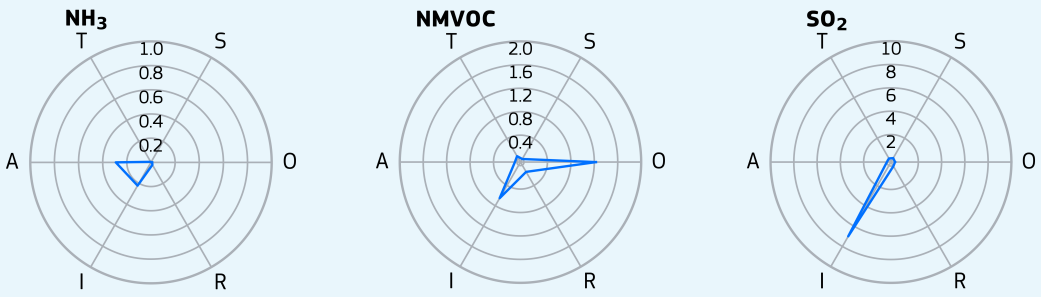


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



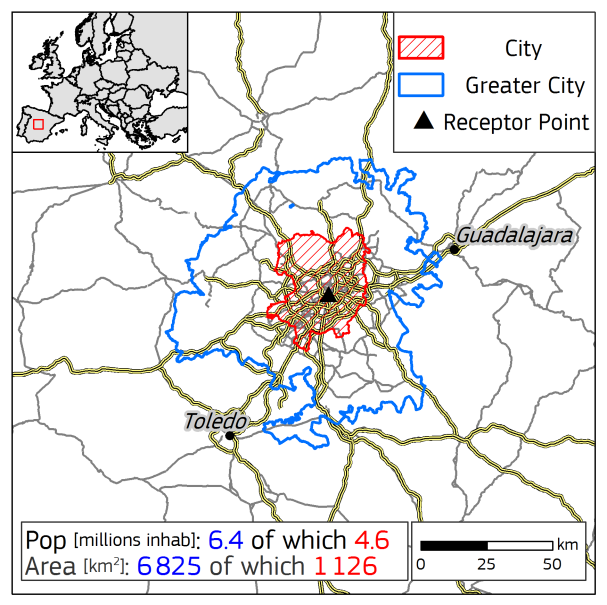
Emissions [kton/year]



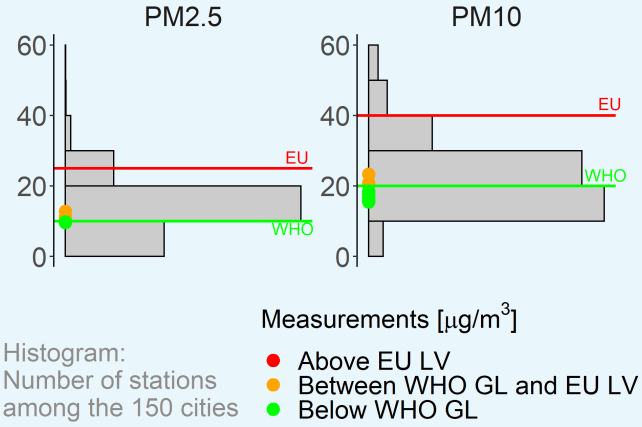


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

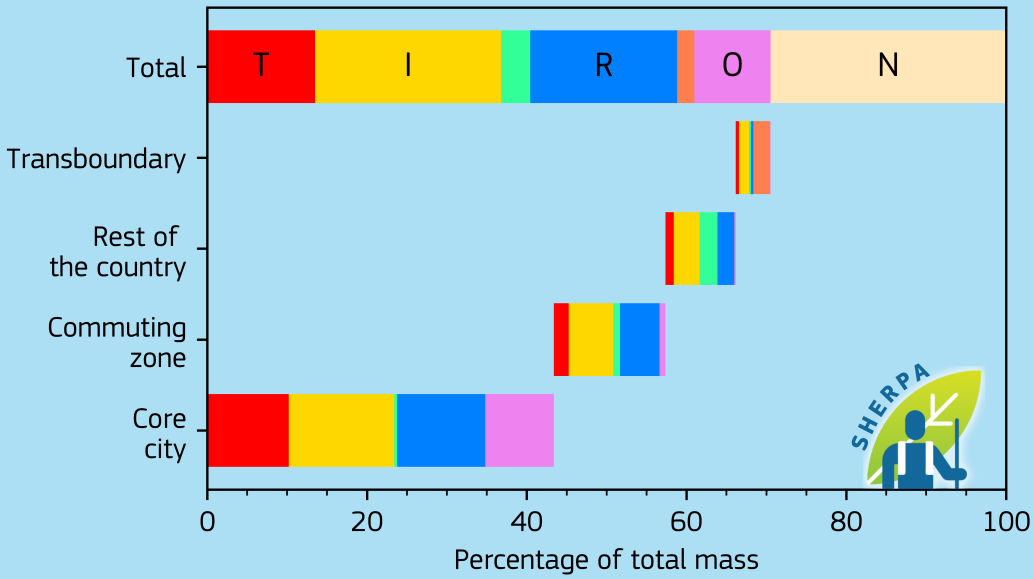
Spain, Madrid



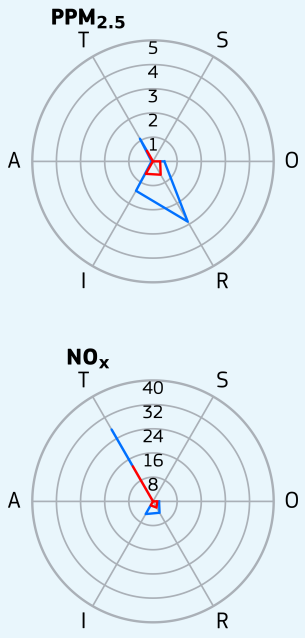
Yearly average urban concentrations (2018)

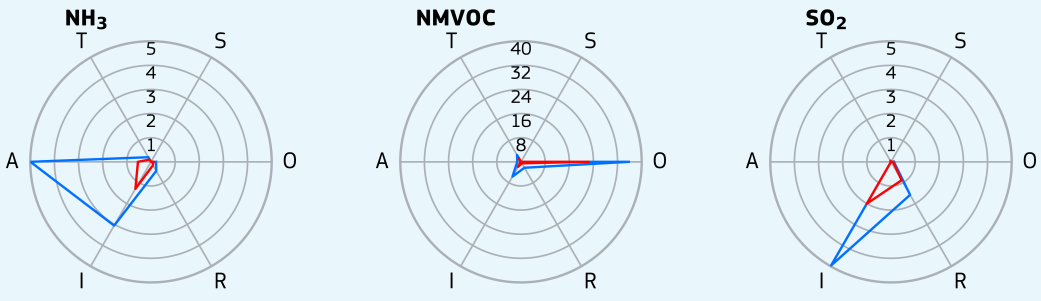


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

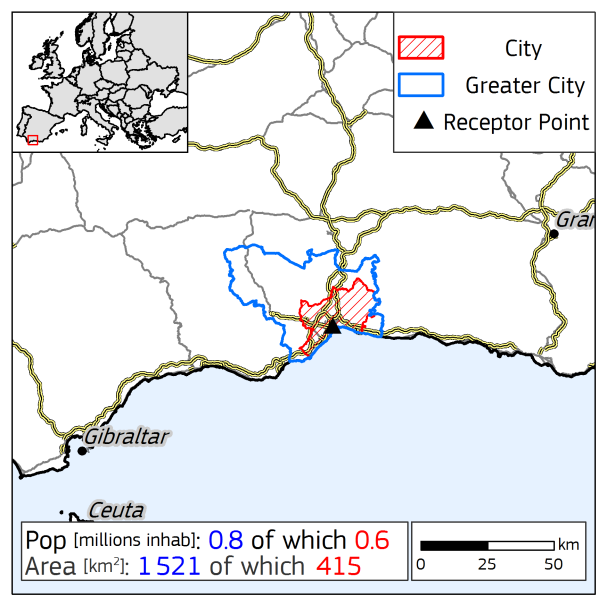


Emissions [kton/year]

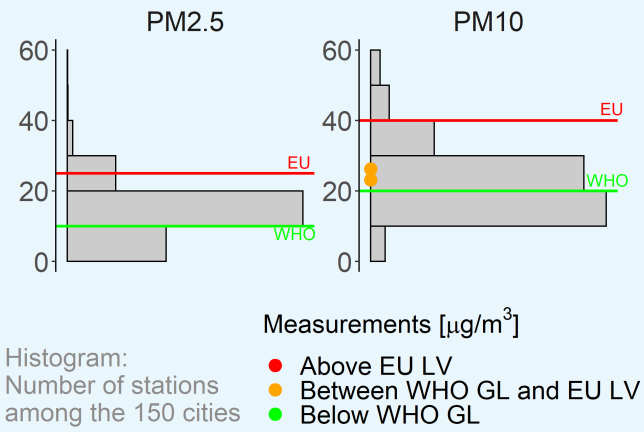




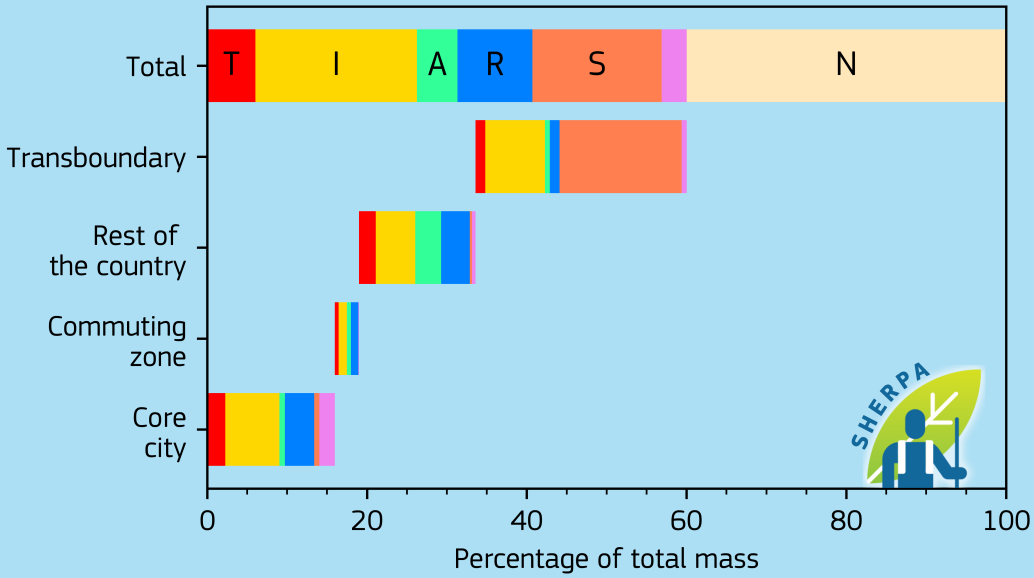
Spain, Malaga



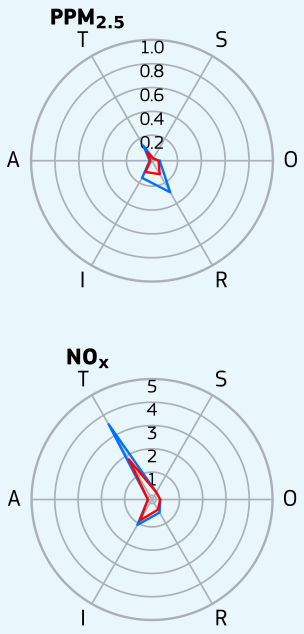
Yearly average urban concentrations (2018)

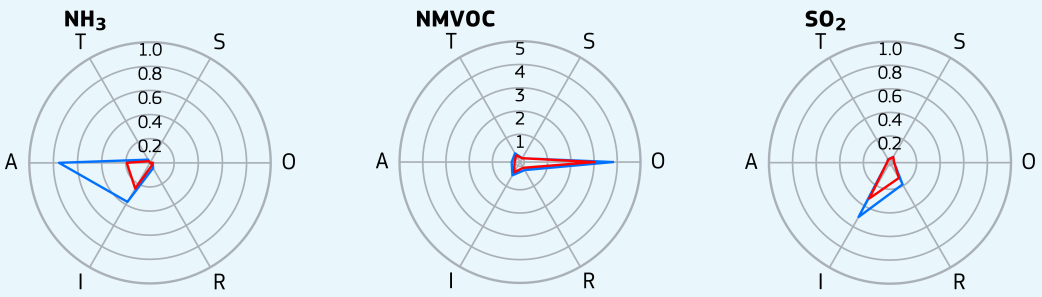


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



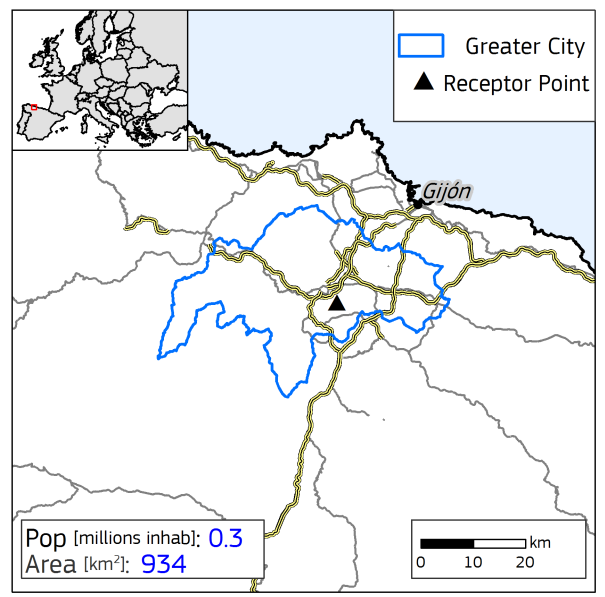
Emissions [kton/year]



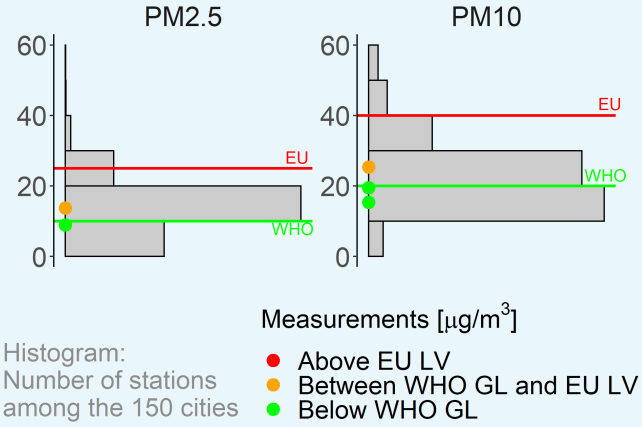


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city
Core city

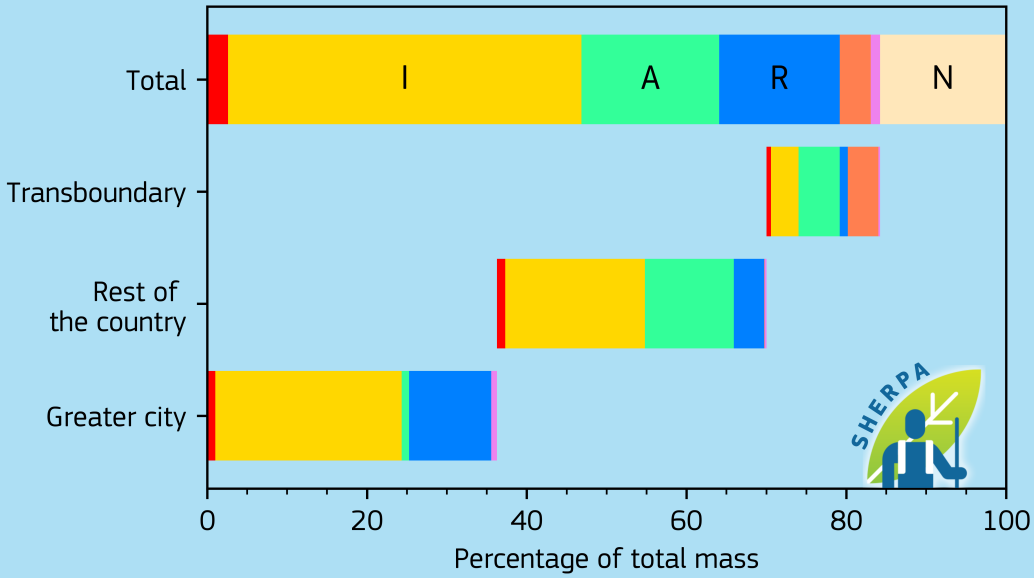
Spain, Oviedo



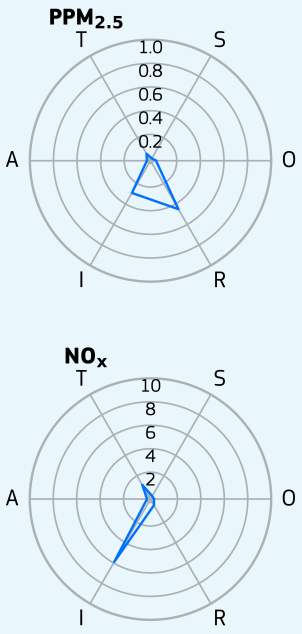
Yearly average urban concentrations (2018)

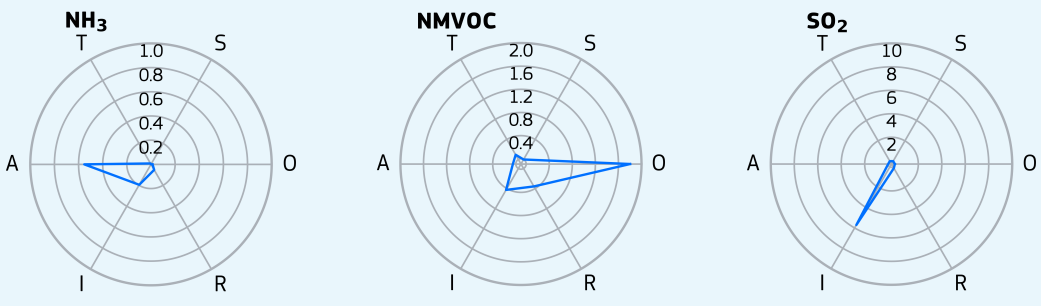


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



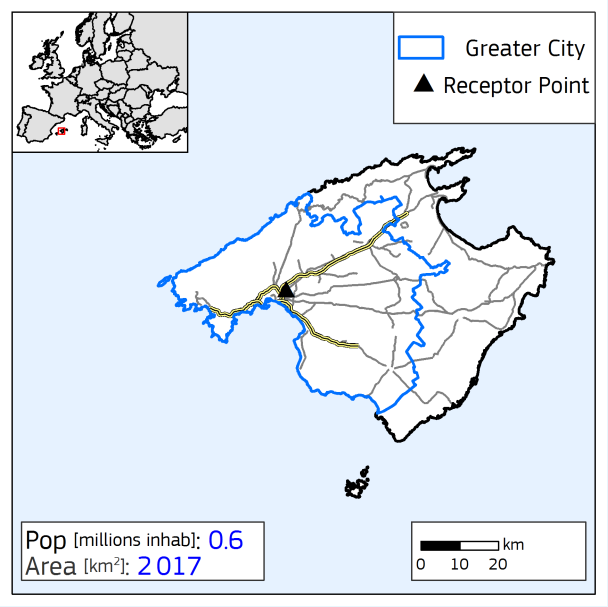
Emissions [kton/year]



