Clean Air in Cities

Position paper from the Expert Panel on Clean Air in Cities (EPCAC) under the UNECE's Air Convention (CLRTAP) Task Force on Integrated Assessment Modelling (TFIAM)

November 27, 2024

Summary

Air pollution is the most harmful environmental risk factor to human health as cities are densely populated – the air pollution in cities is breathed by thousands or even millions of people. Cities are a unique opportunity to significantly improve public health. The major sources of air pollution in cities differ from city to city and from pollutant to pollutant. In most cities combustion from either residential heating or transport are the most relevant (local) sources of PM and NO_2. Many sources also lie outside of the city and demand effective collaboration at the regional, national and international level. At the national and international level, tackling industrial emissions and ammonia (as a precursor for secondary PM, as well as ozone precursors (NO_X, VOC, methane)) are important. The diversity of sources and types of pollutants means that no single government can effectively improve the air quality solely on its own. Another reason that cross-governmental collaboration is needed is that measures that reduce emissions in a wider region could result in more health gains than specific local measures or changing the spatial location of sources. The larger the region where measures are taken, the higher the health gains, since most population wide health benefits come from reduction of the average exposure in a region, not from spatially limited reduction at a certain hotspot.

Local information on sources of air pollution as well as air quality monitoring and modelling results are helpful means to assess which sectors are most important for each city. A wide range of policies exist to improve the air quality in cities. The most effective combination of policies depends on the local context and sources, but in all cases collaboration across governments is essential. All governance levels must work together to ensure that all requisite measures can effectively be implemented, independent from the pollutant and the spatial scale on which the respective action is put in practice. In this paper we gave examples of how these levels of air quality management interact. National Air Pollution Control Programs (NAPCP), among other, could serve as a potential instrument in this.

In addition to coherence between different levels of government, the same is needed across different policies, notably between climate action, transport and air quality policy, when taking action to save the climate, to make our cities a livable place through sustainable mobility planning and to improve the air quality and ultimately public health. The suite of policies to improve air quality policies often provide many benefits to other environmental issues, and vice versa. For example, the on-shore power (electrical charging for moored boats) reduces air pollution but also the emissions of greenhouse gases. Likewise, modal shift of commuters from cars to public transport reduces not only greenhouse gas emissions but also PM and NO_2 emissions, and is often beneficial for spatial planning and noise pollution in cities. However, in some cases policies can work against each other, such as when a shift from natural gas to a 'sustainable' fuel such as biomass leads to more air pollution. It remains important for policymakers to seek out the co-benefits and be alert for policies that work against air pollution.

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1) Introduction: Air quality is still a problem, especially in cities

The Expert Panel on Clean Air in Cities (EPCAC) was established at the 38th Executive Body of the Air Convention, December 2018. The mission of the EPCAC is to analyse and communicate the potential benefits of multi-scale air quality management and find an optimal mix of local, national and international policy actions. EPCAC should also raise awareness among national and local policy makers of the multi-scale interactions.

The key questions to be addressed by EPCAC:

- Which actions at which government level are most effective to reduce the negative health impact of air pollution (expressed as loss of life years)?
- Can we say more about the cost-effectiveness of measures at different government levels?
- What knowledge should be improved for robust policy advice (e.g. on emission data, dispersion modelling, health impact assessment, costs and effects of measures, multi-scale multi-objective policy design)?

This position paper is meant as an introduction into the subject and to explore possibilities for further guidance documents and research. It is based on an EPCAC meeting in Bratislava (in 2019) and online meetings (in 2020, 2021 and 2022). The paper is written by a core team of experts, discussed at an EPCAC meeting in September 2024, and reviewed and improved following written feedback from the EPCAC community in October/November 2024.

Before we dive further into the body of this position paper, a definition issue needs to be addressed. In this paper, we both use the terms 'city' and 'urban' to describe areas of settlement with a high population density and supporting infrastructure. We recognize that how urban areas and cities function and what they look like varies between different regions of the UNECE. Measures can therefore also differ in, for example, costs and effectiveness.

Effects of air pollution on human health

Air pollution is harmful to human health and the environment. Human activities cause air pollution with particles, gases, heavy metals and persistent organic pollutants, such as polycyclic aromatic hydrocarbons. There is strong scientific evidence for the negative impacts of air pollutants such as particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3) to both human health and to the environment. This position paper focuses on these pollutants, while acknowledging that there is growing evidence on health and environmental effects, for example for ultrafine particles or the substance group of per- and polyfluoroalkyl substances (PFAS). Despite great progress in recent decades and successes in air quality management policy, current air pollution levels remain the largest environmental threat to public health globally. Exposure to air pollution can lead to many health problems including respiratory and cardiovascular diseases, as well as cancer (Figure 1). Latest estimates suggest that several hundred thousand premature deaths are attributable to air pollution in the European region (see EEA, 2022 or WHO, 2024). The effects of air pollution on human health and environmental quality also place a burden on the healthcare system and the broader economy.

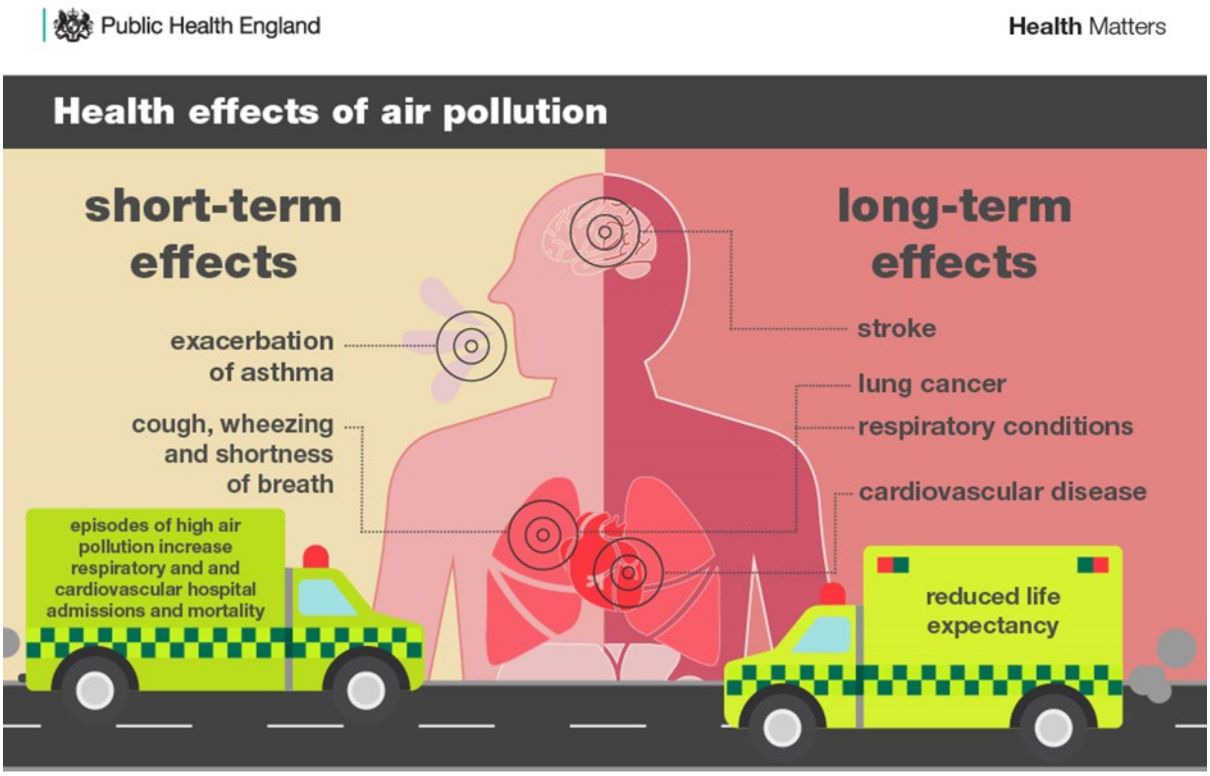

Figure 1: Health effects of air pollution (Public Health England, https://www.gov.uk/government/publications/health-matters-air-pollution/health-matters-air-pollution, accessed 21-08-2024)

The most common and evident metrics for assessing health burden of air pollution are mass concentrations of fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2) and ground-level ozone (O_3). This paper focuses primarily on air pollution over the longer term (years) as opposed to day-to-day variations. This is because: (i) long-term concentrations (e.g. annual averages) are better correlated with the effects on human health, and (ii) short-term policies to improve the air quality, i.e. within hours or a few days, are limited in scale and effectiveness. Chapter 4 further explores the difference between the different (time) scales of policies.