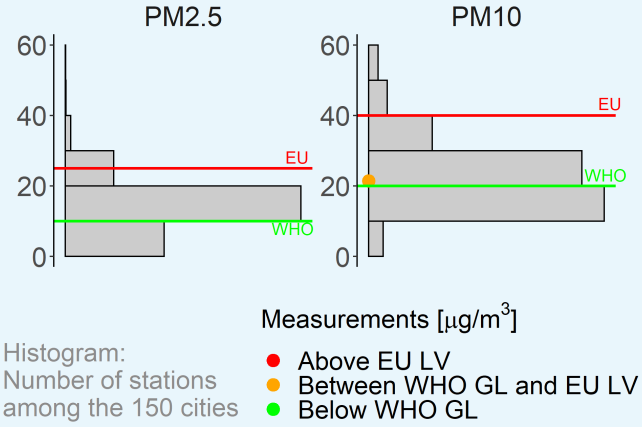


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

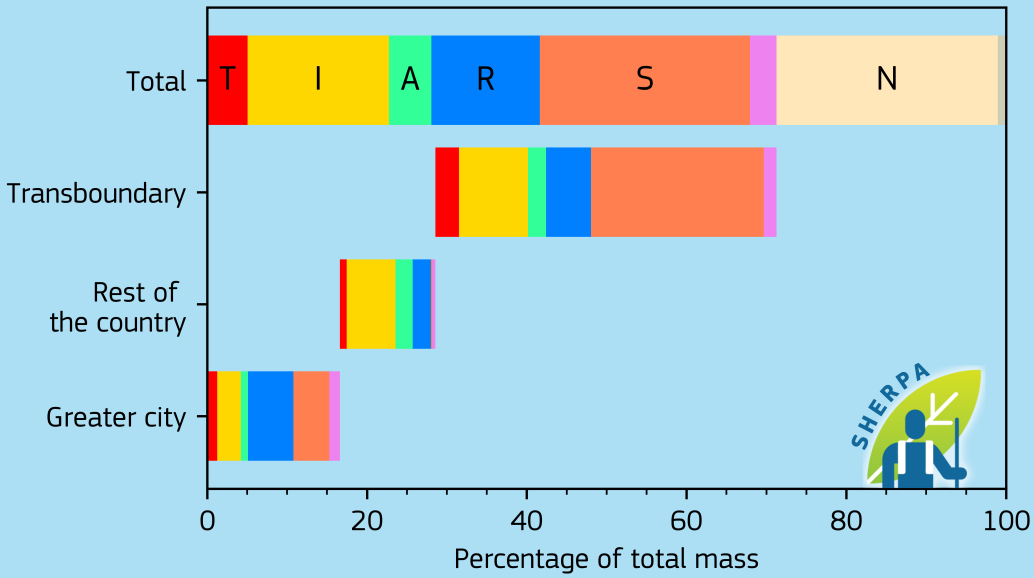
Spain, Palma de Mallorca



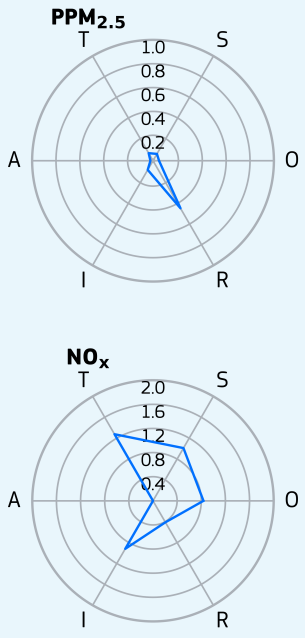
Yearly average urban concentrations (2018)

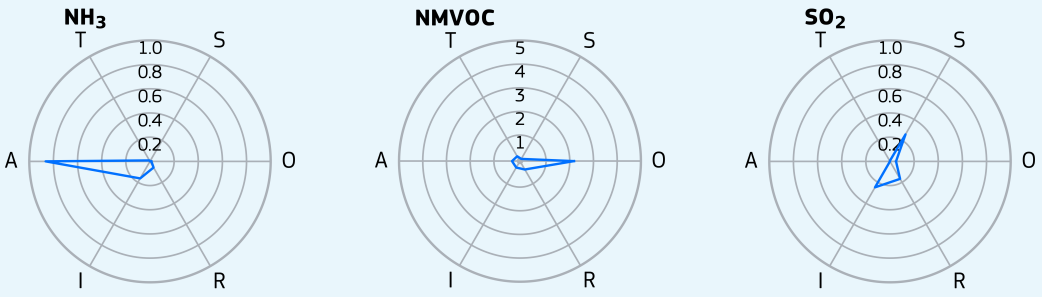


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



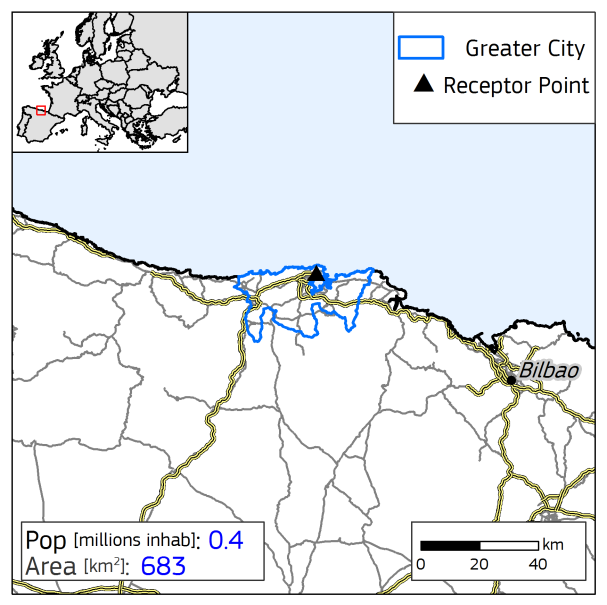
Emissions [kton/year]



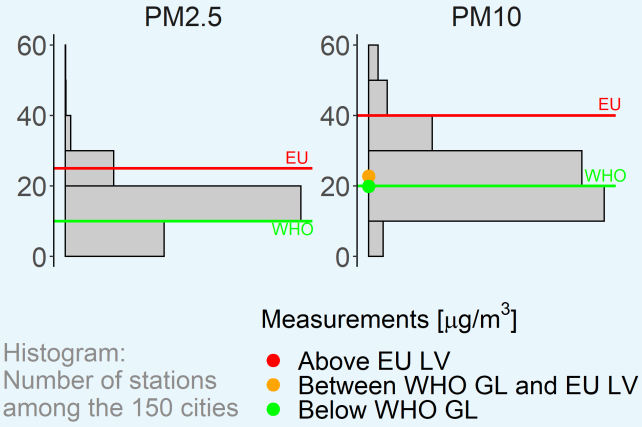


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

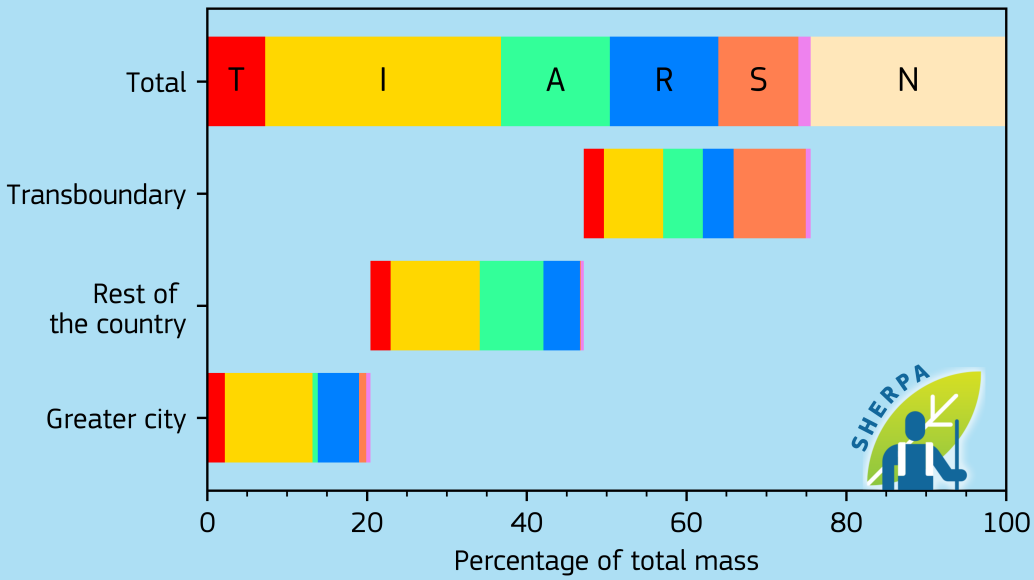
Spain, Santander



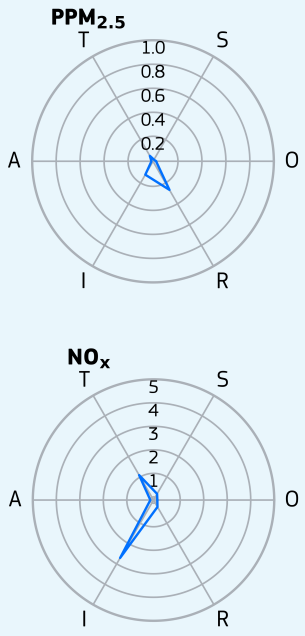
Yearly average urban concentrations (2018)

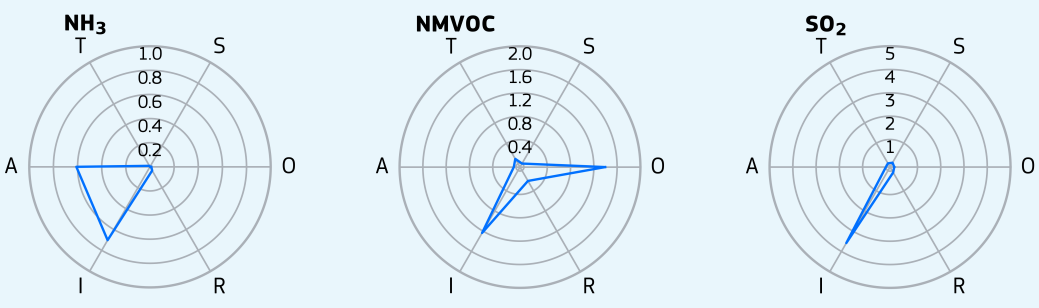


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



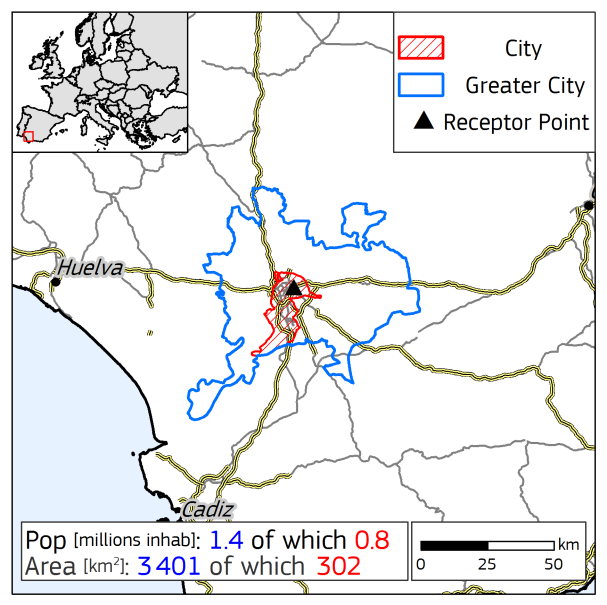
Emissions [kton/year]



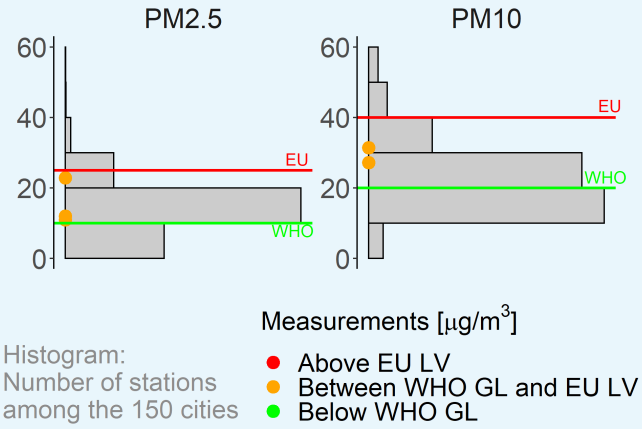


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city

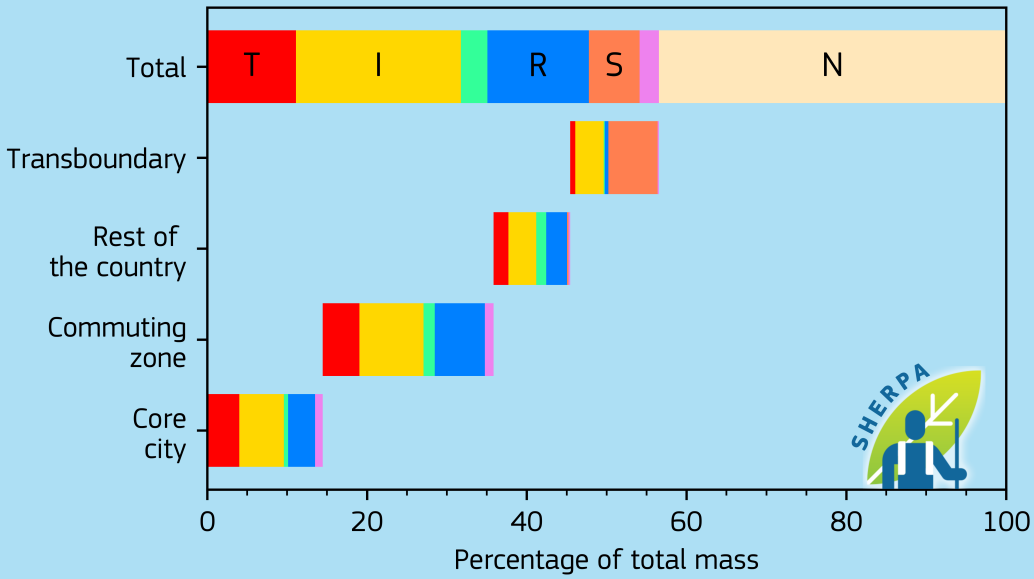
Spain, Seville



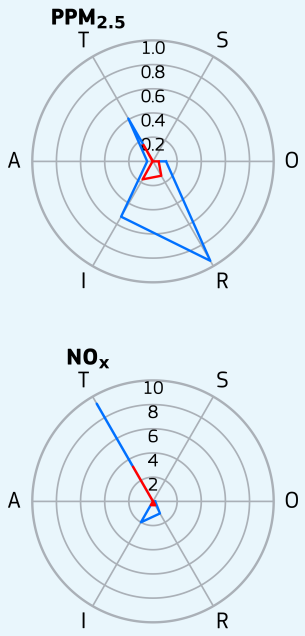
Yearly average urban concentrations (2018)

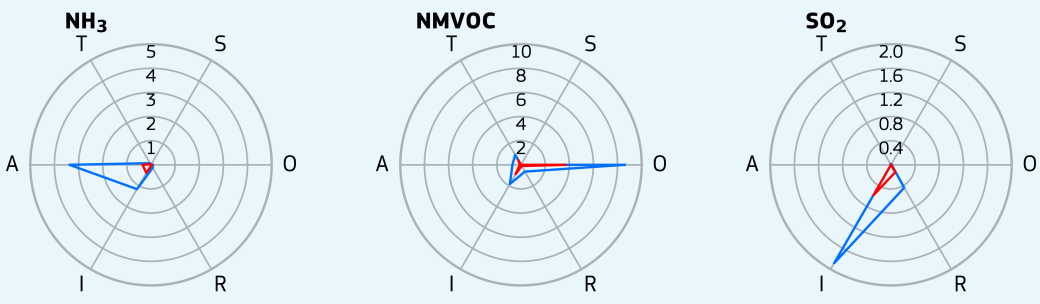


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



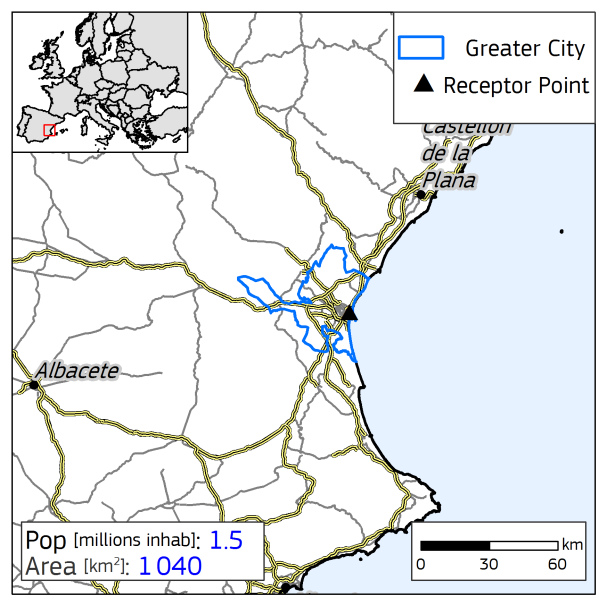
Emissions [kton/year]



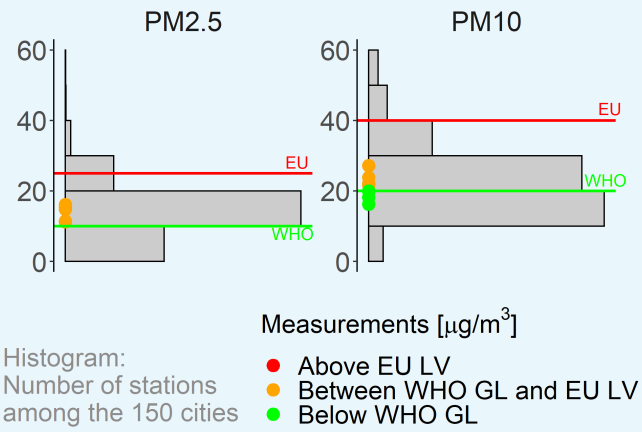


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
Greater city
Core city

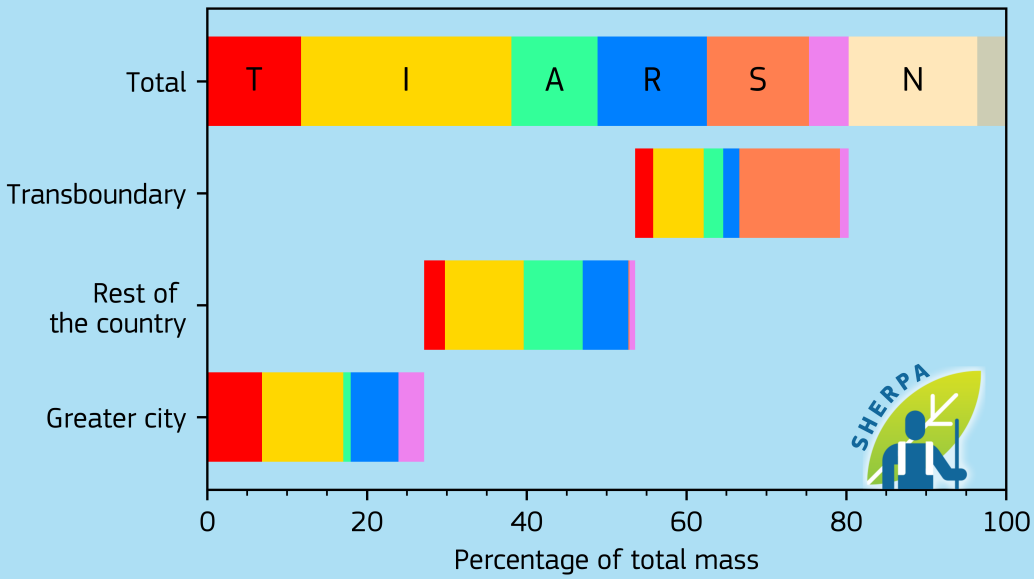
Spain, Valencia



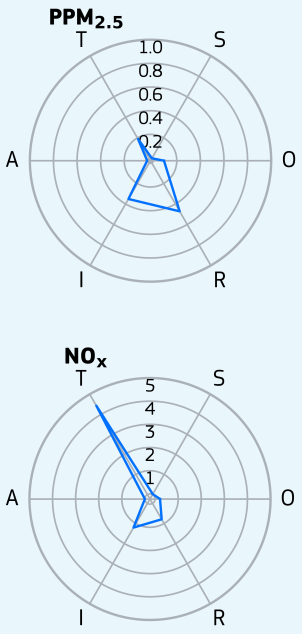
Yearly average urban concentrations (2018)

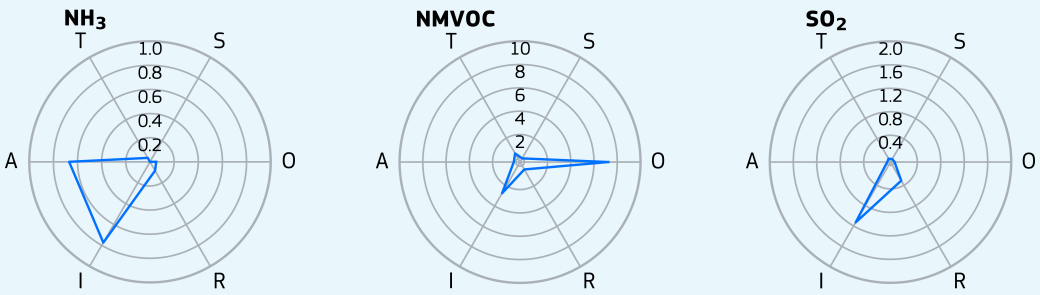


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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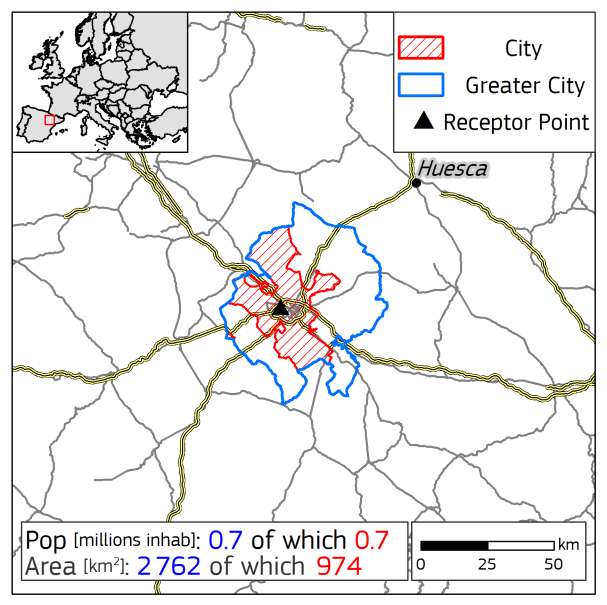
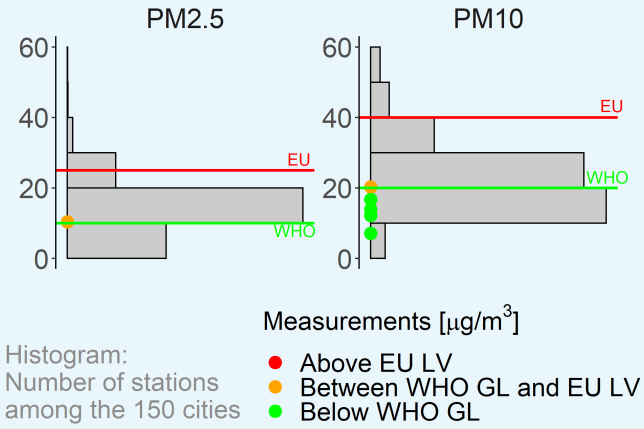
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

Spain, Zaragoza

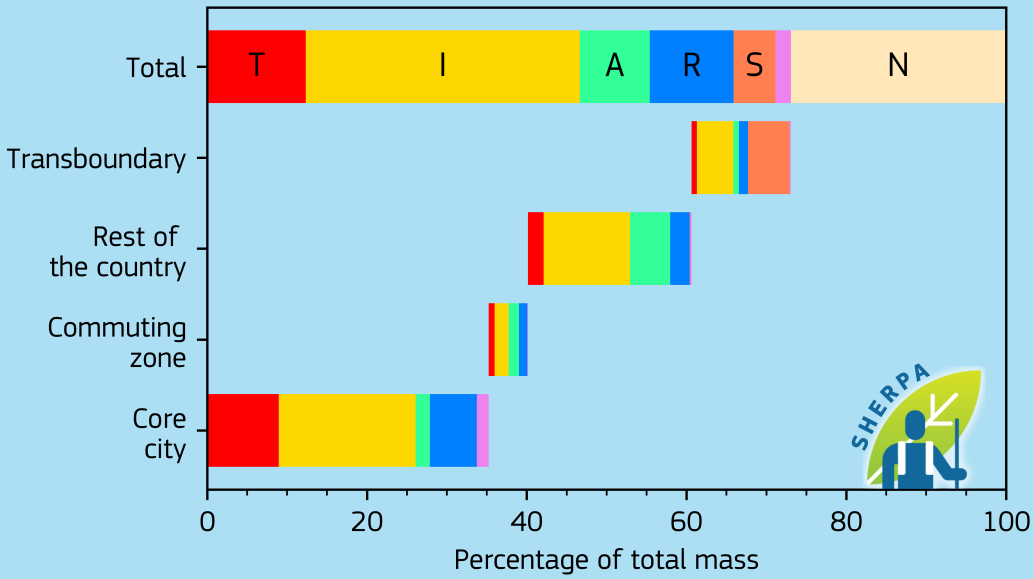


Yearly average urban concentrations (2018)

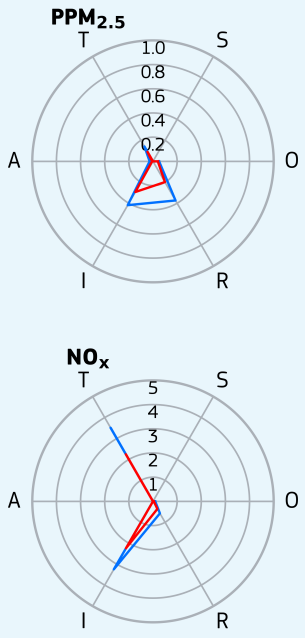


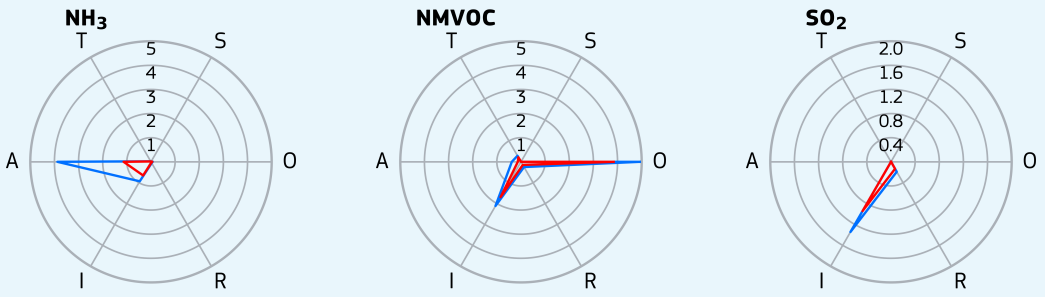
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



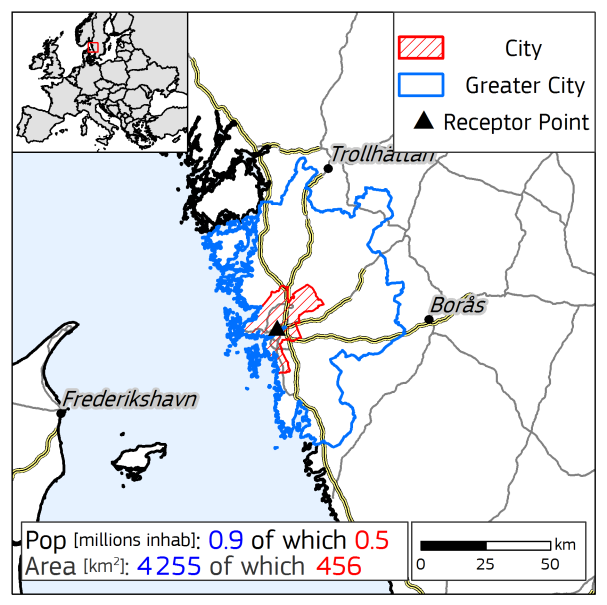
Emissions [kton/year]



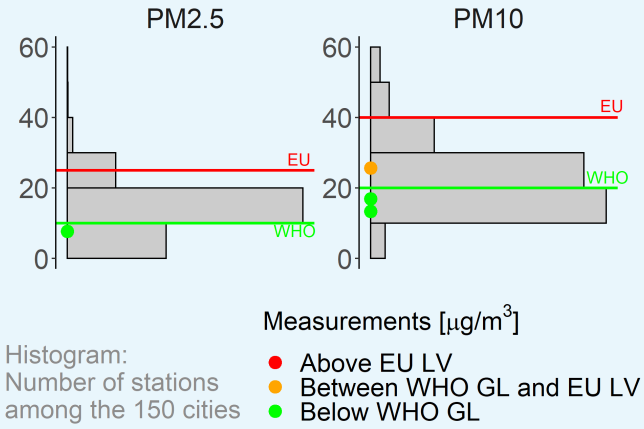


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- Greater city
- Core city

Sweden, Gothenburg



Yearly average urban concentrations (2018)



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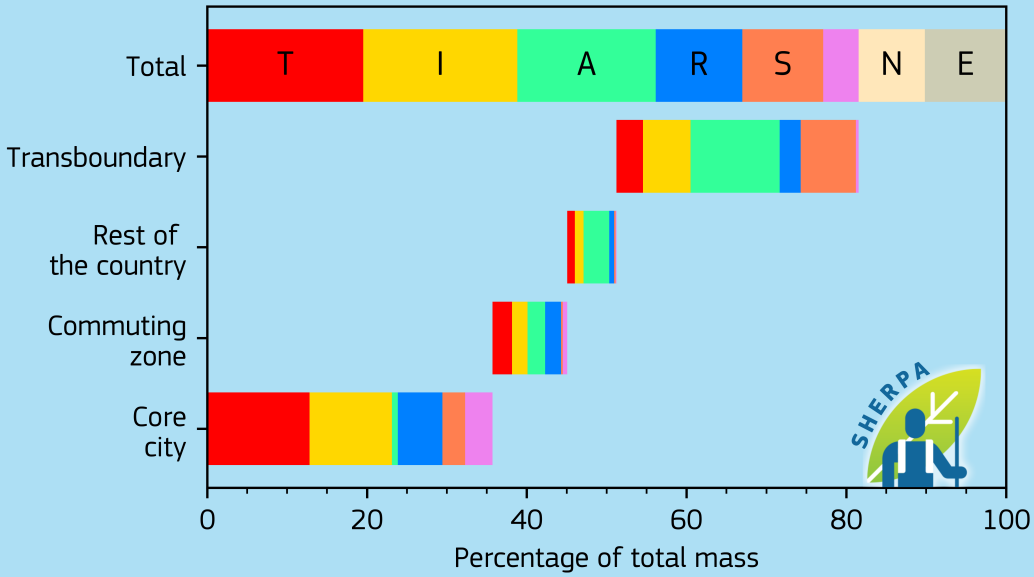
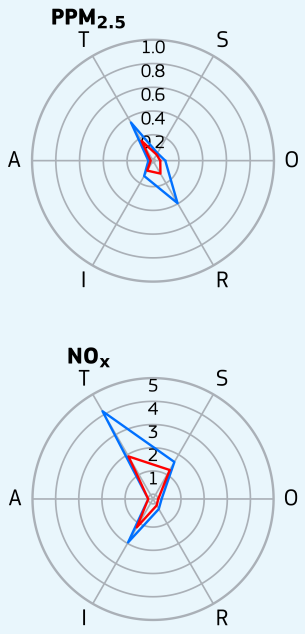
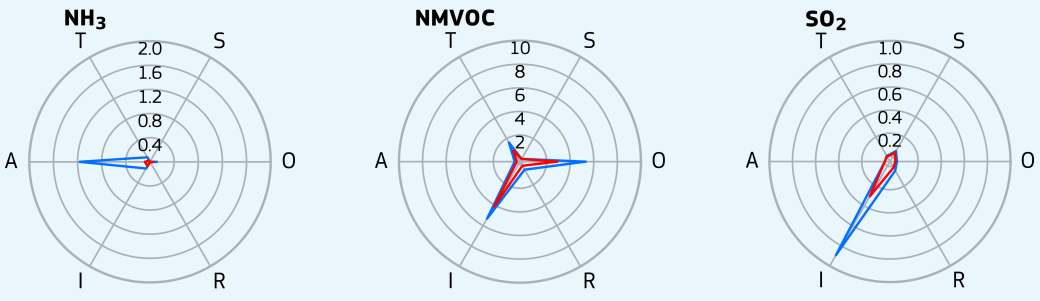


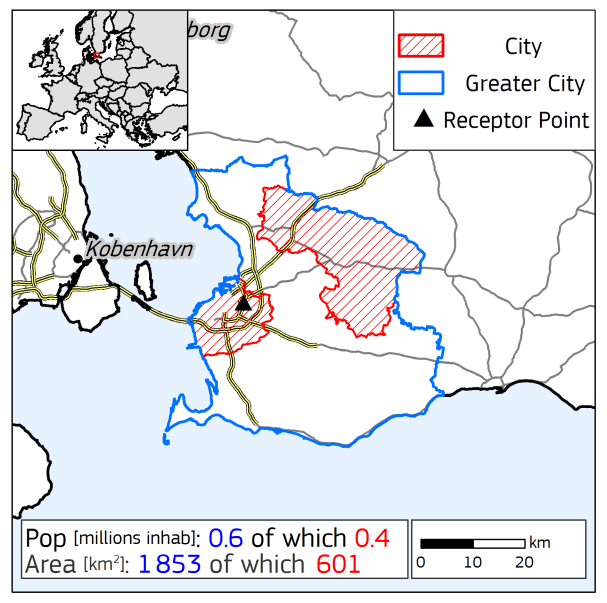
Emissions [kton/year]



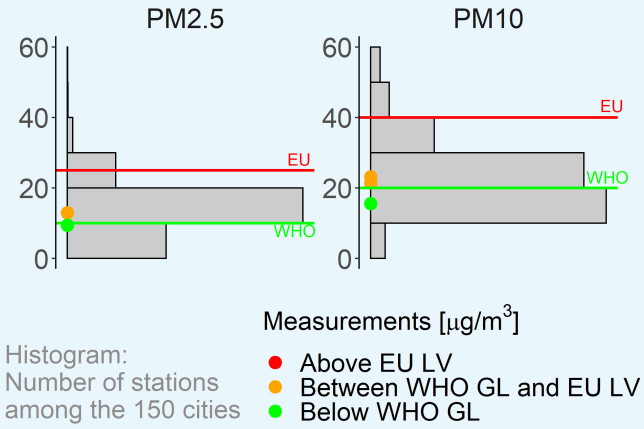


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

Sweden, Malmö



Yearly average urban concentrations (2018)



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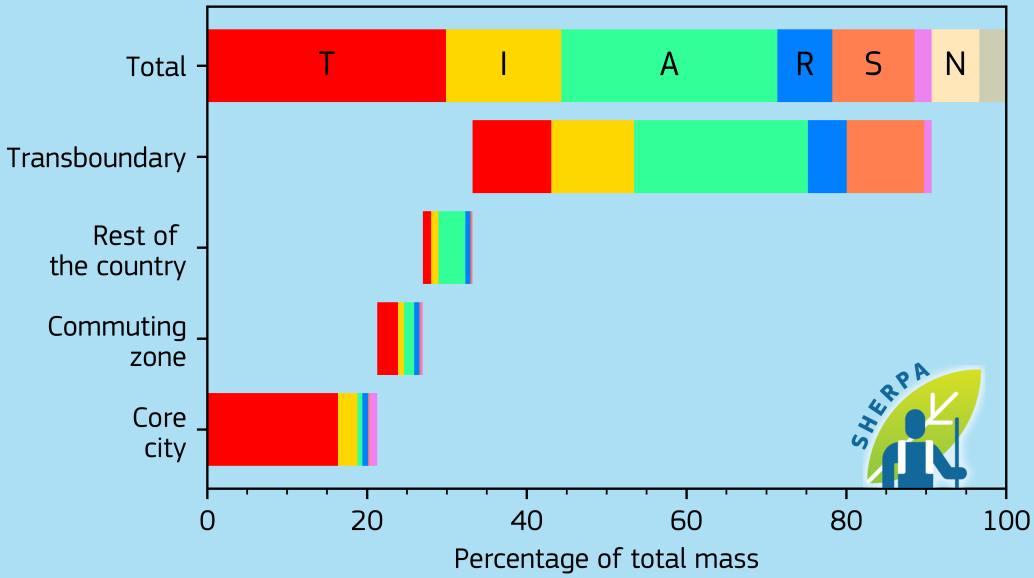
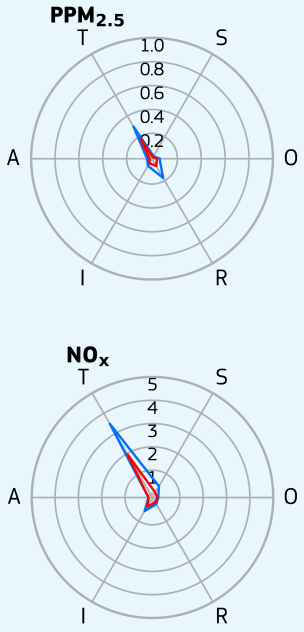
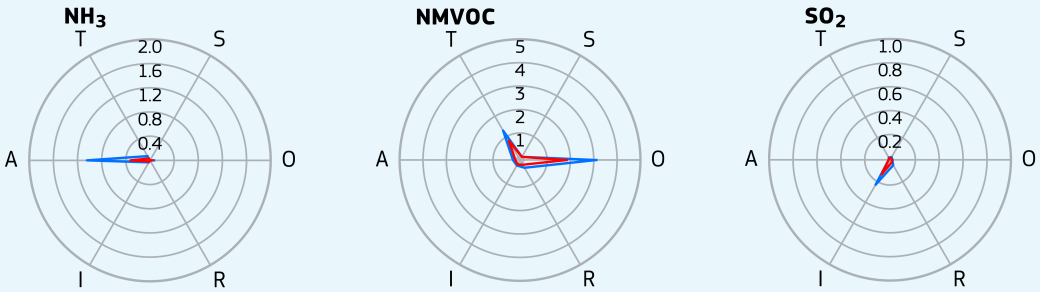


Emissions [kton/year]





- T - Transport
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- R - Residential
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- O - Other
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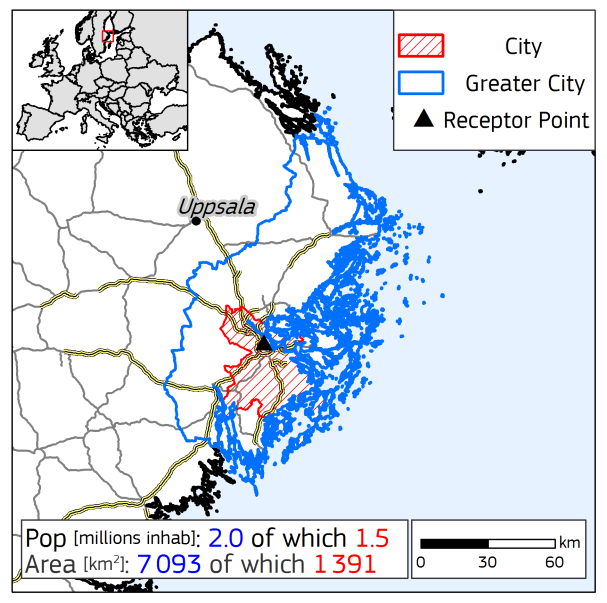
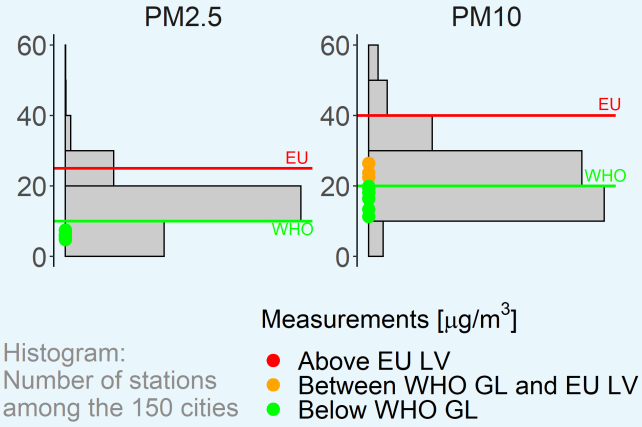
- E - External
- Greater city
- Core city