The WHO has set air quality guidelines for the mass concentrations of harmful air pollutants. These guidelines are not legally binding, and each country in the UNECE sets its own air quality standards. While most countries have not adopted the recent WHO guidelines as their own air quality limit values, most regard them as rigorous evidence-based guidelines. For instance, the revised EU air quality limit values do not yet align with the WHO air quality guidelines. However, an average exposure reduction obligation has been set to meet the WHO guidelines for NO_2 and $PM_{2.5}$, at least in urban background, in the long-term. Furthermore, the EU is aiming to meet the WHO air quality guidelines in 2050 as part of its broader Zero Pollution Action Plan.

Co-benefits with other policy fields

In many cases, policies to reduce greenhouse gas emissions also improve air quality. Policies that lead to electrification of industrial processes, transportation and other sectors shift away from combustion and lead to a reduction of both CO_2 and air pollutants such as NO_2 and $PM_{2.5}$, if the power generation shifts to renewables in parallel. This is also the case with policies that encourage modal shift of transportation away from roads and towards more energy-efficient modes such as public transport, walking, cycling, etc. (see chapter 4 for more examples). However, in some cases climate mitigation policies can be a risk to air quality, such as when biomass is substituted for coal or natural gas in combustion processes. This can lead to higher emissions of particulate matter, and even of black carbon, which ironically is a climate driver at the same time.

Multi-level governance is needed

Air pollution does not respect borders. Therefore, efforts to address air pollution have to be multi-level and transboundary. Not in the least since the rural population also benefits from multi-level air quality management, as the rural population is also affected by pollution from the urban areas (e. g. Thunis, et al. 2021). Policies at the local or regional level can require legislation or coordination at the national or supranational level. The national levels of air pollution are in turn made up of the regional contributions. This position paper further addresses the need for multi-level governance, that accounts for each pollutant specificities, to tackle air pollution. In the next chapter, we describe why it is important to address air quality at the city level. The third chapter describes sources of air pollution impacting cities. In chapter four we will look at the measures that can be taken on city, national, regional and supranational level and how these are linked.

2) The air quality situation in cities

A city can be defined as a densely populated settlement with numerous functions, such as housing, transportation, production of goods, sanitation, communication and many others. In short, a place where many people live, work, recover and breathe. Air quality in cities is a key issue for human health. Harmful air pollutants are emitted in cities and get transported to and from cities.

Air quality standards such as limit values are established and regularly revised in order to minimise the health burden of air pollution. Air quality standards are the result of political negotiations, where trade-offs are made between public health and other common objectives, such as economic ones. Air quality management in cities is therefore always a compromise between reducing the average exposure of the city's population to air pollution while still facilitating the activities of people and businesses that make up a city.

Air quality management has already achieved significant reductions in urban air pollution. Some examples are flue gas cleaning in industrial plants and plants for power generation, particulate filters in diesel vehicles and the expansion of renewable energy. Examples of positive actions in cities are given in WEF (2024). However, current concentrations are still above the values recommended by the WHO (Figure 2). For example, in the year 2021, 97 % of the urban population in EU member states was exposed to concentrations of particulate matter ($PM_{2.5}$) above the recent WHO air quality guidelines. For nitrogen dioxide (NO_2) and ozone (O_3) this was 90 % and 94 %, respectively (EEA, 2024). Especially regarding $PM_{2.5}$, this challenge is particularly large in countries that still rely on burning fossil fuels for residential heating.

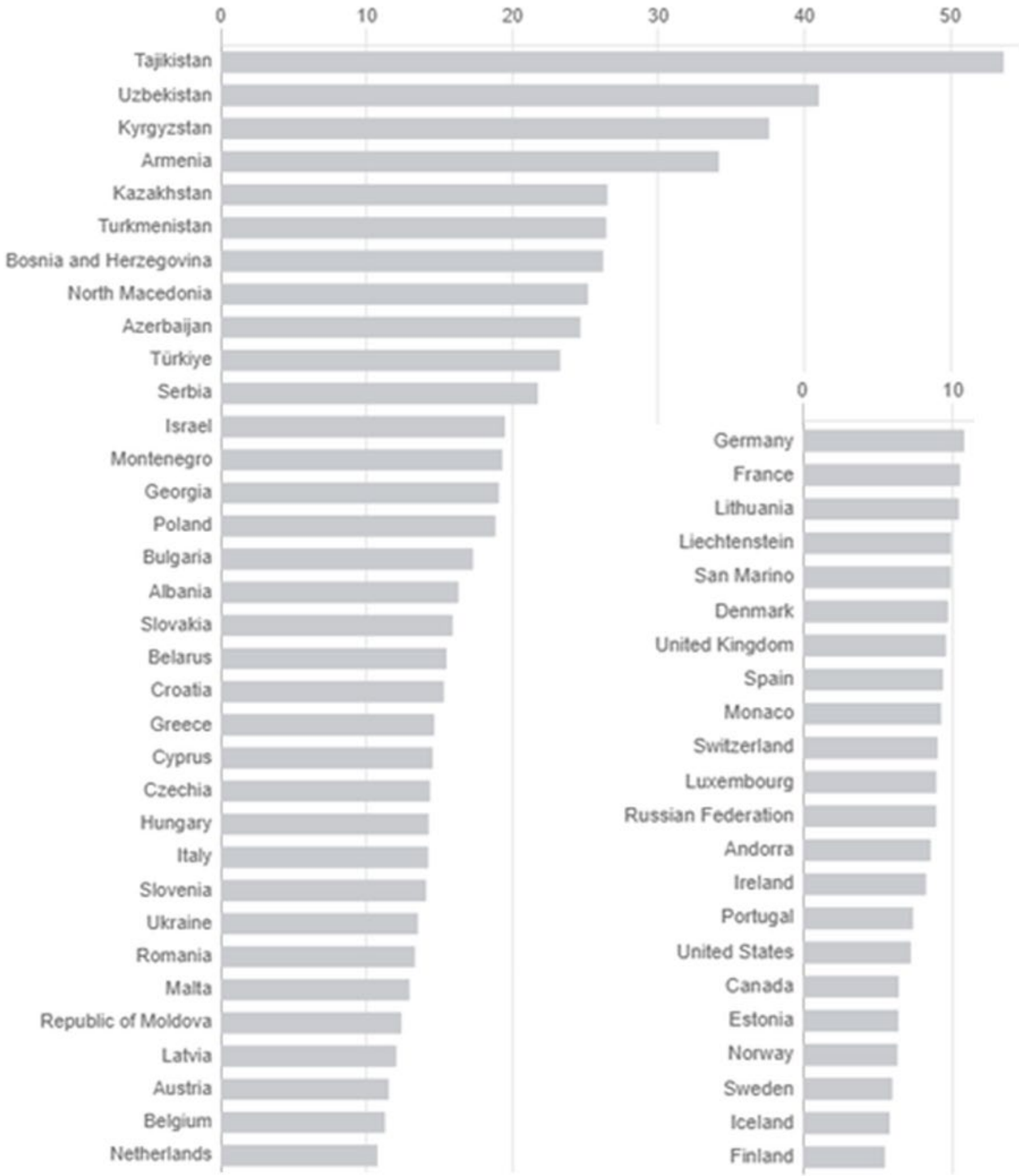

Figure 2: Measured annual mean levels of $PM_{2.5}$ (population weighted) in µg/m³ for the UNECE region in 2019 (UNECE, 2024)