Sweden, Stockholm



Yearly average urban concentrations (2018)



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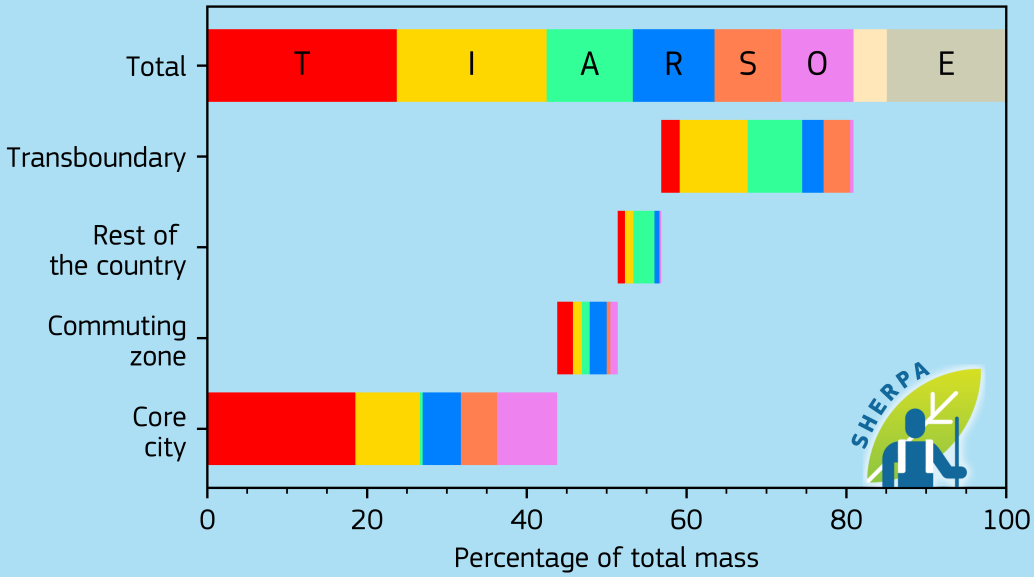
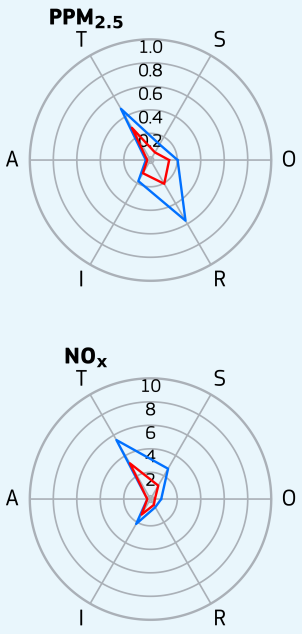
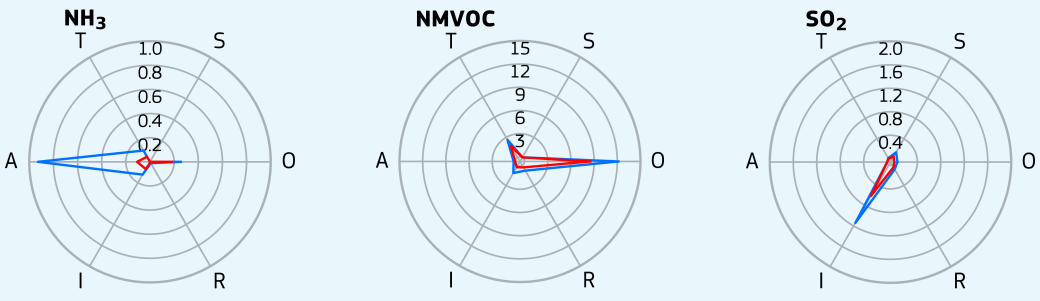


Emissions [kton/year]





- T - Transport
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- R - Residential
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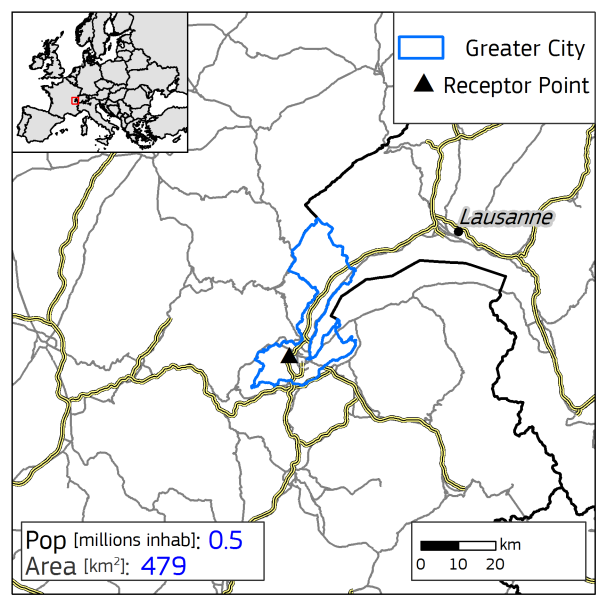
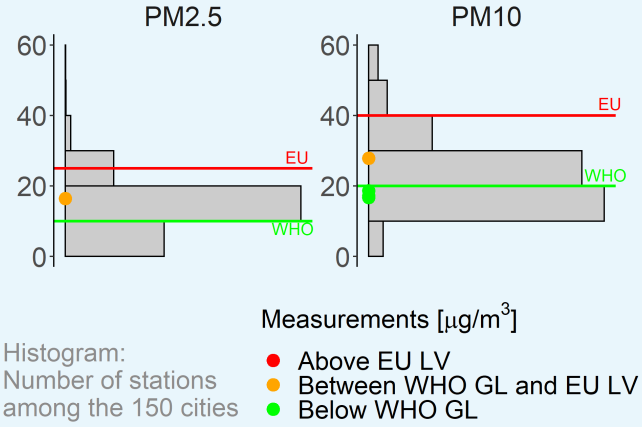
- Core city

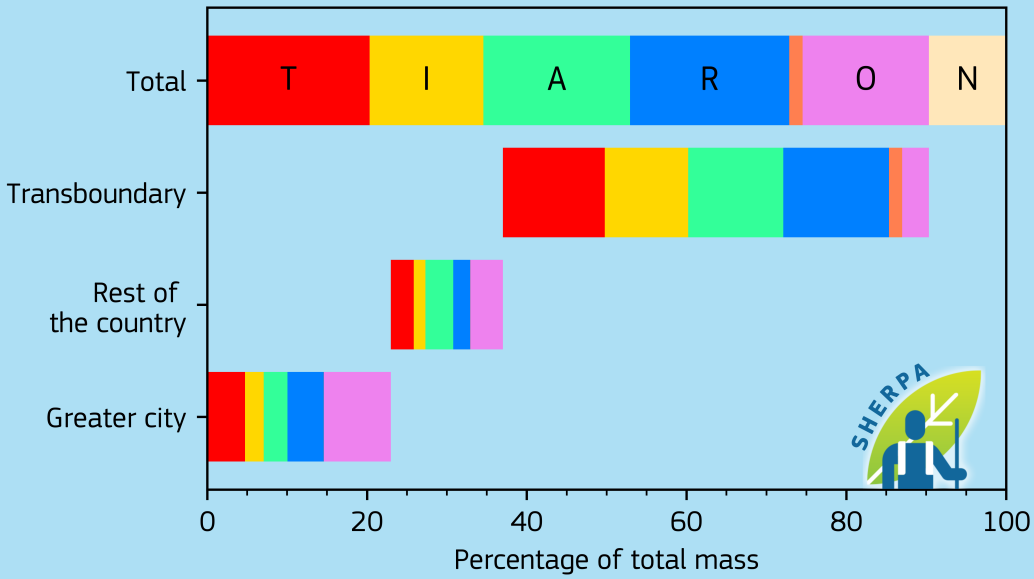
Switzerland, Geneva



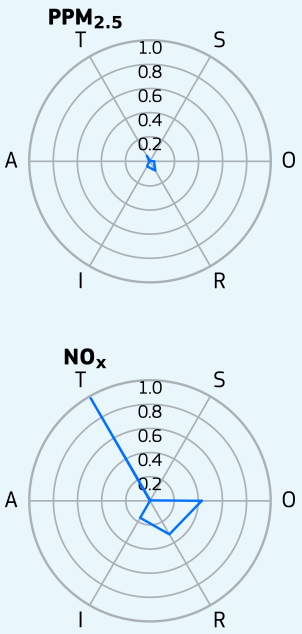
Yearly average urban concentrations (2018)

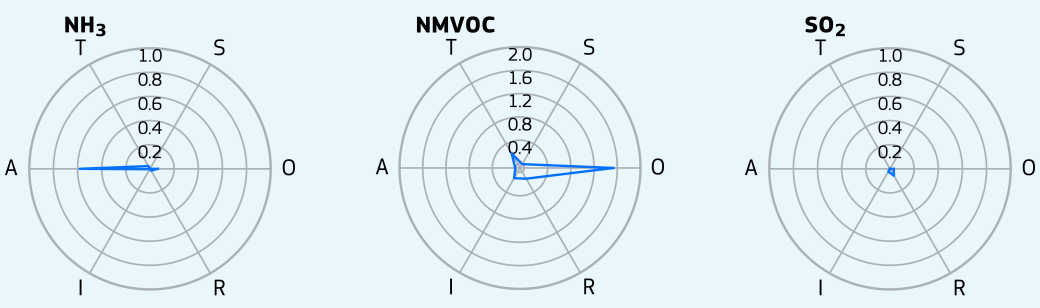


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
- I - Industry
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- S - Shipping
- O - Other
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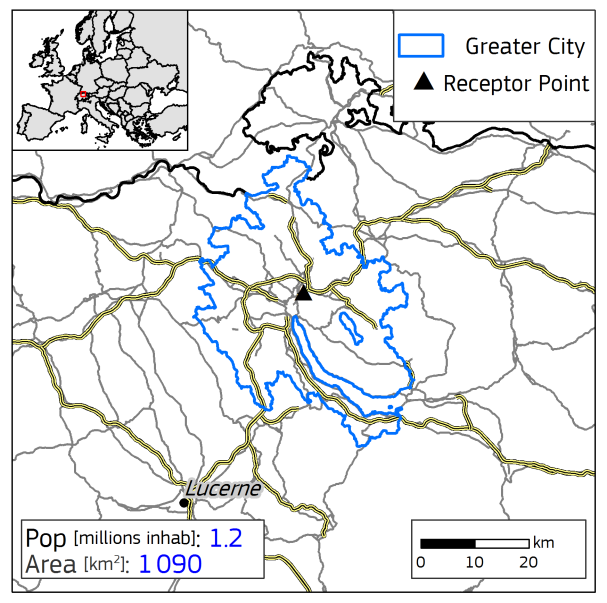
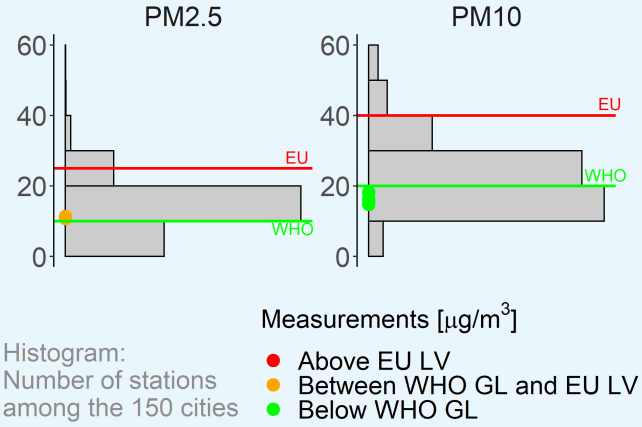
- Greater city

Switzerland, Zürich

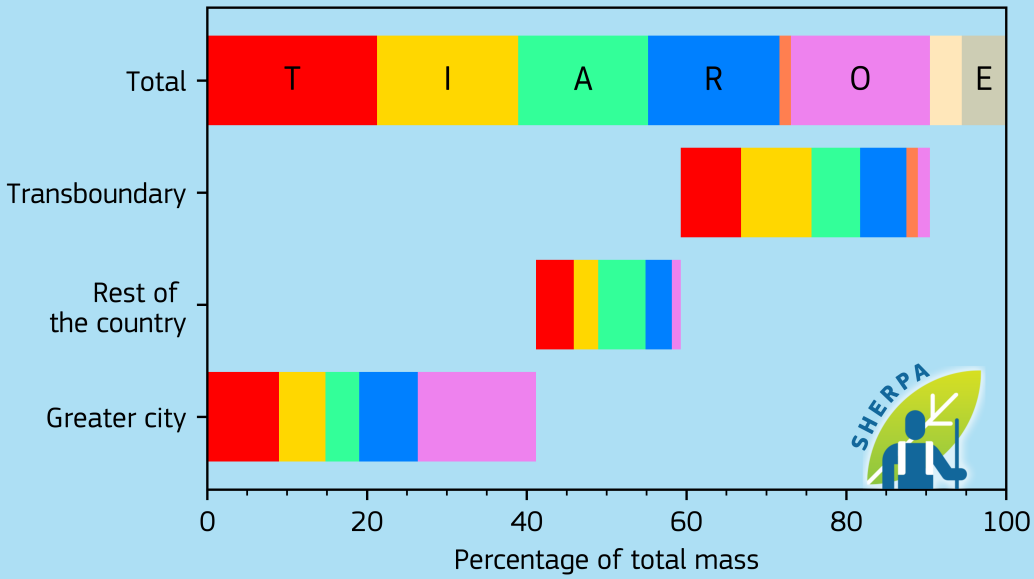


Yearly average urban concentrations (2018)

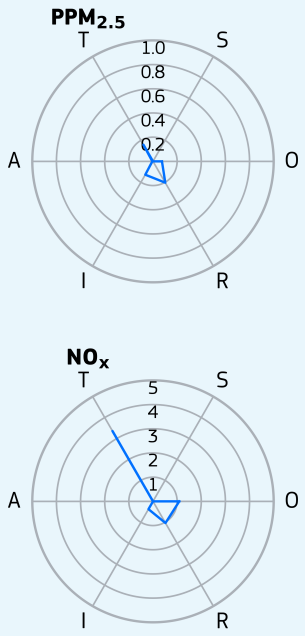


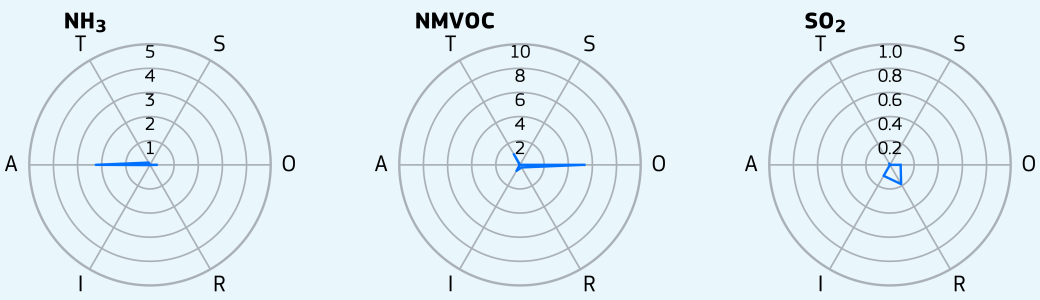
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



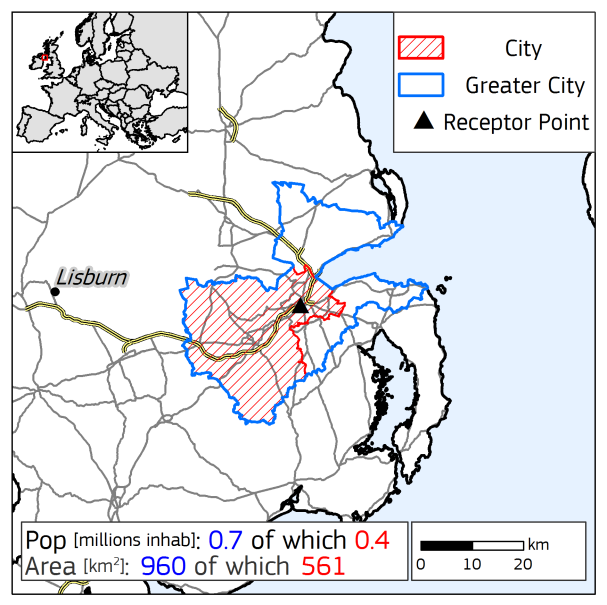
Emissions [kton/year]



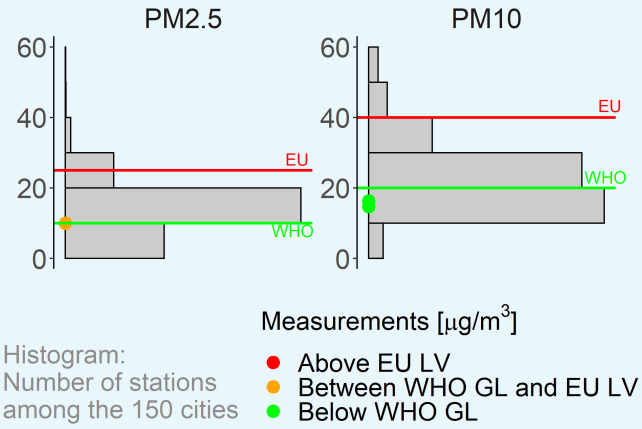


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

United Kingdom, Belfast



Yearly average urban concentrations (2018)



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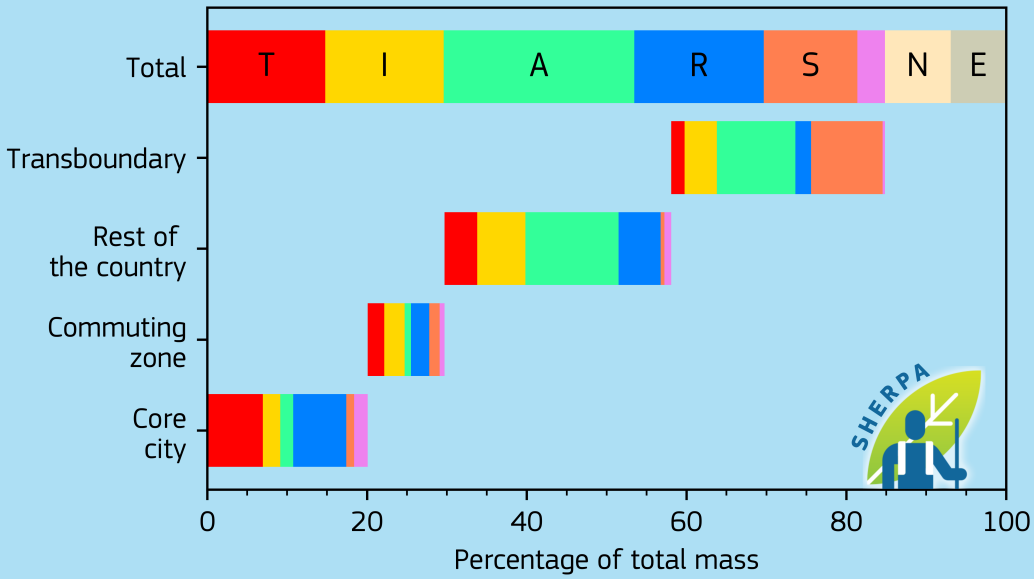
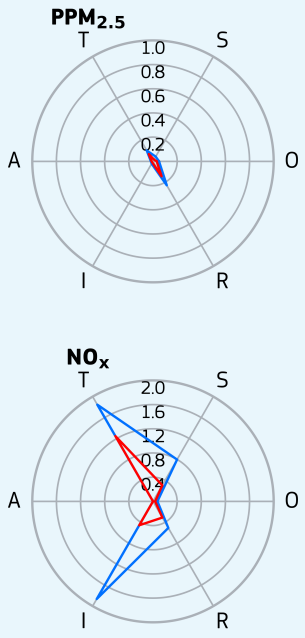
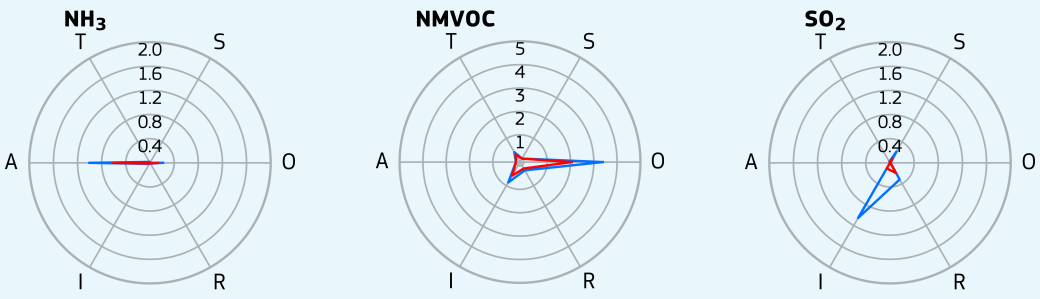