There are large differences between cities, with large conglomerations of closely connected cities (e.g. Paris region, Po basin in northern Italy), cities in large industrial areas (e.g. Ruhr area in Germany, Upper Silesian region in Poland, southern Bulgaria), and cities surrounded mostly by agricultural land (e.g. Netherlands) or mountains (e.g. Balkans). However, there are a few key points that are crucial for managing air quality in cities, regardless of the specific source contribution:

- The contribution of cities to their own air pollution is dominating for NO_2, often significant for PM, depending on city specifics, and generally low for O_3.

- At the same time, a significant part of urban air pollution comes from sources outside the city itself. This is especially the case for precursor emissions for secondary inorganic aerosols (SIA) and ozone.
- Cities emit relevant quantities of air pollutants, in particular of primary $PM_{2.5}$ and precursors of secondary PM like NO_X, that can then be transported over long distances away from the city and influence other cities as well as rural areas, where it is in turn considered part of the background pollution.
- Local measures are essential to improve air quality in order to meet the air quality standards for NO_2 and also $PM_{2.5}$, when the local contribution is highly significant. However, achieving the WHO air quality guideline values for NO_2, $PM_{2.5}$ and ozone, collaboration at the international, national, regional and city levels is necessary. Multi-level action is key to find the most efficient and cost-effective solutions.
- Public health benefits more from the reduction of (average) population exposure than from reducing the number of exceedances of local limit values. Highly local measures, such as reducing the number of traffic lanes for a few hundred meters or restricting vehicle categories for one specific street might solve an NO_2 exceedance locally, but will not reduce the average exposure in the city significantly.
- There are many measures that offer win-win solutions to objectives in other policy areas, such as the energy transition, healthy diet or transport transition in combination with urban planning to reduce overall 'fossil' mileage. It may be even easier to begin by removing pre-existing lose-lose policies such as tax breaks for diesel fuel.

For improving health, reducing the average exposure to air pollution in cities is key and multi-level approaches to improve air quality inside and outside the cities are needed and have already been demonstrated. For example, the EU emissions standards for vehicles in combination with local low emission zones, to accelerate the entry of vehicles compliant with the new standards into the local fleet, reduced PM as well as NO_2 significantly. Or the EU Ecodesign framework in combination with national regulations, which stipulates an end date for the operation of old installations, reduced PM concentrations or at least stop emissions from further increasing due to increased number and use of solid fuel boilers. Further, the multi-level Clean Air Agreement in the Netherlands, that contains measures for different levels of government on different topics. This collaboration not only strengthens the effectiveness of measures, but also encourages exchanging knowledge and experience between the parties of the agreement. However, sometimes the benefit of measures is partially or fully compensated, or even overcompensated, by an activity increase or substitution by another activity, such as increasing overall vehicle mileage, power consumption or energy demand for heating and cooling. In the coming years, decarbonisation will be one of the key issues and sectors need to come together to leave silo-thinking behind and find comprehensive bundles of measures.

3) Sources of air pollution impacting cities

The contribution of different sectors and regions to the concentration levels in cities differ among cities. Source apportionment (SA) is the first step in designing a cost-effective multi-scale air quality strategy. As two examples for Europe-wide estimates derived from model calculations, the JRC-urban $PM_{2.5}$-atlas and calculations by EMEP/GAINS on the contributions of emission sources in urban environment show the relative importance of local, regional and transboundary sources to urban air quality. The dominant source sectors identified by these two assessments are shown in Figure 3 for the JRC atlas and in Figure 4 from the GAINS calculations. While both assessments agree on the dominance of residential combustion in many Central and Eastern European countries, GAINS sees transport sources dominant in Western Europe, while the JRC atlas ranks agricultural contributions first in the BeNeLux (Belgium, Netherlands and Luxembourg) and residential sources in Western Europe. Differences are likely due to a combination of factors like the model setup (SHERPA vs GAINS), the emission inventory, the emission year, and the year for which the atmospheric calculations were developed. Since the maps show only the most important sector, it is not straightforward to tell how different results really are. A breakdown of the GAINS results for sector contributions to country averages of cities is shown in Figure 5.

The importance of a sectoral or spatial source contribution depends on how the indicator is calculated at the receptor location. While the focus is often to perform source apportionment at a specific hot-spot, it can also be performed in population weighted terms over an entire city area. Analysis shows that source apportionment based on population exposure tends on average (over all cities) to lower the local urban contribution by around 15 % (based on the JRC Urban $PM_{2.5}$ Atlas, Thunis et al., 2023). While differences are significant between the two indicators when assessing the spatial shares of sources, assessing the sectoral share leads to more similar results. There are however exceptions when pollution sources have a very local character, like harbours or large point sources (e.g. waste incineration, large industrial areas), where differences can be important.