Emissions [kton/year]





- T - Transport
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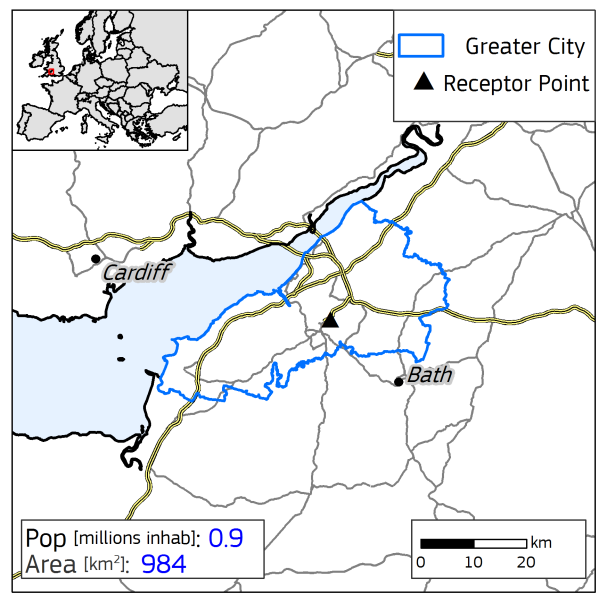
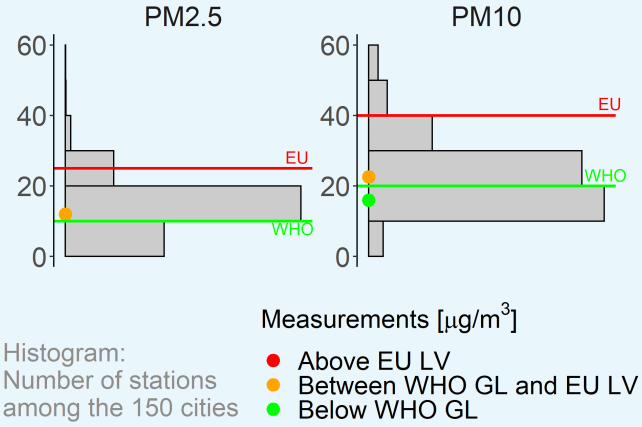
- Greater city
- Core city

United Kingdom, Bristol



Yearly average urban concentrations (2018)



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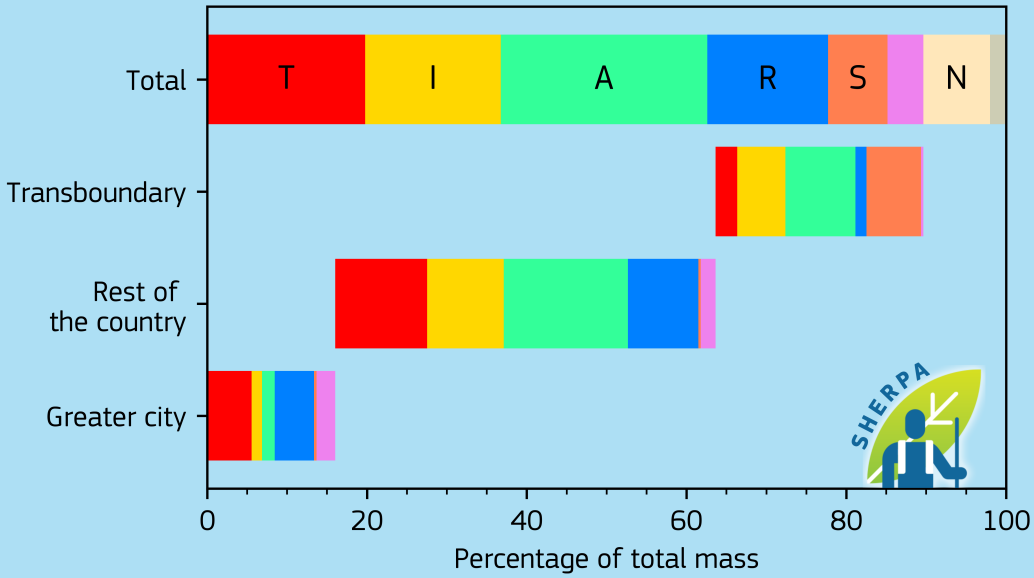
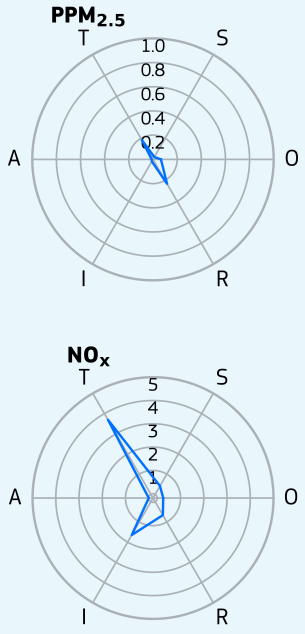
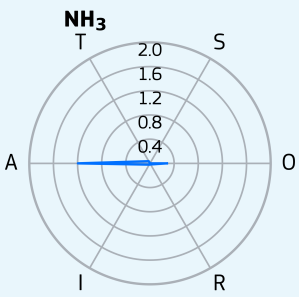
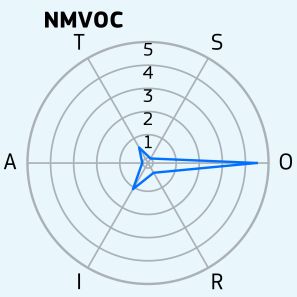
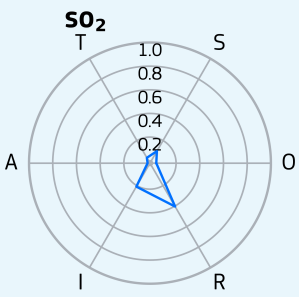


Emissions [kton/year]









- T - Transport
- I - Industry
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- O - Other
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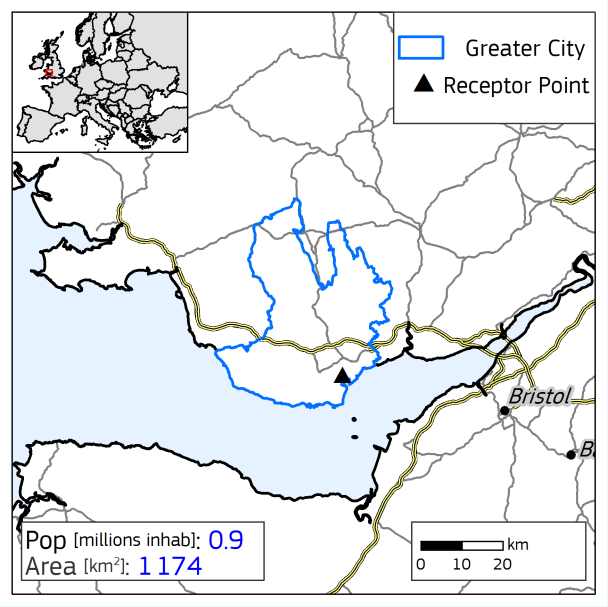
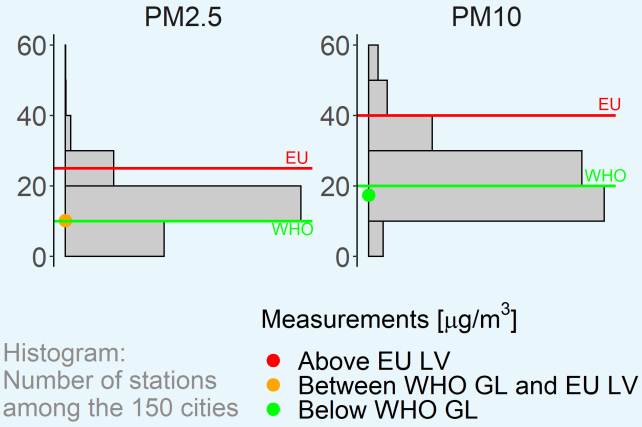
- Greater city

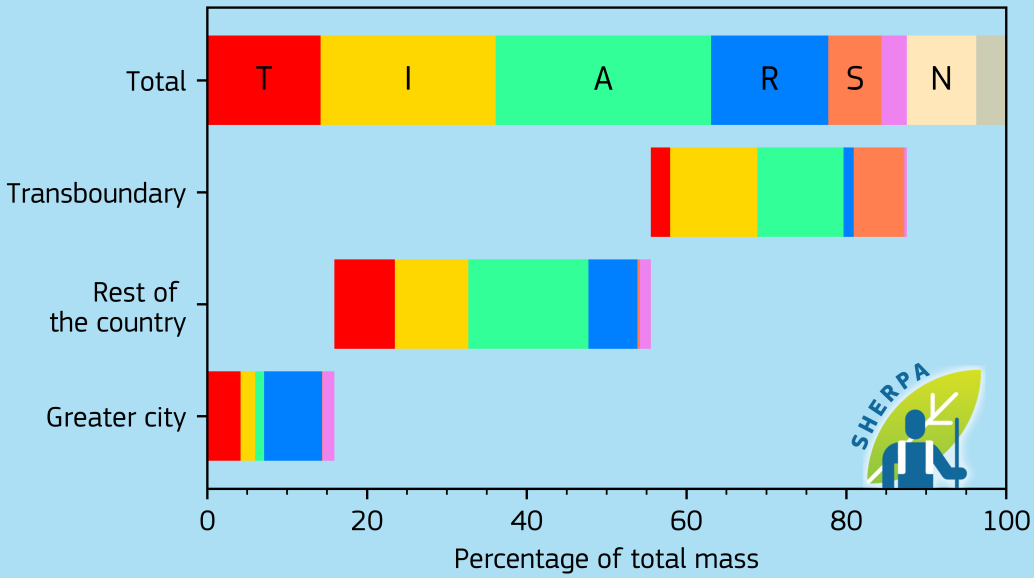
United Kingdom, Cardiff



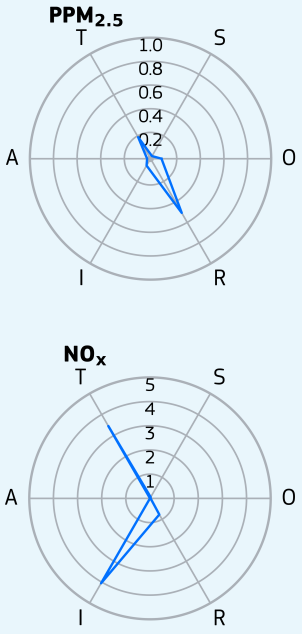
Yearly average urban concentrations (2018)

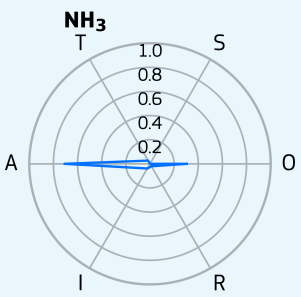


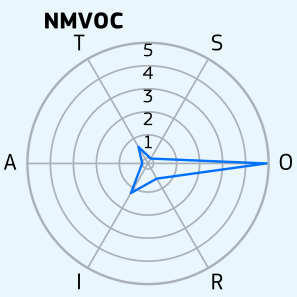
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

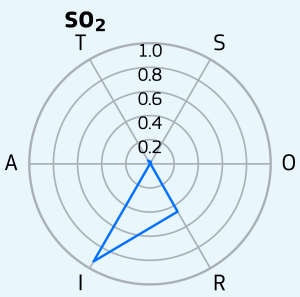


Emissions [kton/year]









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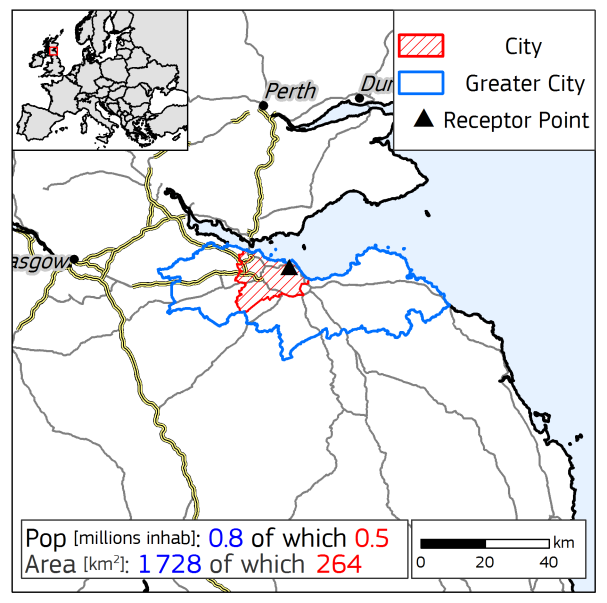
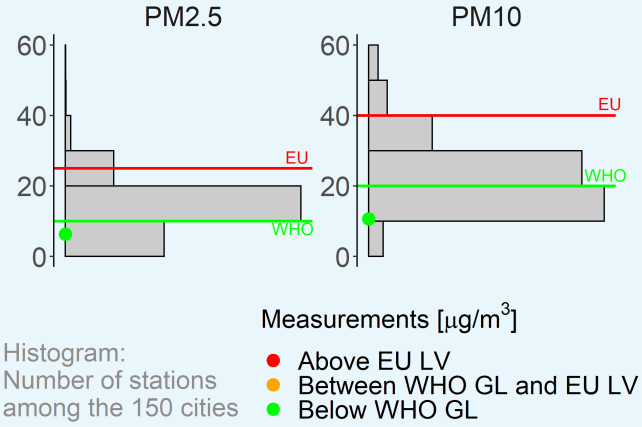
- Greater city

United Kingdom, Edinburgh



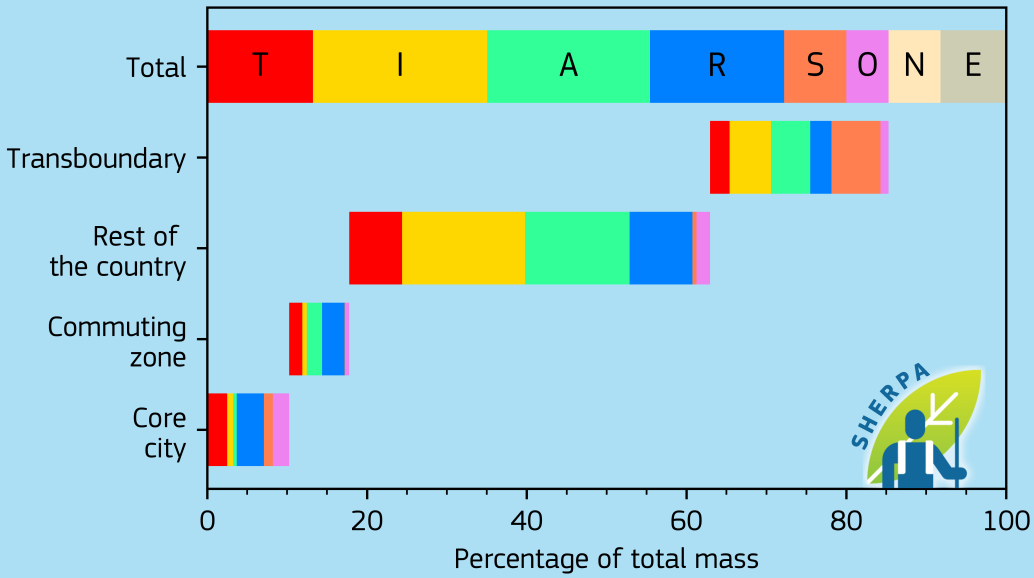
Yearly average urban concentrations (2018)



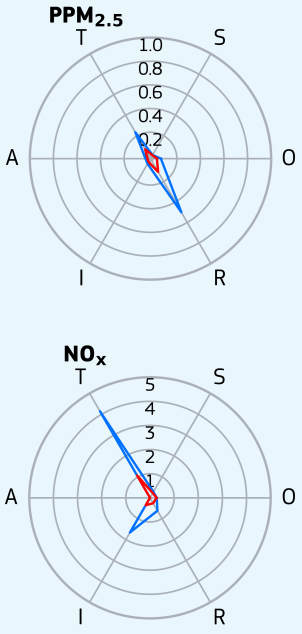
Histogram:
Number of stations
among the 150 cities

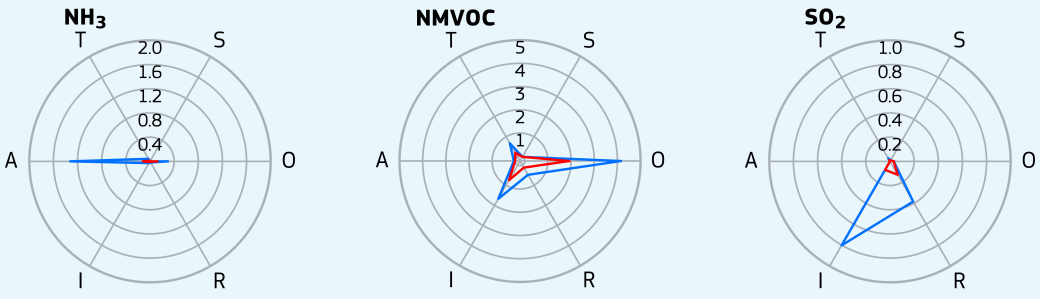
- Above EU LV
- Between WHO GL and EU LV
- Below WHO GL

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



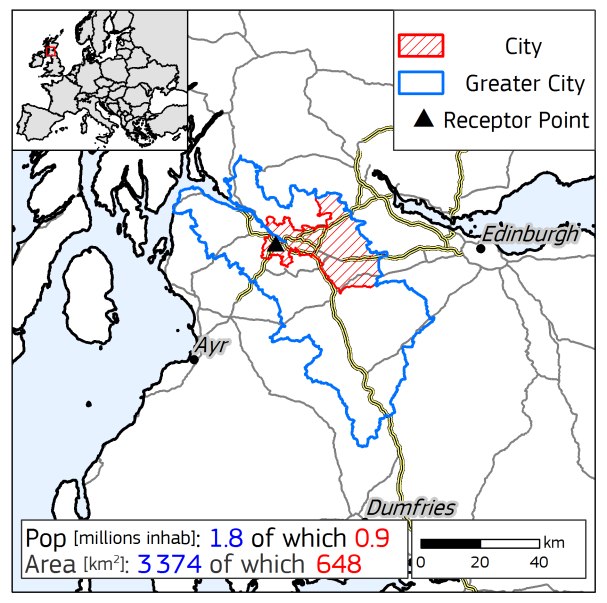
Emissions [kton/year]