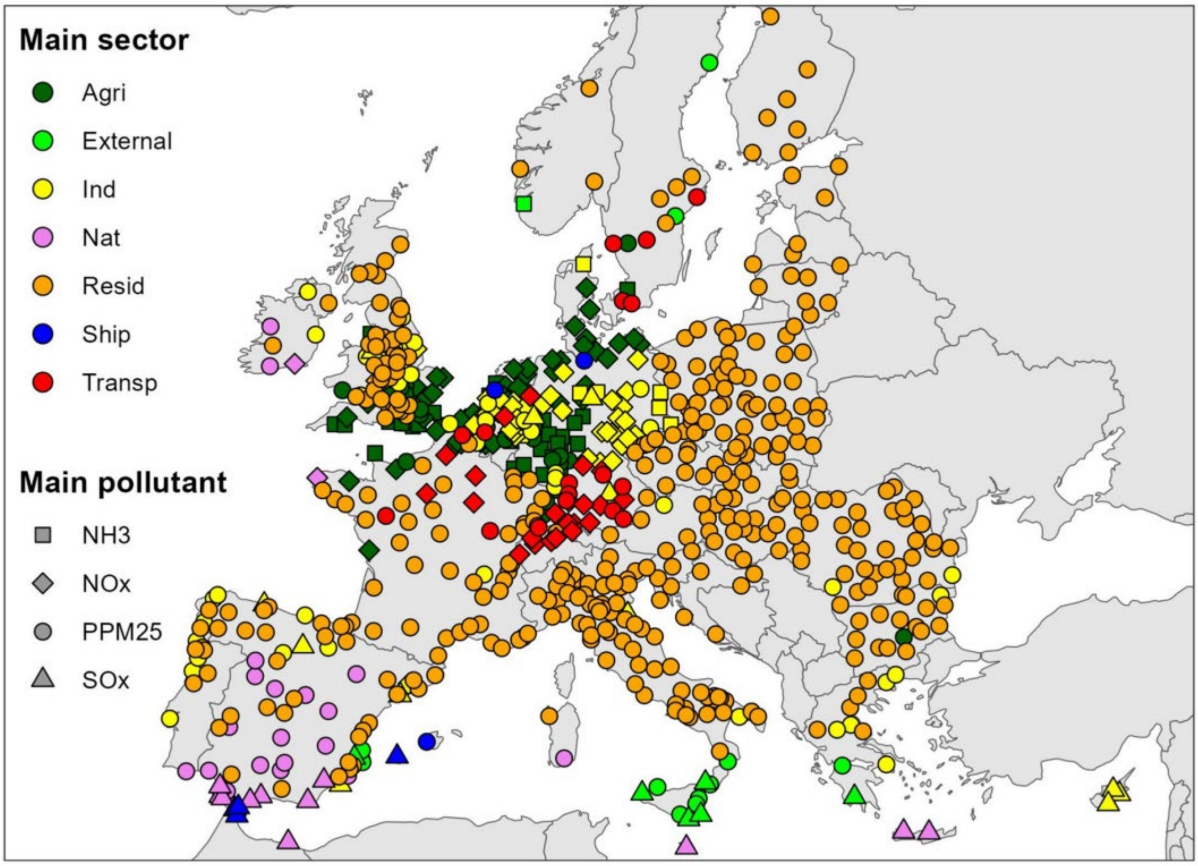

Figure 3: Main emission sector and precursor in each city in 2019. Sectors are expressed by colour, and precursors by shape, showing how they are contributing to $PM_{2.5}$ concentrations in each city ($PPM_{2.5}$ means primary $PM_{2.5}$) from Zauli-Sajani et al. (2024). Note that the main sector and main precursor are estimated independently from each other.

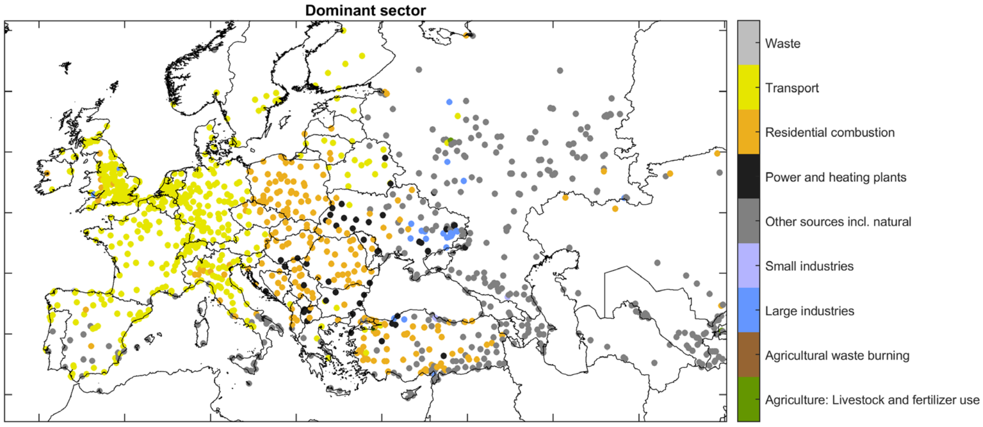

Figure 4. Main emission sector contributing to ambient $PM_{2.5}$ in cities in the UNECE area, as estimated with the GAINS model.

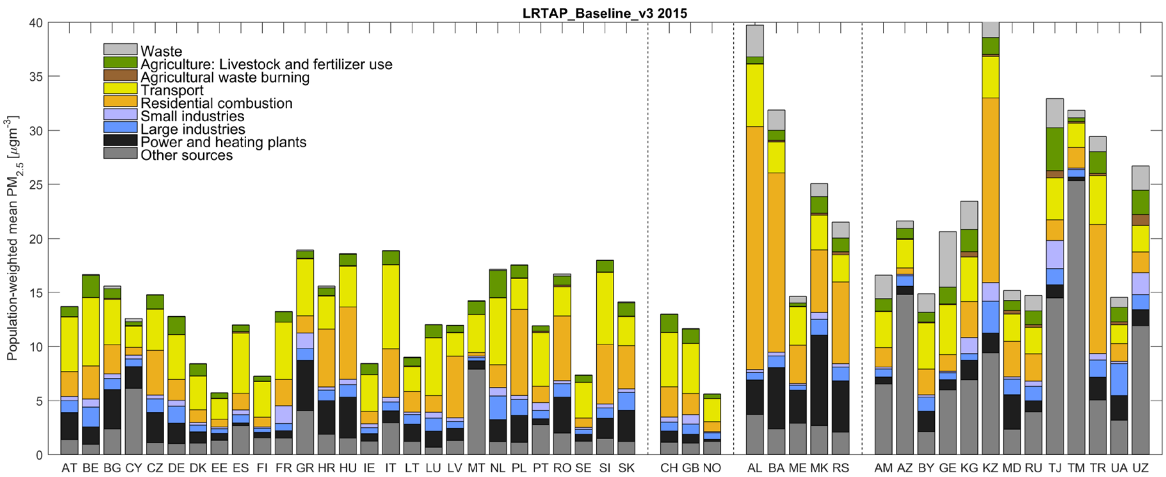

Figure 5. Sector source contributions to cities in UNECE countries (population-weighted average of all cities > 50,000 inhabitants within each country). Source: CIAM/IIASA, GAINS model calculations for the Gothenburg Protocol Revision, described in TFIAM Policy Brief.

A) Fine particulate matter (PM)

- <u>Local sources</u>

Emission sources at low altitude (near-ground) contribute significantly to peaks in local air pollution while emissions from high-stack industrial sources, even within cities, are emitted at higher altitude and are dispersed more widely. In locations with stable inversion layers in winter and/or mountainous terrain which limits air exchange, the importance of local sources is strongly increased compared to windy flatter areas. Sources that are important at the local scale include:

  - Residential combustion with solid fuels leads to large quantities of primary $PM_{2.5}$ along with condensables and to some extent NO_X, especially in central and eastern European countries (EE, LT, LI, PL, RO, BG, CZ, SK, HR, HU), the West Balkans, and some EECCA (Organisation for Economic Co-operation and Development, Eastern Europe, Caucasus and Central Asia) countries. In cities without district heating network, this can be a dominant source for local $PM_{2.5}$ concentrations.

- Road transport is an important source of emissions from combustion (e.g. NO_X and $PM_{2.5}$ from diesel engines) and of non-exhaust emissions (PM from brake and tyre wear and road abrasion), especially in many of the larger cities like Paris, London, Stockholm, Madrid, etc.
- Construction activities can contribute significantly to the urban population's exposure to PM. Despite their fairly local and time-limited impact, which is often not represented by the measured annual means, construction emissions are a ubiquitous urban source. Combustion emissions from construction machines appear in the ultra-fine and $PM_{2.5}$ fraction in terms of toxic, ultra-fine Diesel particle emissions since the majority of such machinery still lacks a Diesel particle filter. On the other hand, rather coarse particles are generated during the demolition of buildings and through re-suspension of deposited construction waste and mostly contribute to PM_{10}.
- Municipal waste burning can be an important source locally in cities where the collection system is not functioning well or where landfills are not well managed. In the UNECE region, this is relevant in some non-EU countries.
- In some cities with large industrial facilities in the city, e.g. in the Netherlands, Portugal, Germany or Belgium, industry can also make a significant contribution to urban background levels.
- The same holds for emissions from ports (shipping and port activities) in cities like Rotterdam, Malaga, Valletta, Genova or Hamburg.

- <u>National and regional sources</u>

Potentially important national and regional sources of primary PM and NO_X[1] are large industrial plants, highways, airports, national shipping and agriculture (both intensive livestock farming and greenhouse-agriculture). Although these sources of emissions are distant from the city environment, they significantly impact ambient air quality in cities and contribute to the urban background concentrations. National and regional authorities therefore have an important role in achieving clean air in cities. Combustion of solid fuels for heating often takes place outside cities, with exceptions in countries in e.g. Eastern Europe and western Balkan, but can still significantly impact urban air quality. Agriculture emissions of ammonia have a significant impact on urban background PM concentrations with impacts reaching up to 25 % of the observed urban levels in north-western Europe (DE, UK, BE, northern FR). Note that the agricultural impact slightly decreases with time as a result of the uneven NO_X and NH_3 emission reductions. While NO_X emissions continue to decrease in many places, this is not the case for the NH_3 emissions leading to less marked NH_3 limited regimes resulting in larger sensitivity to NO_X emission reductions. Therefore, larger NH_3 reduction is necessary to get the same reduction in $PM_{2.5}$ concentrations. This process has been noted by Jonson et al. (2022).

An important part of the national/regional contribution are secondary inorganic aerosols (SIA): mainly aerosol formation in the atmosphere from ammonia and nitrogen oxides, or from ammonia and sulfur oxides. However, primary PM-emission sources also contribute: wood burning (for example in the northern part of Italy), agricultural waste burning, forest fires, as well as large industrial combustion plants , which can sometimes also still be a major source of sulfur dioxide.

[1]and partly SO_2 in case of lacking emission standards and controls

- <u>Transboundary sources</u>

The contribution of transboundary sources largely depends on the location of the city with respect to the country borders and on the size of the country itself. Transboundary in this context does not necessarily mean long-distance, but simply the fact that air pollution travels across borders.

For **$PM_{2.5}$** concentrations the contribution of transboundary sources can be significant, especially in smaller cities. Similarly to national and regional sources, the transboundary contribution is mostly secondary aerosols, but primary PM-emission sources also contribute, such as wood burning, agricultural waste burning, forest fires as well as large industrial combustion plants.

B) Nitrogen dioxide (NO_2)

Most of the **NO_2** originates from local sources of which transport remains the main one in most urban environments. In some cities industry and shipping are significant sources too.

C) Ozone (O_3)

Ozone is a typical transboundary pollutant. It is formed in the atmosphere from anthropogenic and biogenic emissions of nitrogen oxides, non-methane volatile organic compounds (NMVOC) and methane, under the influence of sunlight. Precursor emission sources can be thousands of kilometers from the places where high ozone concentrations are experienced.

Cities actually help reduce ozone concentrations when destruction through nitrogen monoxide is locally dominating. Due to relatively high share of NO close to NO_X-emission sources, reduction of NO_X-emissions in urbanized areas can lead to higher ozone concentrations in those cities. This should however not be seen as a reason to not reduce the emissions of NO_X.

Effectively tackling O_3 sources requires internationally coordinated actions, with increased attention to methane mitigation. However, to reduce O_3 peak season concentrations, local to regional reduction of NO_X and VOC emissions is still necessary (Lupascu and Butler, 2019).

4) Measures

A great variety of measures have been taken by cities to reduce the exposure to air pollutants and to meet air quality standards (see for example Khreis et al., 2017 and 2023 as well as Annex 1).

The question is, however, to what extent local measures will be applicable and sufficient to meet for instance the EU's long-term goal of a "toxic-free environment", which is reflected by the WHO air quality guidelines.

<u>Impact versus spatial scale of implementation</u>

The effect of measures on air quality can vary quite a lot, depending on the pollutants to be tackled and also depending on the spatial scale on which they were implemented. Figure 5 from Pisoni et al. (2022) shows the relative response of measures taken on a large-scale (EU, in red) and only locally (in blue) to reduce NO_2, $PM_{2.5}$ (annual means) and ozone (8h maximum), assessed at the city location with the maximum modelled concentration. The responses of local measures on those concentrations were simulated with the EMEP model by switching off the emissions over the city area, plus the surrounding economic and functional extent of cities based on daily people's movements. Responses were expressed as percentages of a base case with all emissions everywhere in the model domain. All emissions were switched off in Europe to determine the EU responses.

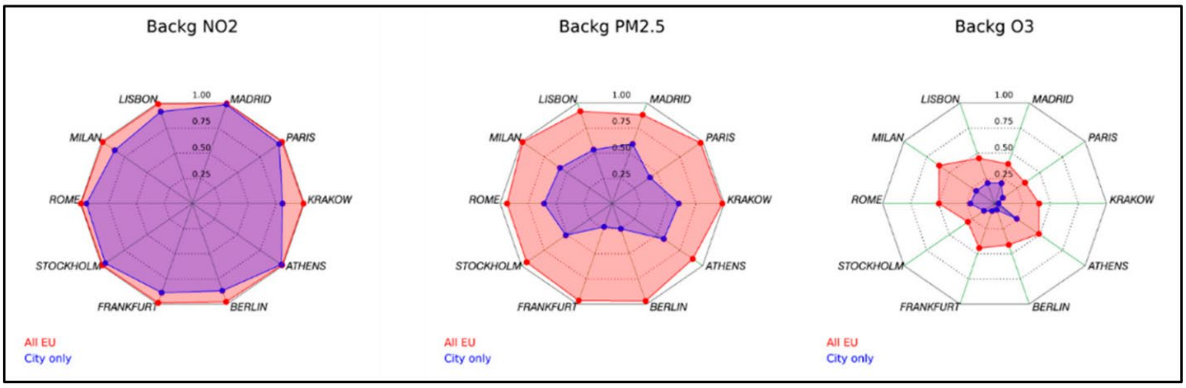

Figure 6. Comparison of EMEP responses (relative potential) to local (blue) and EU reductions (red) for annually averaged $PM_{2.5}$, annually averaged NO_2 and summertime daily 8-hour maximum of ozone. Emission reduction impacts are assessed at the city location where the maximum base case concentration is modelled. Pisoni et al. (2022)

For $PM_{2.5}$ both large-scale (European and national) and local measures are almost equally important, but their relevance varies from city to city. In cities at the outer regions of the EU (e.g. Athens, Madrid, Lisbon) there is even some need for action from non-EU countries. The recently updated "Urban $PM_{2.5}$ Atlas" (Thunis et al., 2023) provides useful information for 150 cities in the EU about where to act most effectively, on which spatial scale and in which sector. From that, **it can be concluded that measures to effectively tackle $PM_{2.5}$ need to be taken on all spatial scales, given the long- and medium-range transport of $PM_{2.5}$ and its precursors for secondary PM.**

For ozone, there should be an even stronger focus on large-scale measures even outside of Europe, while local measures in city domains are barely relevant. There are exceptions in a few urban areas in the Mediterranean, where orography and rather stable land-sea breeze wind patterns hamper the transport of precursors and ozone over larger distances.

For a locally dominated pollutant like NO_2, local measures can be very effective. It seems that the bulk of the NO_2 exposure reduction can largely be achieved almost entirely by local air quality management. Here, and equally important with respect to $PM_{2.5}$ abatement, the question arises, however, to what extent urban measures would require regulatory and financial support from national governments (or the EU) in order to be practically feasible? For instance, while local traffic is a major local source of NO_2, much of the regulation around vehicle traffic is done at a national or even international level. Cities are sometimes limited in what they can do if the national or international governments do not cooperate or share their goals for air quality.

<u>Local versus national / international level of implementation</u>

In order to highlight that issue, Annex 1 gives a list of measures relevant for local or regional authorities to improve the air quality and public health in urban areas. The table presented in Annex 1 is largely derived from a "Review of interventions to improve outdoor air quality and public health" from Public Health England (PHE, 2019). It covers 86 measures on mobile and stationary sources as well as some urban planning and behavioural interventions. A few more measures on residential heating, industry and non-road mobile sources were added, based on other research activities and expert judgement. We took also into account the "*indicative list of air pollution abatement measures*" in Section B of Annex VIII of the revised EU Air Quality Directive, recently adopted by the EU Council and Parliament (AAQD, 2024), which local authorities should consider in their air quality plans.