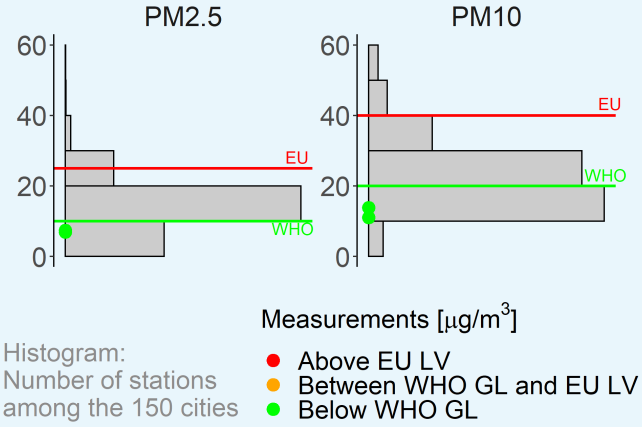


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

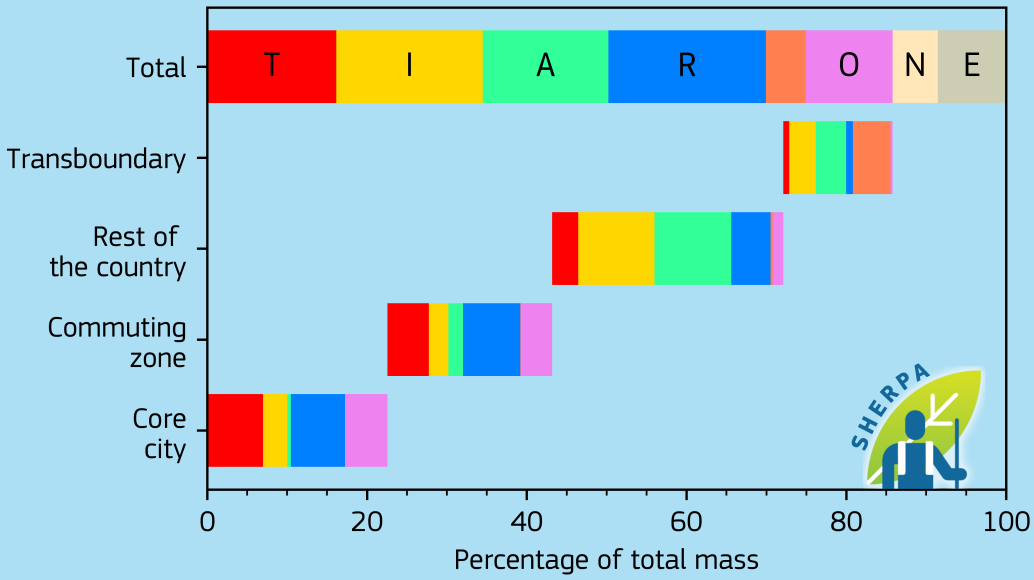
United Kingdom, Glasgow



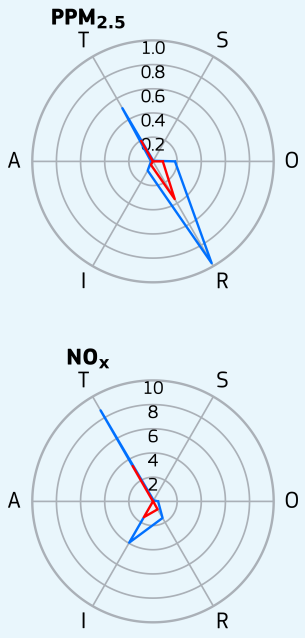
Yearly average urban concentrations (2018)

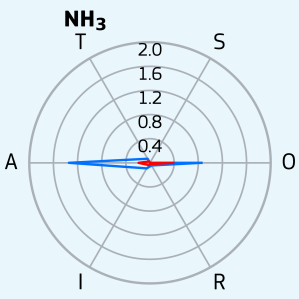


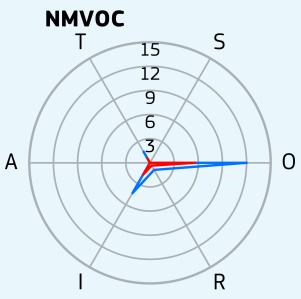
$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)

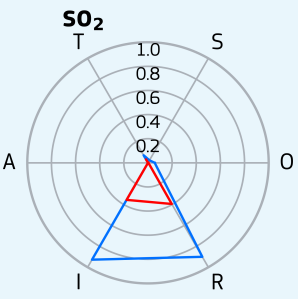


Emissions [kton/year]



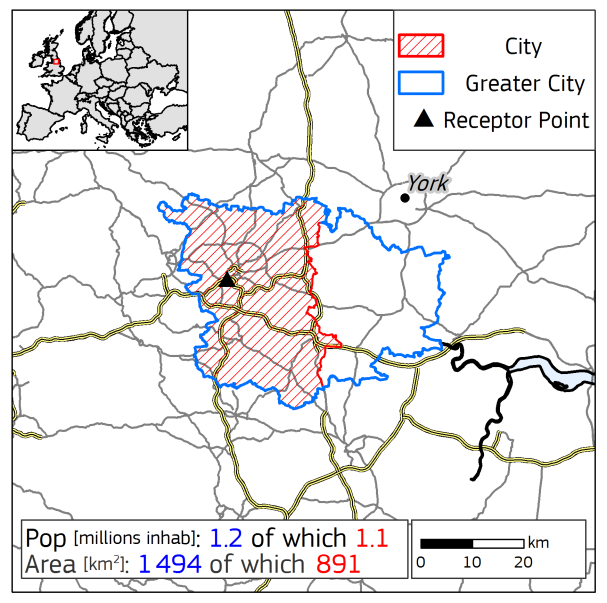




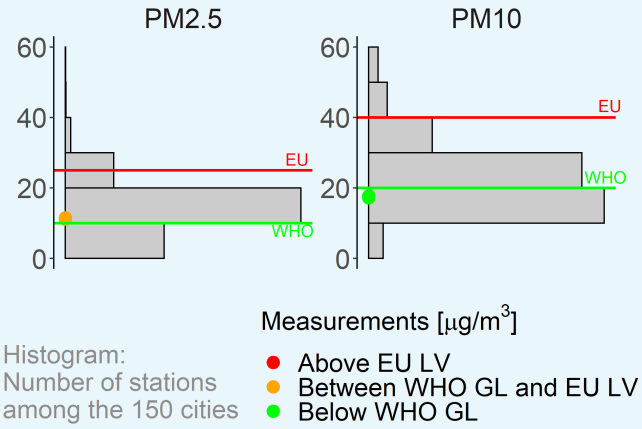


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

United Kingdom, Leeds



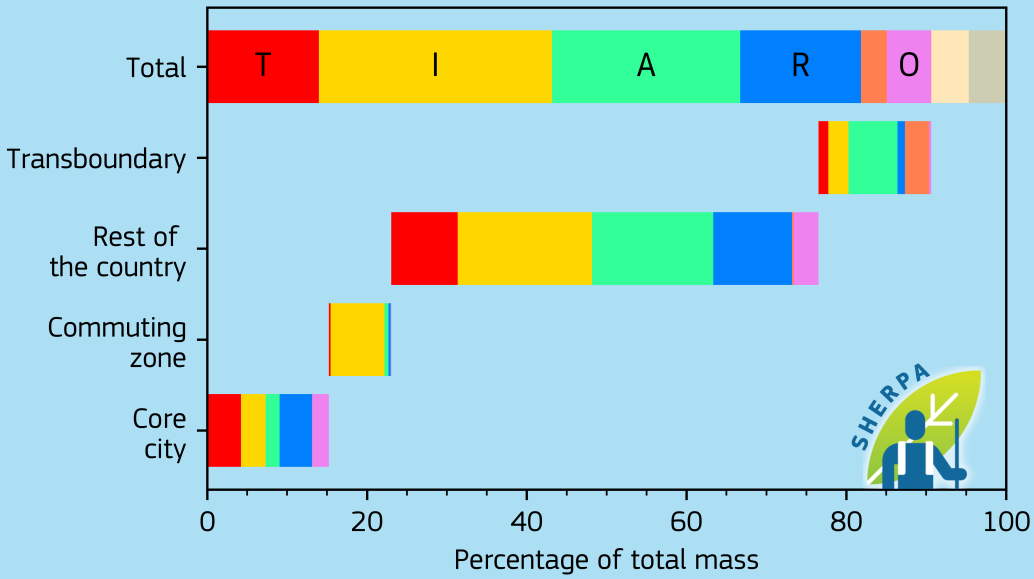
Yearly average urban concentrations (2018)



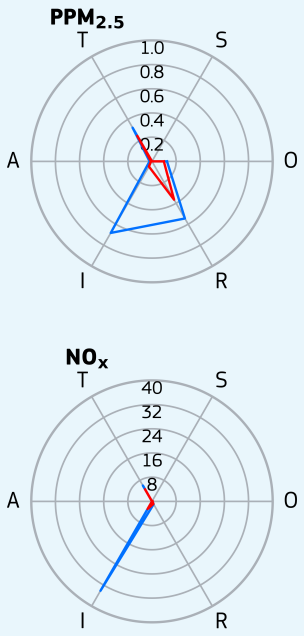
Histogram:
Number of stations
among the 150 cities

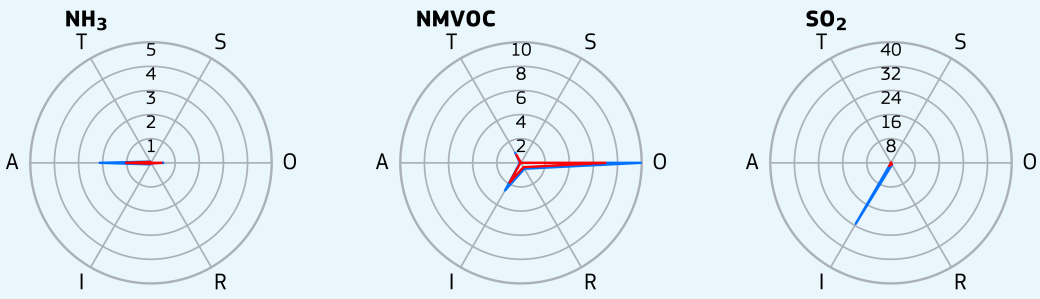
- Above EU LV
- Between WHO GL and EU LV
- Below WHO GL

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



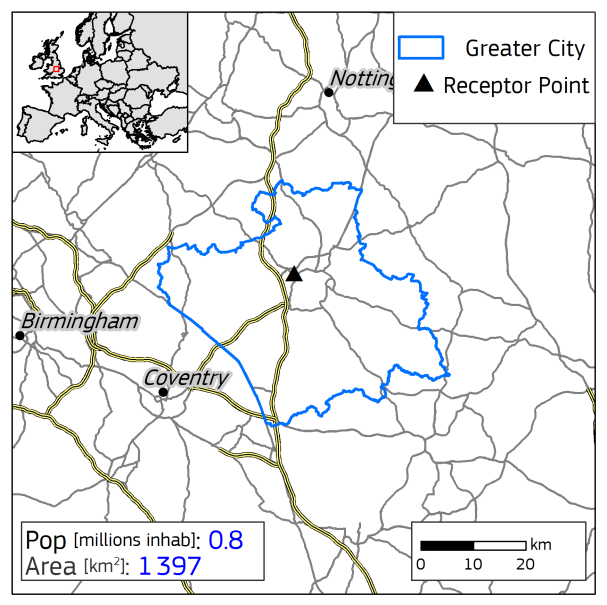
Emissions [kton/year]



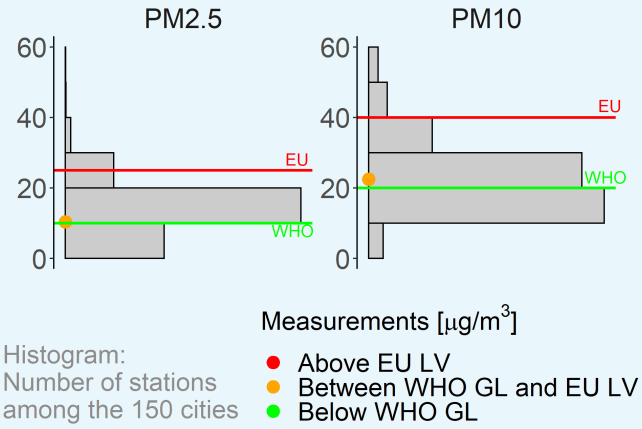


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

United Kingdom, Leicester

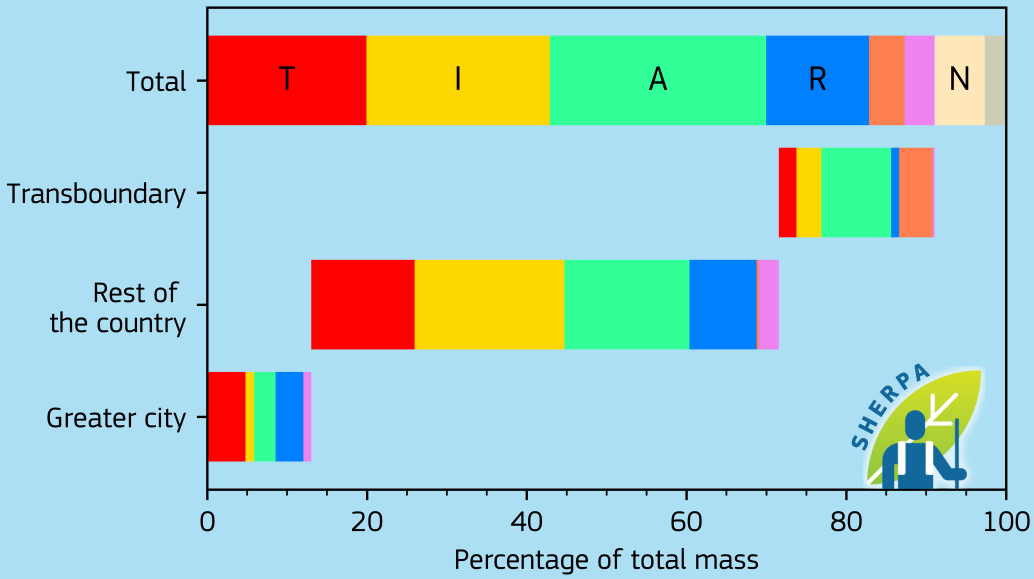


Yearly average urban concentrations (2018)

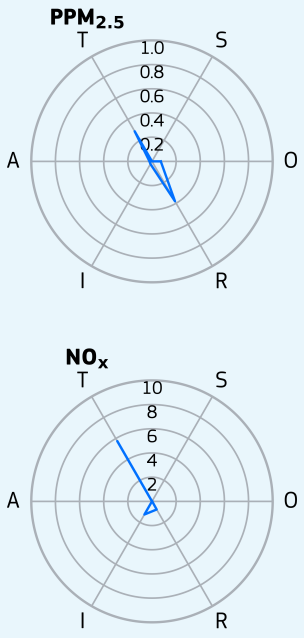


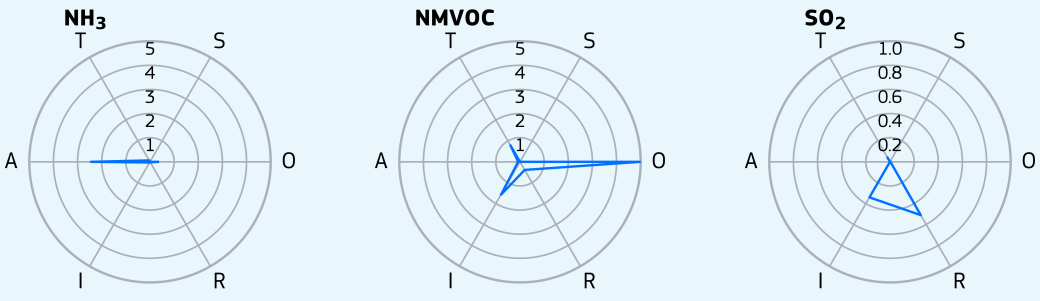
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



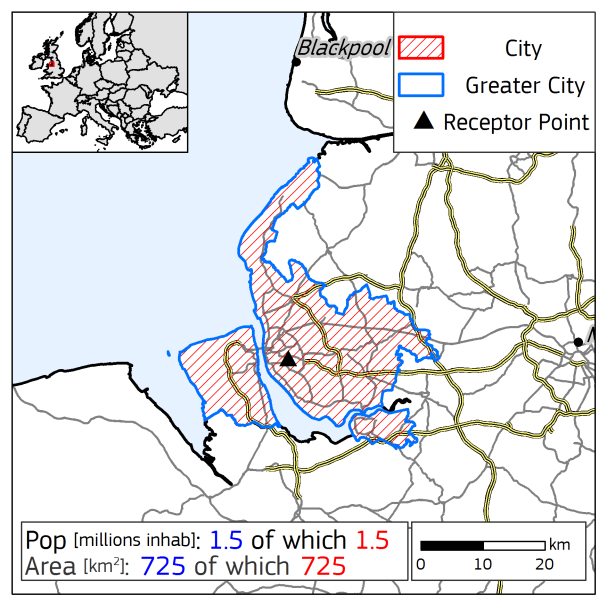
Emissions [kton/year]



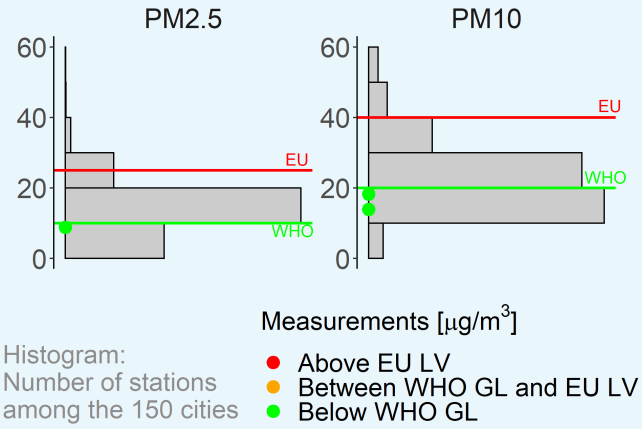


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city

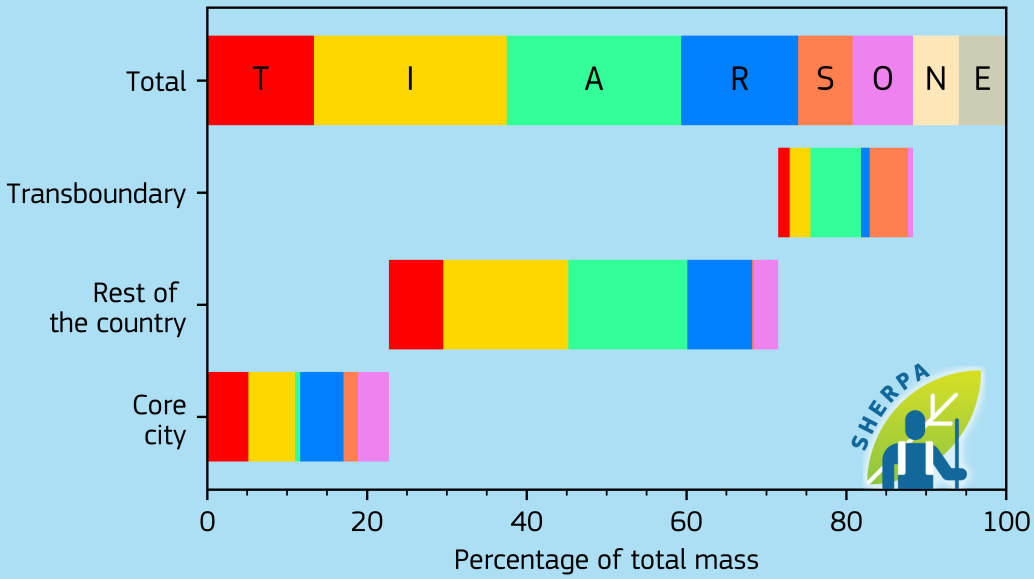
United Kingdom, Liverpool



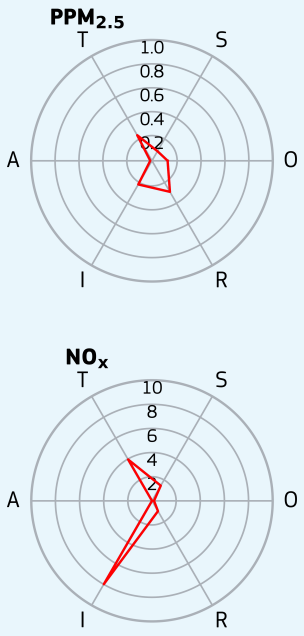
Yearly average urban concentrations (2018)