Agricultural measures were not explicitly included as they are rarely on the list of measures of urban air quality management. However, it should be emphasised that measures to control ammonia emissions from livestock, manure management, storage and nitrogen fertiliser application are essential to significantly reduce $PM_{2.5}$ exposure in cities. As outlined in the previous section on the sources, NH_3-redution needs to happen on a regional (or larger) scale in order to decrease the regional background of $PM_{2.5}$. Action at a national or even international governance level is therefore of paramount importance, even for local air quality.

In order to highlight the multi-governance aspect of air quality management, two columns were added to the table in Annex 1: one indicating the main governance level responsible for the implementation and enforcement of each intervention and another highlighting the international bodies, where supportive action (regulatory and/or financial) is important for the local measure to be feasible in practice. The table also indicates where potential measures need to be accompanied by actions on the EU / international governance level.

Given the urban focus of this paper, the list of measures focuses on actions particularly relevant for urban air quality planning (see Annex 2). Not surprisingly, for the majority of the measures in Annex 1 local authorities are the main actor. With the exception of a few cases with mixed responsibility, national authorities bare the main responsibility for many other measures. It is interesting to note that around half of the local interventions cannot be implemented without some sort of national endorsement: be it in the form of funding city's infrastructure enhancement, direct investments in infrastructure (rail, power grids, renewables, charging) and, most frequently, by providing the necessary jurisdiction, regulatory power or technical specifications for cities to act. One prominent example are measures necessary for the implementation of Low or Zero Emission Zone (LEZ / ZEZ) schemes, which requires in many cases (e.g. Czech Republic, France, Spain, Germany, Belgium, the Netherlands, Luxembourg, Italy, United Kingdom, Norway) an amendment of national legislation: traffic laws, vehicle labeling regulations, as well as technical specifications for vehicle retrofit and charging infrastructure. Many other traffic interventions, especially those aiming to benefit cleaner and active transport modes, rely on amendments of national road transport laws, too, while steps to influence people's behaviour to avoid polluting activities lies almost solely in the hands of the local authorities. Unfortunately, the latter have a limited impact. Hence, even for NO_2 as a locally driven pollutant, where cities have a huge mitigation potential, more than half of the potentially useful measures depend on support at the national or even international level.

Local measures addressing residential heating and industrial sources are also strongly bound to national or EU regulations by setting emission limit values, prescribing the scope of "best available techniques" for various types of industries, fuel quality and other product standards on which local interventions strongly rely in technical and judicial terms.

<u>Air quality versus other policy areas</u>

A recent example in Germany illustrates this dependency, not only between governance levels, but also across different policies: While national climate action strongly drives the decarbonisation of the house-heating sector and thereby incentivises inter alia the use of biomass, the respective law fails to require PM precipitators to be installed when opting for a new pellet boiler. Given the concurrent lack of the EU's EcoDesign regulation to require dust precipitators for new biomass boilers, this could result in a stagnation or even increase of the PM emissions from domestic heating because burning wood without filters always comes with high emissions of particles, some of which are ultrafine, toxic and drivers for climate-change. Unfortunately, local or regional authorities cannot counteract for legal reasons unless the PM limit value is violated again, regardless of the current PM concentrations being more than twice as high as WHO's air quality guideline value. As a result, climate action policy in order to meet its, sometimes sectoral, goals can create a risk for air quality policy to comply with its legally binding standards, notwithstanding the considerable co-benefits of most decarbonisation measures for air quality.

<u>Short-term actions versus long-term measures</u>

Experience with short-term actions in the form of smog alerts have shown that, with the exception of momentarily raising awareness for a pressing environmental problem, their effectiveness in terms of a long-lasting emission reduction is fairly small. As noted in the recent UK health review of interventions (PHE, 2019 p. 60 and 217): "*An evidence assessment of short-term action plans (measures taken to reduce the risk of exceedance of pollutant levels or the duration of the exceedance) concluded that there is little or no evidence that such measures will be effective in reducing the intensity, extent or duration of pollution events*. […] *Most of the burden of disease of air pollution is due to long-term exposure. Therefore, the primary focus should be on addressing this issue.*"

Apart from prioritizing measures with a long-term effect, the global health effects community (Hoffmann et al., 2021) calls for a reconsideration of current air quality legislation and regulations: "*To maximise health benefits, we now understand better the importance of implementing measures to reduce average exposures of all people*. *Such an approach must complement reductions in exposure at 'hotspots' with high levels of air pollution*". Rather than concentrating on the extremely small-scale decrease of pollutant levels in the immediate surrounding of monitoring stations as was done with air purifiers for example in Stuttgart, Germany (Bächler et al., 2021), measures should be designed to generate improvements over a wider city area, in order to gain health benefit for large parts of the urban population.

<u>Air quality versus other policy areas</u>

It can be concluded, that

- a wide range of measures exist to improve the air quality in cities. The most effective combination of policies depends on the local conditions and distribution of sources. There is certainly no 'magic' intervention, but rather the combination of several measures, which leads to a widespread and tangible reduction of the exposure of urban dwellers.
- While local authorities are the main actor, collaboration across all level of governments is essential to ensure that all requisite measures can effectively be implemented, independent from the pollutant and the spatial scale on which the respective action is implemented. This is echoed by the international scientific health effects community (Hoffmann et al. (2021)): "*To tackle the health effects of air pollution, bold air quality actions are needed at all levels – international, national, local – and across all sectors such as transport, energy, industry, agriculture, and residential*".
- Coordination and coherence between different policy areas is also essential, notably between air quality and climate action policy. While there is often a natural symbiosis between sectoral decarbonisation and control of air pollutants, promoting biomass as a climate-friendly fuel for residential heating would result in higher particle emissions (and other toxic substances) unless filter technologies were required.
- In order to maximise the health benefits, measures with a larger, city-wide effect on the population exposure should receive much more focus than purely hot-spot driven interventions with a small spatially limited impact.

5) The way forward

There are several emerging aspects which are already discussed within the bodies of the Air Convention and may play a more significant role in air quality planning in the future (see also Annex 2):

- a rating of synergies between climate change adaptation, e.g. measures to reduce heat stress in cities, and air quality management and further synergies (e.g. yield increases by less air pollution from cities, measures to reduce air pollution and noise, etc.);
- the varying health impact of the various particle species in particulate matter;
- the health benefits of combined PM, NO_2 and ozone mitigation;
- considering the distribution and effects of particle number concentration and the fraction of ultra-fine particles;
- air pollutant emission factors for combustion of modern fuels (hydrogen, ammonia, etc.);
- particle emission factors for non-exhaust emissions from road transport (differentiation between fossil fuels and electric vehicles as well as between vehicle categories);
- promising approaches for non-technical measures where regulation reaches its limits (creating catchy mission statements / scenarios / utopias, that are desirable for people living in cities).

Annex 1: List of potential interventions for local or regional authorities to improve the air quality and public health in urban areas

The list of potential interventions is largely based on the *Review of interventions to improve outdoor air quality and public health (PHE (2019), REA (2019))* conducted on behalf of Public Health England, the executive agency of the UK Department of Health and Social Care. Given their limited direct relevance for urban air quality management, which is the main topic here, we left out agricultural measures, but added a few more on residential heating, industry and mobile sources, based on own experience and other references (UBA (2016), UAEU (2018), Burns, J. et al. (2020), Sarmiento, L. et al. (2023)). We skipped the qualitative rating of the "effectiveness of measures in terms of the impact on air quality and public health outcomes" by that review, because it very strongly depends on many confounding factors, such as orographic barriers for pollution dispersion, meteorology, economic and structural situation, technological progress and spatial source distribution in and outside of an air quality management area. As these factors vary greatly in cities across the signatory states of the Air Convention, it would be difficult to make sweeping generalisations about the impact of local interventions, let alone the impact of national and international interventions in the local context.

Instead of focusing on the specific impact of measures, the table aims to highlight that, while local and regional authorities are the main actors to implement and enforce these measures, other governance levels often play an important, if not decisive role. These are mostly the national governments, but also the EU in the case of the European Union member states or the international bodies, like the UNECE Air Convention, which in turn require national governments to come forward with national strategies or programmes. Without support by national governments, local authorities are often hampered to take these measures because of lacking jurisdiction, financial resources and personnel capacities. Vice versa, without cities and regions taking action, national commitments to meet emission reduction and air quality standards can hardly be achieved. In order to illustrate the close linkages among different governance levels we added two columns highlighting the division of competence between the different governance levels with regard to different steps and conditions needed for their implementation.

A) Measures in the transport sector, including non-road mobile machinery

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
Reduce demand for more polluting forms of transport **by reducing overall travel or restricting certain types of vehicles or encouraging the uptake of sustainable transport**						
T1	Promote freight modal shift from road to rail through pull measures	Funding Infrastructure	national	NO_X, PM	National, by funding schemes and investments in rail infrastructure	EU/international through coordination of rail infrastructure investments to facilitate

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
T2	Emission dependent lorry road user charging	Taxation	national	NO_X, PM CO_2	National, by operating road pricing schemes on national motorways and main roads	EU/international by providing or harmonizing regulatory framework for road user charging, as relevant
T3	national road pricing for all vehicles and/or vehicle taxes, preferably emission-dependent	Taxation	National	NO_X, PM CO_2	National, by operating road pricing schemes on national motorways and main roads	EU/international by providing or harmonizing regulatory framework for road user charging, as relevant
T4	*Gradual increase of taxes for fossil vehicle fuels*	Taxation	National	NO_X, PM CO_2	National	
T5	Subsidising public transport (PT)	Funding Infrastructure	National	NO_X, PM CO_2	Local/regional by investing in and operating PT systems, through attractive ticket pricing and subventions	National, through funding of cities' PT operation and of investments into subway & local rail infrastructure
T6	Provision of school buses	Funding	Local	NO_X, PM CO_2	Local	
T7	Designating priority measures to buses and trams	Infrastructure Regulation	local	NO_X, PM CO_2	Local, through construction of separate bus & tram lanes and prioritization at traffic lights	National, by providing the requisite traffic regulations
T8	Promote walking and cycling	Funding Infrastructure Regulation	local	NO_X, PM CO_2	Local, through investments in safer/attractive infrastructure and road traffic orders	National, by funding and providing traffic regulations favouring active mobility
T9	Promote car sharing and new mobility services	Funding Infrastructure Regulation	Local	NO_X, PM CO_2	Local, by allocating the requisite parking space and building of EV charging infrastructure	National, by providing the requisite regulatory framework
T10	Workplace charging levies on private non-domestic off-street parking provided by employers.	Taxation	Local	NO_X, PM CO_2	Local	National, by providing the requisite regulatory framework, if relevant
T11	High-occupancy vehicle lanes	Regulation	Local	NO_X, PM CO_2	Local	National, by providing the requisite road traffic regulation, if relevant
T12	Emission dependant local congestion charging	Taxation	Local	NO_X, PM CO_2	Local	National, by providing the requisite road traffic regulation

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
T13	*Expand parking management in urban areas*	Taxation	Local	NO_X, PM CO_2	Local, by setting an impactful pricing level, creating the necessary infrastructure to collect/enforce the fees	National, by providing the requisite road traffic regulation
T14	Promote tele-working/video conferencing	Guidance/Info	National	NO_X, PM CO_2	All levels	
T15	Travel planning	Guidance/Info	Local	NO_X, PM CO_2	Local, by funding or creating information platforms and Apps to facilitate intermodal trip planning	
Reduce emissions from existing vehicles through affecting vehicle speed, congestion levels, improve the overall management of traffic flows, and technical measures to reduce the direct emissions from a vehicle						
T16	Allow more night time freight delivery	Regulation	Local	NO_X, PM CO_2	Local	
T17	Lorry overtaking bans	Regulation	Local	NO_X, PM CO_2	Local	
T18	Promote or *require* abatement retrofit of Diesel (DPF, SCR) or *petrol (3-way catalyst)* vehicles	Funding Regulation	National	PM, NO_X	National with regard to funding and setting up the requisite regulatory framework Local, if part of an LEZ scheme	EU/international by providing or harmonizing regulatory framework and by confirming the compatibility of funding with state aid rules to ensure fair trade
T19	Promote eco driving	Guidance/Info	Local/National	NO_X, PM CO_2	Local	National campaign would be more effective
T20	Vehicle emissions tests *during periodical vehicle inspection*	Regulation	National	NO_X, PM	National	EU/international by providing guidance for harmonized implementation
T21	Roadside vehicle emissions tests	Regulation	National	NO_X, PM	Local	National, by providing the requisite technical regulation, if necessary
T22	Active traffic light management	Infrastructure	Local	NO_X, PM CO_2	Local	
T23	Intelligent speed adaptation	Infrastructure	Local	NO_X, PM CO_2	Local	
T24	*Speed limits on highways (80/60 kmph) in urban areas*	Regulation	Local	NO_X, CO_2	Local National (on motorways)	National, by providing the requisite road traffic regulation

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
T25	*Speed limit on urban main roads (30 kmph instead of 50 kmph)*	Regulation	Local	NO_X, PM CO_2	Local	National, by providing the requisite road traffic regulation
T26	Improved anti-idling enforcement and campaigns	Guidance/Info Regulation	Local National	NO_X, PM CO_2	Local	National, by providing the requisite road traffic regulation
T27	Promote/*require* air quality beneficial bio-fuels	Funding Taxation Regulation	National	NO_X, PM CO_2	Local/Regional as regards to enforcement National as regards fuel tax discounts and funding of production	EU/international by defining bio-fuel blending quotas
Promoting vehicles with low emissions through low emissions zones, scrappage and fiscal incentive schemes, such as parking charges and taxation						
T28	Scrappage schemes	Funding	National	NO_X, PM CO_2	National	EU/international by confirming the compatibility with state aid rules to ensure fair trade
T29	Fleet recognition schemes that promote low emission vehicles	Guidance/Info	Local	NO_X, PM CO_2	Local	
T30	Reduced Vehicle Excise Duty for early purchase of new vehicles	Taxation	National	NO_X, PM CO_2	National	
T31	*Grant purchase of ultra-low emission cars*	Funding	National	NO_X, PM CO_2	National	EU/international by confirming the compatibility with state aid rules to ensure fair trade
T32	Low emission zones, i.e. access restrictions for polluting vehicles	Regulation	Local	NO_X, PM	Local	National, by providing the requisite regulatory framework
T33	Priority parking for low emissions vehicles	Regulation	Local	NO_X, PM CO_2	Local	National, by providing the requisite regulatory framework
T34	Pollution car labelling scheme	Regulation	National	NO_X, PM CO_2	Local	National, by providing the requisite regulatory framework
T35	Development of electric vehicle charging infrastructure	Infrastructure Funding	National	NO_X, PM CO_2	Local	National, by providing funding and EU/international by defining the harmonized technical requirements
T36	Public information campaign to promote cleaner vehicles	Guidance/Info	National	NO_X, PM CO_2	National	