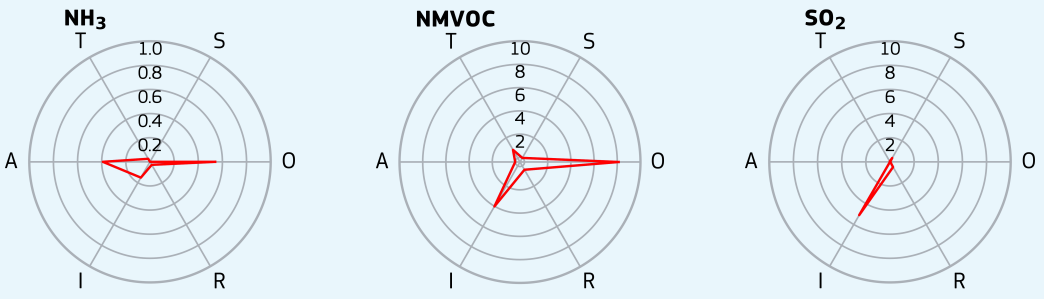


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



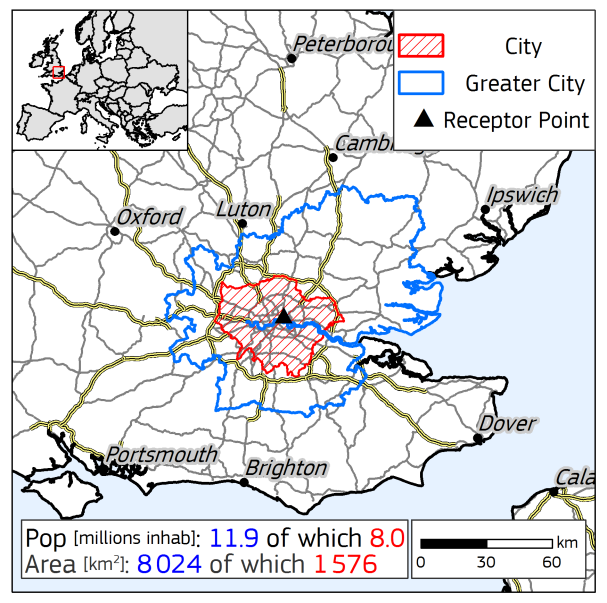
Emissions [kton/year]



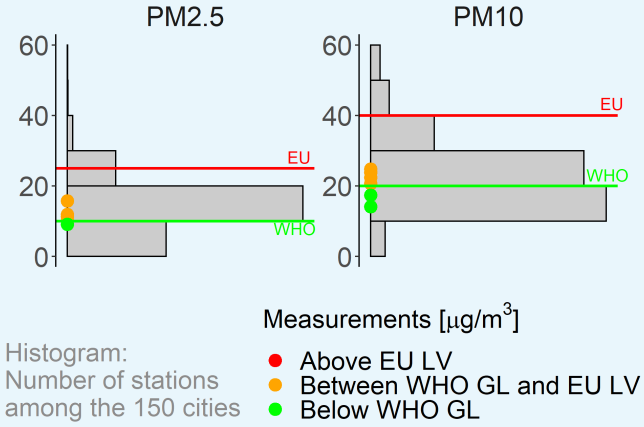


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

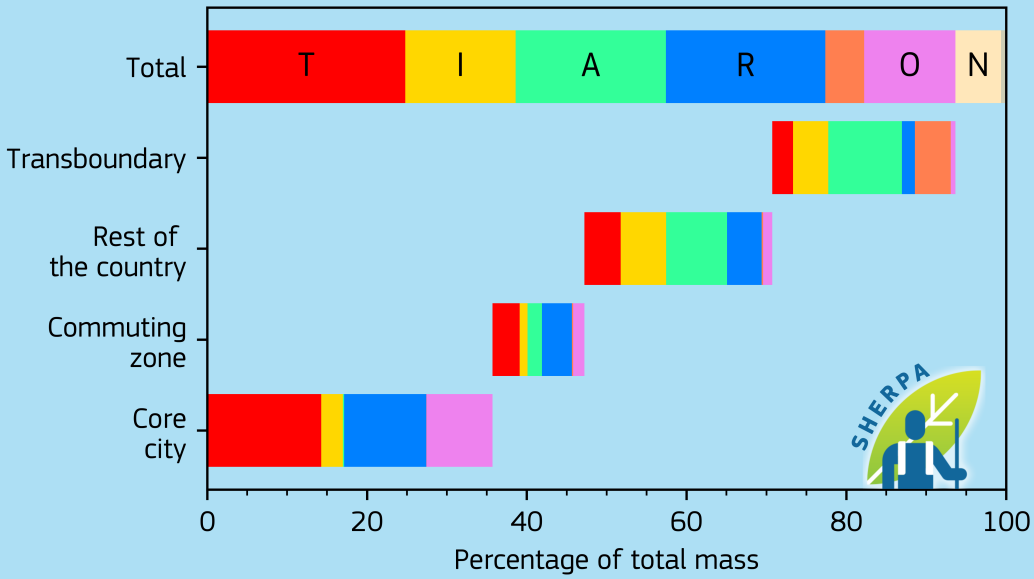
United Kingdom, London



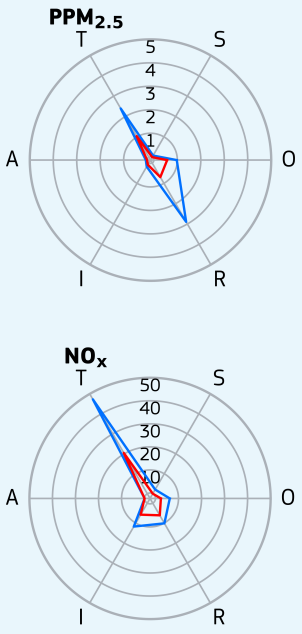
Yearly average urban concentrations (2018)

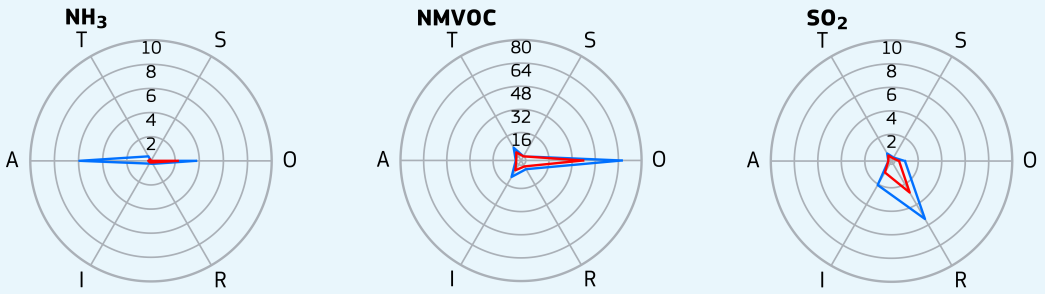


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



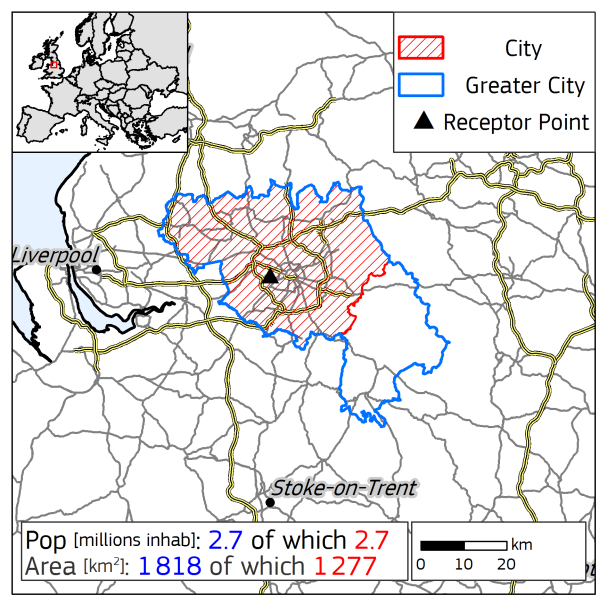
Emissions [kton/year]



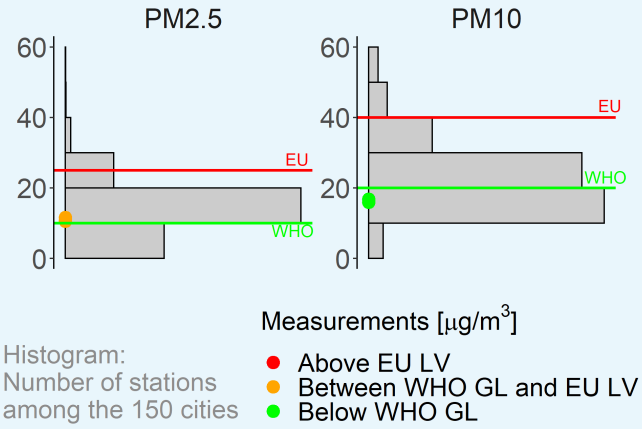


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

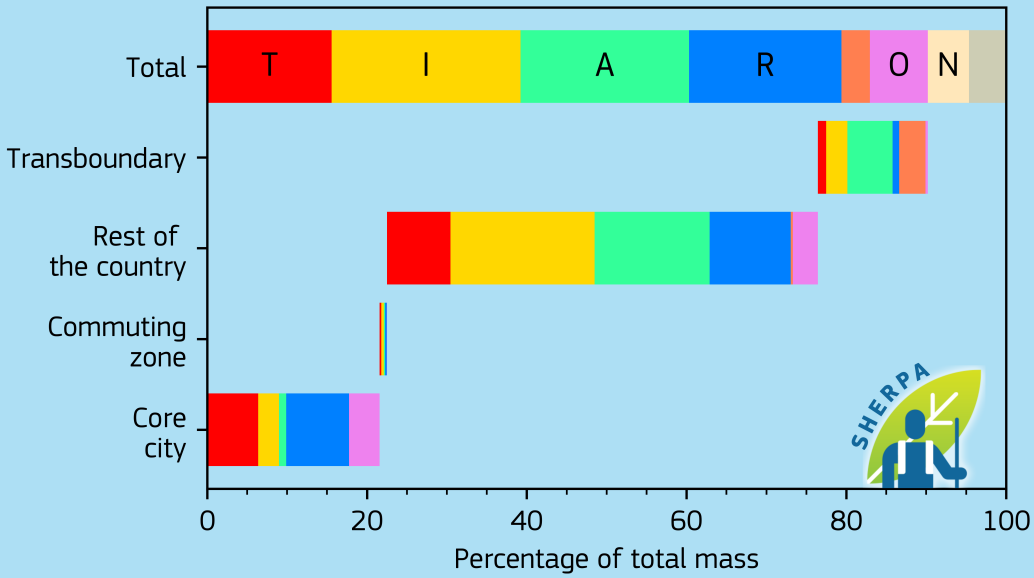
United Kingdom, Manchester



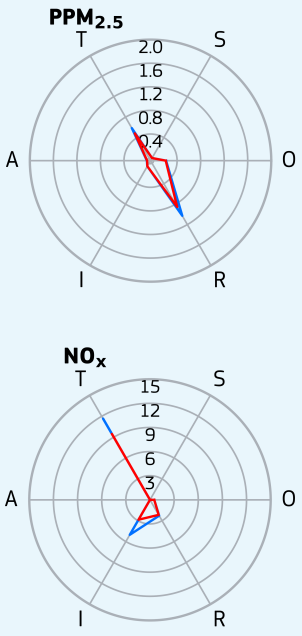
Yearly average urban concentrations (2018)

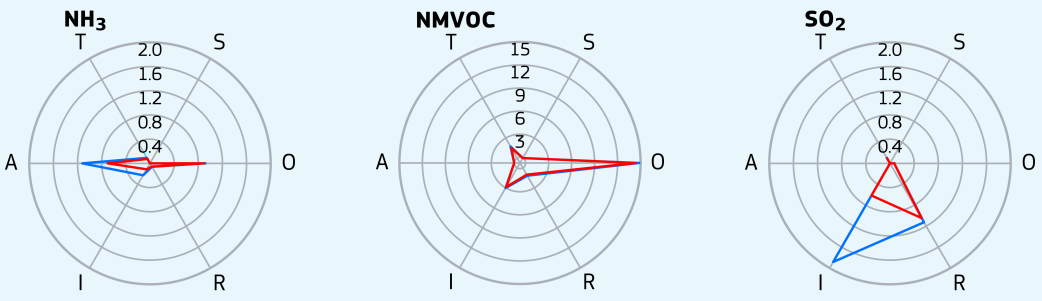


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



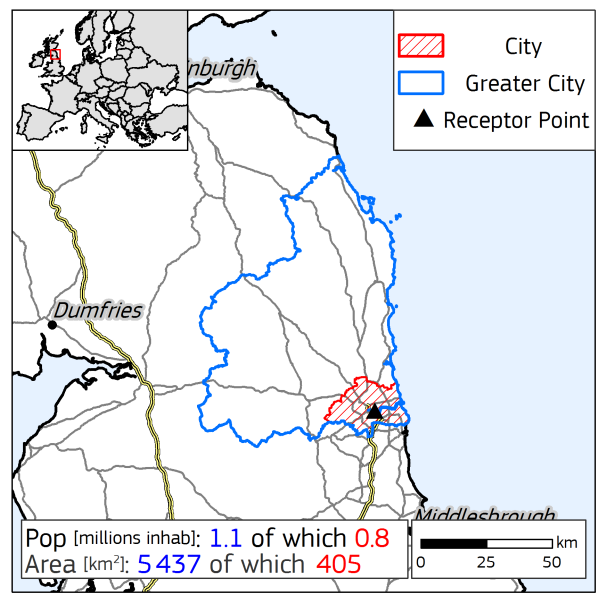
Emissions [kton/year]



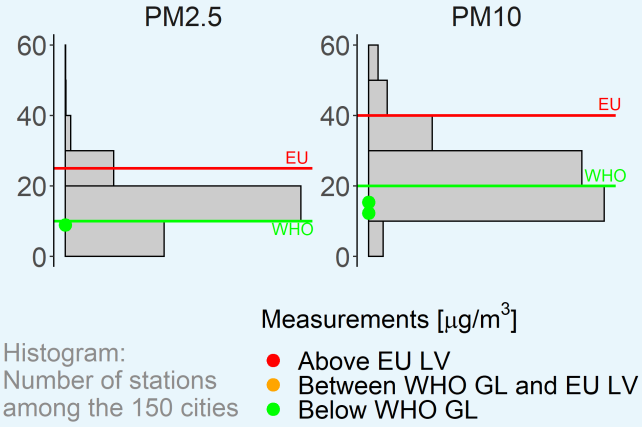


T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

United Kingdom, Newcastle upon Tyne

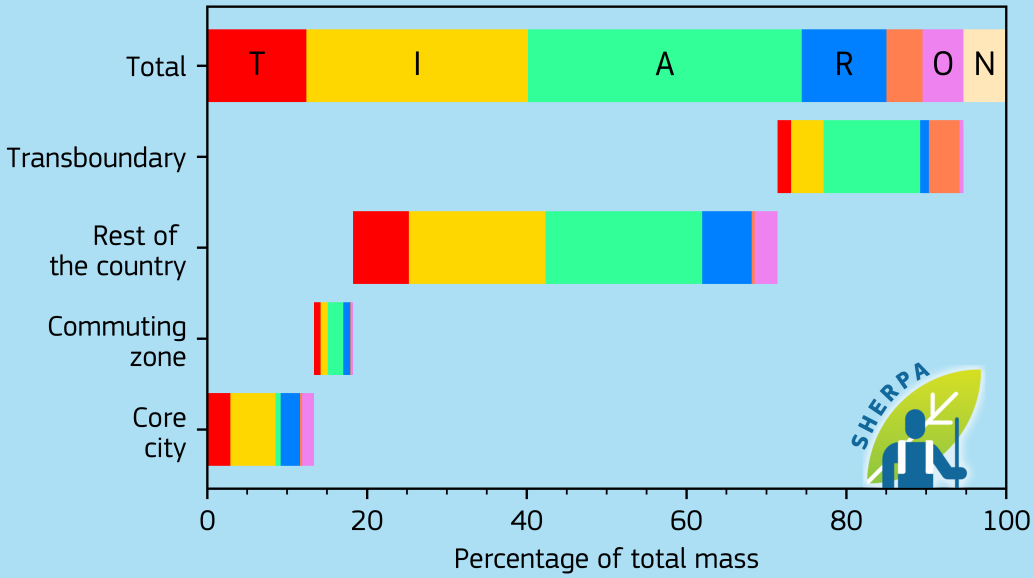


Yearly average urban concentrations (2018)

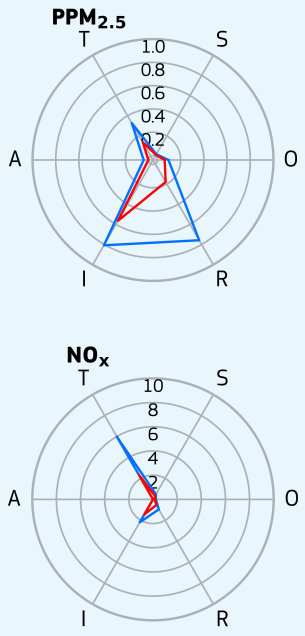


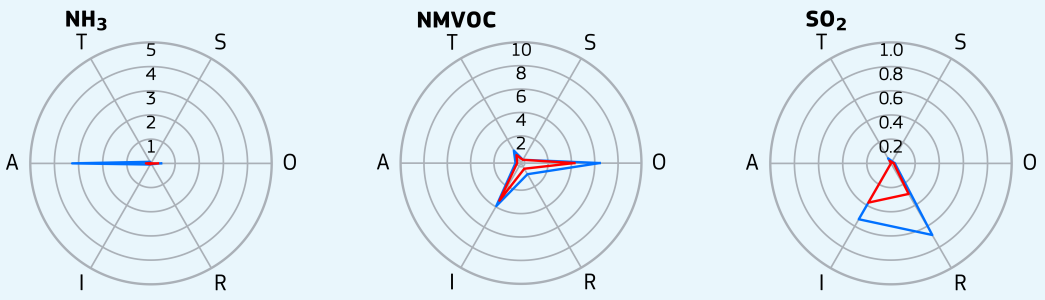
Histogram:
Number of stations
among the 150 cities

$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



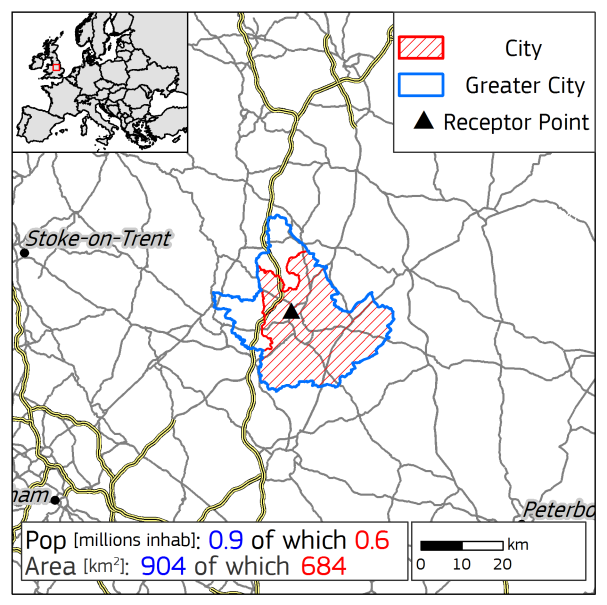
Emissions [kton/year]



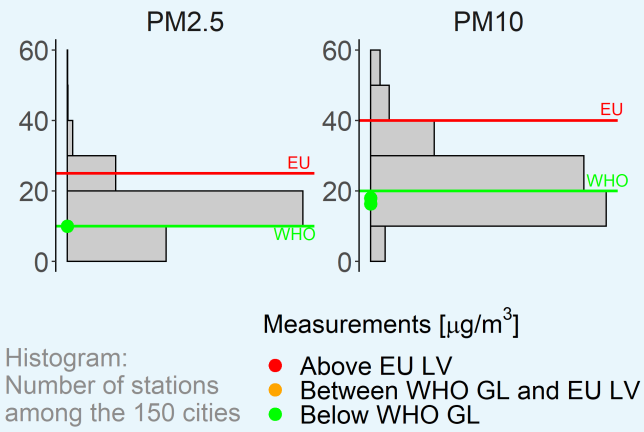


- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- Greater city
- Core city

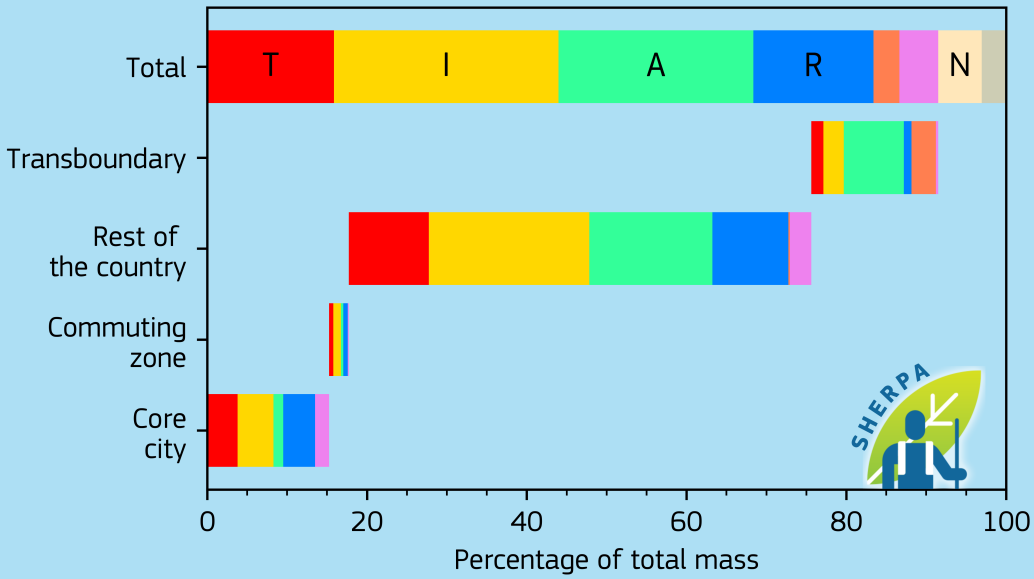
United Kingdom, Nottingham



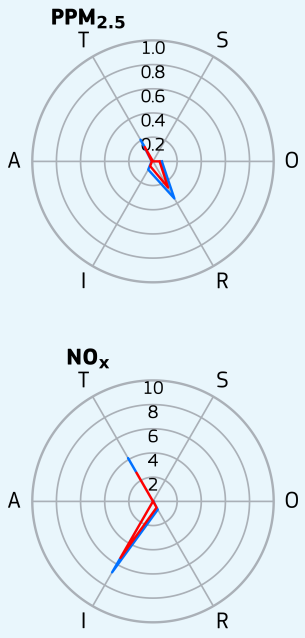
Yearly average urban concentrations (2018)

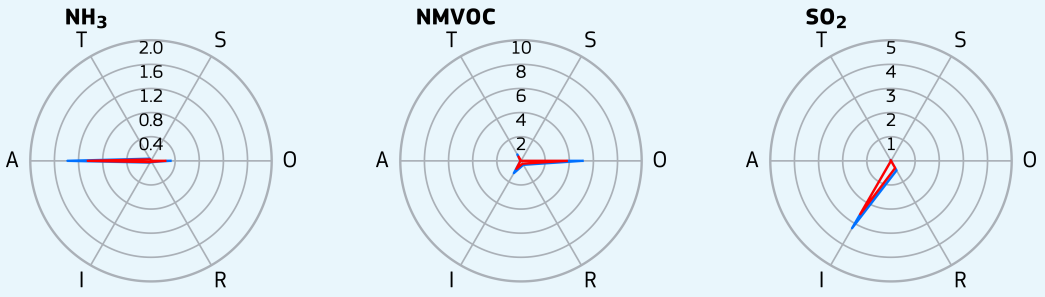


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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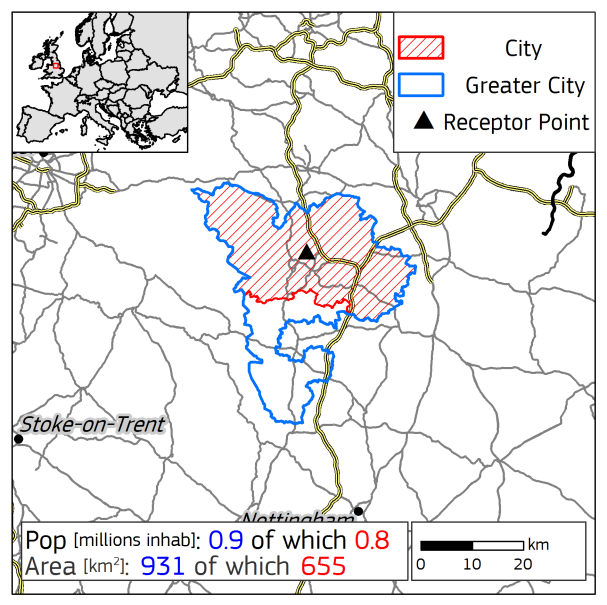
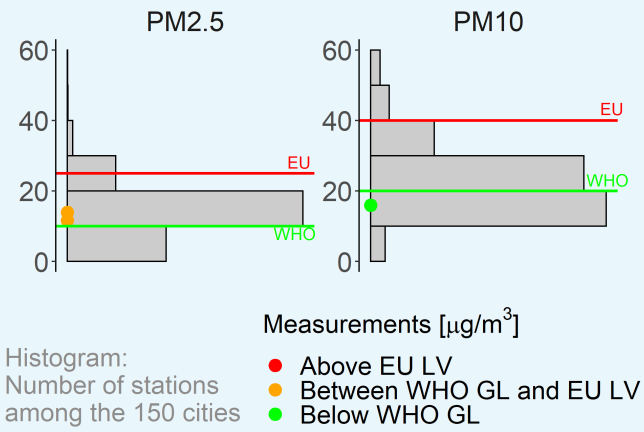
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External
- Greater city
- Core city

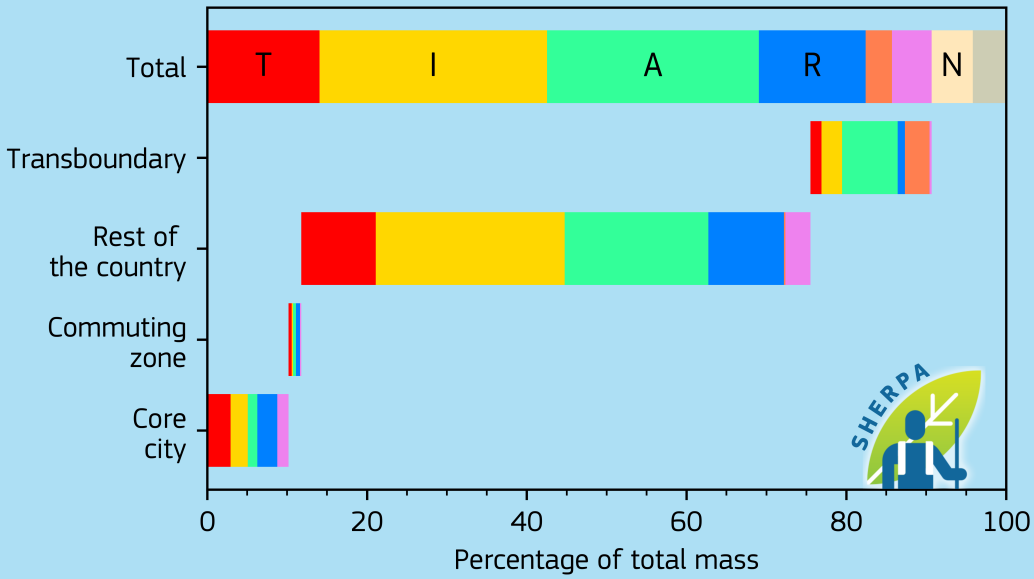
United Kingdom, Sheffield



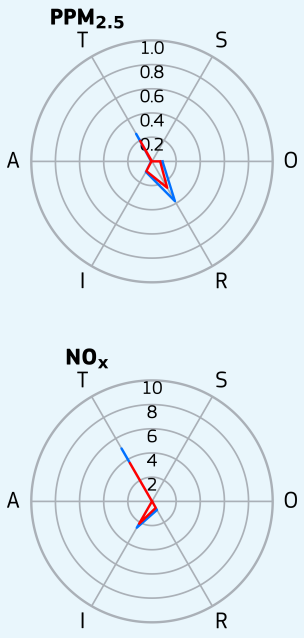
Yearly average urban concentrations (2018)

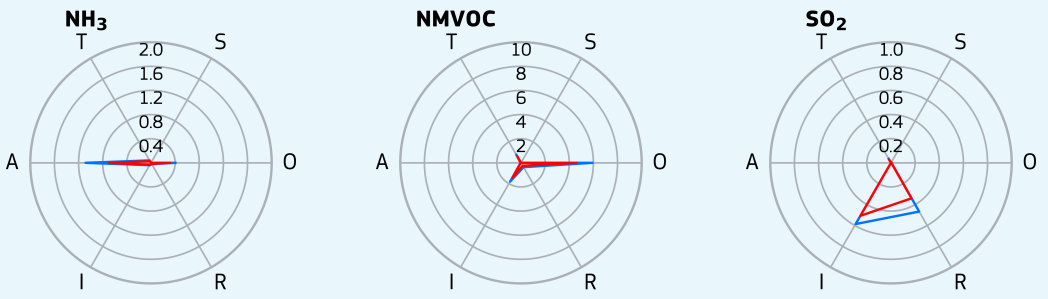


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





- T - Transport
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- S - Shipping
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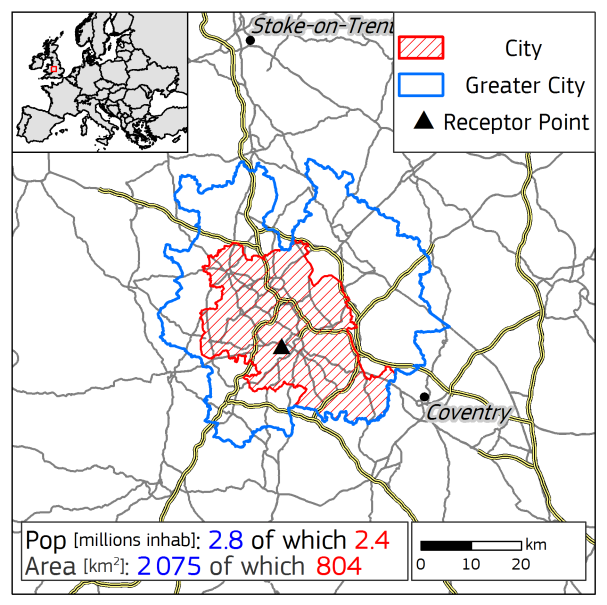
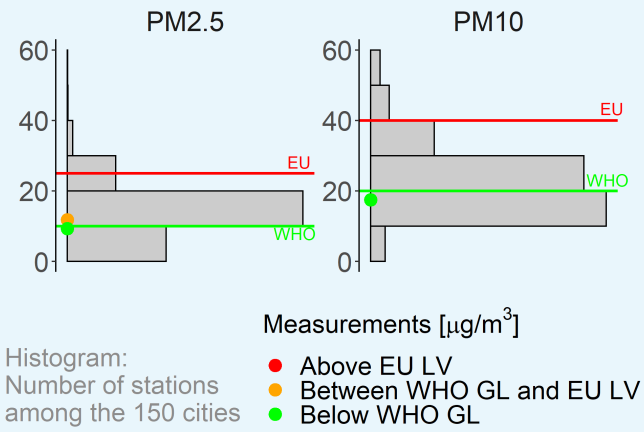
- E - External
- Greater city
- Core city

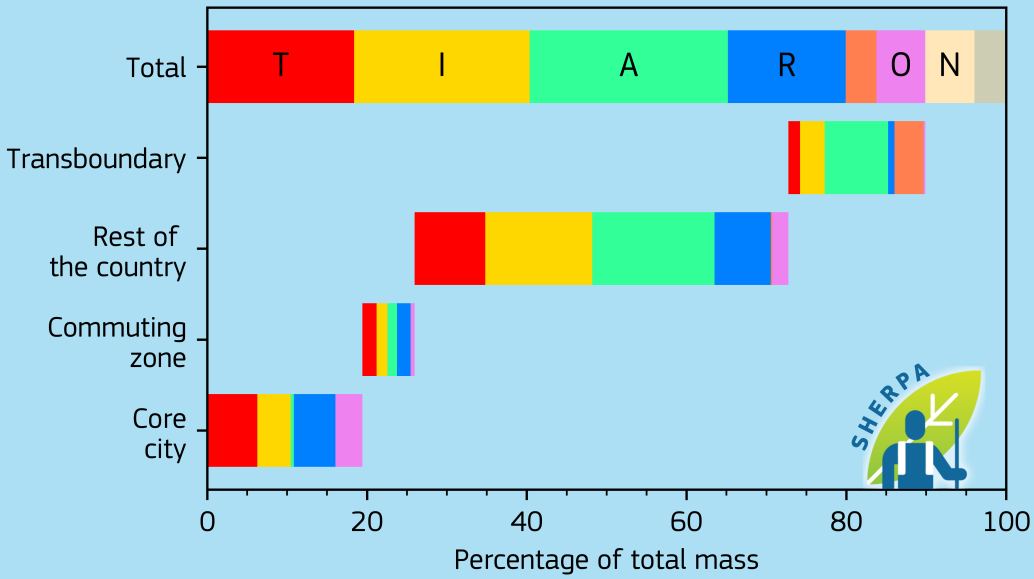
United Kingdom, West Midlands urban area



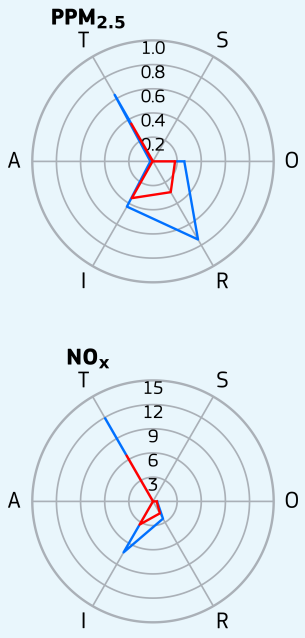
Yearly average urban concentrations (2018)

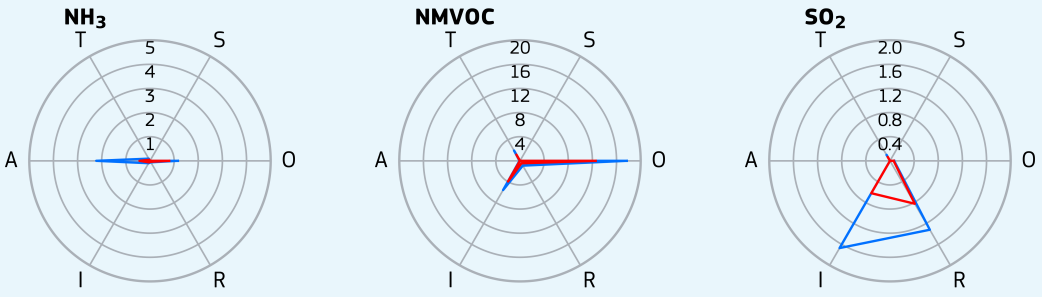


$PM_{2.5}$ Spatial and sectoral allocation (SHERPA v.2.2.0)



Emissions [kton/year]





T - Transport
I - Industry
A - Agriculture
R - Residential
S - Shipping
O - Other
N - Natural
E - External
Greater city
Core city

Annex 4: Cities index

Country	City	Page
Austria	Graz	35
Austria	Linz	36
Austria	Vienna	37
Belgium	Antwerp	38
Belgium	Brussels	39
Belgium	Liege	40
Bulgaria	Burgas	41
Bulgaria	Plovdiv	42
Bulgaria	Sofia	43
Bulgaria	Varna	44
Croatia	Zagreb	45
Cyprus	Limassol	46
Cyprus	Nicosia	47
Czech Republic	Brno	48
Czech Republic	Liberec	49
Czech Republic	Ostrava	50
Czech Republic	Pilsen	51
Czech Republic	Prague	52
Czech Republic	Ústí nad Labem	53
Denmark	Aarhus	54
Denmark	Copenhagen	55
Estonia	Tallinn	56
Finland	Helsinki	57
France	Angers	58
France	Bordeaux	59
France	Caen	60
France	Clermont-Ferrand	61
France	Grenoble	62
France	Lille	63
France	Lyon	64
France	Marseille	65
France	Metz	66
France	Montpellier	67
France	Mulhouse	68
France	Nancy	69
France	Nantes	70
France	Nice	71

Country	City	Page
France	Orleans	72
France	Paris	73
France	Rennes	74
France	Rouen	75
France	Strasbourg	76
France	Toulouse	77
France	Tours	78
Germany	Augsburg	79
Germany	Berlin	80
Germany	Bonn	81
Germany	Braunschweig-Salzgitter-Wolfsburg	82
Germany	Bremen	83
Germany	Cologne	84
Germany	Dresden	85
Germany	Düsseldorf	86
Germany	Frankfurt	87
Germany	Freiburg im Breisgau	88
Germany	Hamburg	89
Germany	Hannover	90
Germany	Heidelberg	91
Germany	Karlsruhe	92
Germany	Kiel	93
Germany	Leipzig	94
Germany	Mannheim-Ludwigshafen	95
Germany	Munich	96
Germany	Nuremberg	97
Germany	Ruhr Area	98
Germany	Saarbrücken	99
Germany	Stuttgart	100
Greece	Athens	101
Greece	Thessaloniki	102
Hungary	Budapest	103
Ireland	Dublin	104
Italy	Bari	105
Italy	Bologna	106
Italy	Brescia	107
Italy	Catania	108
Italy	Florence	109

Country	City	Page
Italy	Genoa	110
Italy	Milan	111
Italy	Modena	112
Italy	Naples	113
Italy	Padua	114
Italy	Palermo	115
Italy	Parma	116
Italy	Rome	117
Italy	Taranto	118
Italy	Turin	119
Italy	Venice	120
Italy	Verona	121
Latvia	Riga	122
Lithuania	Vilnius	123
Luxembourg	Luxembourg	124
Malta	Valletta	125
Netherlands	Amsterdam	126
Netherlands	Eindhoven	127
Netherlands	Rotterdam	128
Netherlands	The Hague	129
Netherlands	Utrecht	130
Norway	Oslo	131
Poland	Białystok	132
Poland	Bydgoszcz	133
Poland	Częstochowa	134
Poland	Gdańsk	135
Poland	Katowice	136
Poland	Kielce	137
Poland	Kraków	138
Poland	Lublin	139
Poland	Poznań	140
Poland	Rzeszów	141
Poland	Szczecin	142
Poland	Warsaw	143
Poland	Wrocław	144
Poland	Łódź	145
Portugal	Lisbon	146
Portugal	Porto	147

Country	City	Page
Romania	Bucharest	148
Romania	Iaşi	149
Slovakia	Bratislava	150
Slovakia	Košice	151
Slovenia	Ljubljana	152
Spain	Alicante	153
Spain	Barcelona	154
Spain	Bilbao	155
Spain	Gijón	156
Spain	Madrid	157
Spain	Malaga	158
Spain	Oviedo	159
Spain	Palma de Mallorca	160
Spain	Santander	161
Spain	Seville	162
Spain	Valencia	163
Spain	Zaragoza	164
Sweden	Gothenburg	165
Sweden	Malmö	166
Sweden	Stockholm	167
Switzerland	Geneva	168
Switzerland	Zürich	169
United Kingdom	Belfast	170
United Kingdom	Bristol	171
United Kingdom	Cardiff	172
United Kingdom	Edinburgh	173
United Kingdom	Glasgow	174
United Kingdom	Leeds	175
United Kingdom	Leicester	176
United Kingdom	Liverpool	177
United Kingdom	London	178
United Kingdom	Manchester	179
United Kingdom	Newcastle upon Tyne	180
United Kingdom	Nottingham	181
United Kingdom	Sheffield	182
United Kingdom	West Midlands urban area	183

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