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
Displace polluting road vehicles outside hotspots and populated areas						
T37	Lorry ban in urban centres *combined with routing concept in remaining city areas*	Regulation Guidance/Info	Local	NO_X, PM CO_2	Local	National, by providing the requisite road traffic regulation
T38	Freight consolidation centres	Regulation Infrastructure	Local	NO_X, PM CO_2	Local/Regional	National, by providing funding and building railway siding, if relevant
T39	Newer buses used for most polluted routes	Regulation	Local	NO_X, PM CO_2	Local	
T40	*Planning and construction of bypass roads to keep long-distance (freight) traffic out of urban areas*	Infrastructure	Local	*NO_X, PM*	Regional/national depending on the type of road	National, by building national road bypass, if relevant
T41	*Queue relocation*	Infrastructure	Local	*NO_X, PM*	Local, by re-programming traffic light synchronisation	
T42	Traffic calming, different ways of restricting driving	Regulation Infrastructure	Local	NO_X, PM CO_2	Local	National, by providing the requisite regulatory means
T43	*Labelling scheme for clean machinery*	Regulation	National	NO_X, PM CO_2	Local	National, by providing the requisite regulatory framework
T44	*Scrappage schemes for polluting equipment and funds for purchase of electric or low emission machines*	Funding	National	NO_X, PM CO_2	National	EU/international by confirming the compatibility with state aid rules to ensure fair trade
T45	*Fleet recognition schemes that promote low emission machines*	Guidance/Info	Local	NO_X, PM CO_2	Local	
T46	*Promote or require retrofit of machinery with DPF*	Funding Regulation	National	PM	National with regard to funding and setting up the requisite regulatory framework Local, if part of an LEZ scheme	EU/international by providing or harmonizing regulatory framework and by confirming the compatibility of funding with state aid rules to ensure fair trade
T47	*Low emission zones with operation restrictions for polluting machinery*	Regulation	Local	NO_X, PM	Local	National, by providing the requisite regulatory framework

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
T48	*Periodical vehicle emissions tests*	Regulation	National	NO_X, PM	National	EU/international by providing guidance for harmonized implementation
Aviation: operational interventions at airports and alternative fuels						
T49	Electrifying ground support equipment	Funding Infrastructure	Local	NO_X, PM CO_2	Local/Regional	National, by providing funding
T50	Reduction in thrust take-off	Regulation Operation change	Local	NO_X, PM CO_2	National, by amending aviation regulations	
T51	Pushback control (i.e. holding aircraft at their gates up to 25 min to reduce congestion)	Operation change	Local	NO_X, PM CO_2	Local	
T52	Reduction in use of auxiliary power units	Infrastructure	Local	NO_X, PM	Local	
T53	Lower emission road vehicles	Infrastructure	Local	NO_X, PM CO_2	Local	
T54	Alternative aviation fuels	Regulation	National	NOx, PM, SO_2, NMHC, CO_2	Local/Regional as regards enforcement	National, by regulating alternative aviation fuel blending or use
Maritime and inland shipping sector: cleaner fuels and vessels						
T55	Quality standards (e.g. S-content) of marine *and inland* shipping fuels	Regulation	(Inter)national	PM, SO_2	National, by approximating national laws/regulation Local/Regional as regards enforcement	EU/international by setting the respective standards
T56	*Emission-dependant charges for maritime and inland shipping companies at ports*	Taxation	Local	PM, NO_X, SO_2, CO_2	Local/Regional as regards enforcement	National, by providing setting the respective charges
T57	*Provide and require the use of shore power to maritime and inland vessels at berth*	Infrastructure Funding Regulation	Local	PM, NO_X, SO_2, CO_2	Local, by investing in the requisite shore-to-ship power supply	National, by providing the funding for the investments and the requisite regulations

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
T58	Supply of electricity to enable electrification of cargo handling equipment in ports	Infrastructure Funding	Local	NO_X, PM CO_2	Local, by investing in the requisite charging infrastructure	National, by providing the funding for the investments
T59	*Retrofitting inland shipping Diesel vessels with DPF and SCR*	Funding Regulation	National	NO_X, PM CO_2	National, by providing funding schemes and by setting the respective standards for engine retrofit	EU/international by defining the harmonized technical requirements and by confirming the compatibility of funding schemes with state aid rules to ensure fair trade
T60	*Engine replacement and promotion of innovative sustainable propulsion of inland shipping vessels*	Funding Regulation	National	NO_X, PM CO_2	National, by providing funding schemes for clean shipping and, if relevant, by setting the respective standards for engine replacement	EU/international by defining the harmonized technical requirements for replacement engines and by confirming the compatibility of funding schemes with state aid rules to ensure fair trade
Rail sector: electrification of the rail network and promotion of lower emissions from rolling stock						
T61	Electrification of rail network	Infrastructure	National	NO_X, PM CO_2	National	
T62	Promote the uptake of bi-mode trains or other alternative traction types (fuel cell, full battery-electric)	Infrastructure Funding	National	NO_X, PM CO_2	Regional or national, as relevant, by funding innovative traction types and built-up of the necessary infrastructure	
T63	Abatement retrofit (DOF, SCR)	Funding Regulation			Regional or national, as relevant, by requiring retrofit in the procurement of new rail-services	EU/international or national, as relevant, by defining the harmonized technical requirements for retrofit of Diesel trains and locomotives National as regards funding-schemes for retrofit

B) Measures in the industrial and residential heating sector

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
Policy measures						
S1	National emissions ceilings	Regulation	(inter)national	NO_X PM, VOC, SO_2, NH_3	National, by drawing up the National Air Pollution Control Programme setting out measures to achieve the emission reduction commitments	Regional/local, by supporting the implementation of the large-scale measures of the National Air Pollution Control Programme
S2	Installation emission concentration limits: Best Available Technique (BAT) based permitting	Regulation	national	NO_X PM, VOC, SO_2, NH_3	Local/Regional, by issuing operation permits and by monitoring compliance	EU/international or national, as relevant, by defining BAT in harmonized way and by setting emission limits
S3	Installation emission concentration limits: Cost-Benefit-Analysis (CBA) based permitting	Regulation	national	NO_X PM, VOC, SO_2, NH_3	Local/Regional, by issuing operation permits and by monitoring compliance	EU/international or national, as relevant, by defining CBA approach and by setting emission limits
S4	Eco-design and product standards	Regulation Funding	(inter)national	PM, NO_X	National, by setting out the requisite national regulation to ensure efficient monitoring & enforcement (>T5/6)	EU/international, by setting the respective standards
S5	Elimination of polluting plants, small installations, heating systems etc	Funding Regulation	Regional/local	PM, NO_X	Local/Regional	National, by setting up funding schemes and the requisite regulations
S6	Inspections (large installations, boilers, space heaters, fire places) and enforcement actions (e.g. ban of open fires, waste burning)	Regulation	National	PM, NO_X	Local/Regional by ensuring efficient monitoring & enforcement	National, by setting out the requisite regulations
S7	Monetary incentives, e.g. replacement schemes for old polluting heating systems	Funding	National	PM, NO_X	National, by setting up funding schemes	EU/international by confirming the compatibility of funding schemes with state aid rules to ensure fair trade
S8	Monetary penalties for polluting activities	Taxation	National	PM, NO_X, CO_2	Local, by ensuring efficient monitoring & enforcement	National, by setting out the requisite regulations
S9	Emission trading schemes	Regulation	National	PM, NO_X, SO_2, CO_2	Local/Regional by checking emission data from operators	National, by setting out the requisite regulations

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
Technologies						
S10	Dust abatement (secondary) through filters/precipitators	Funding Regulation	National	PM	Local/Regional, through inspections of plants and AQ monitoring	EU/international by providing the underpinning technical framework; National, by setting out the requisite regulations
S11	Primary measures to prevent pollutant formation/generation from industrial activities	Regulation	National	NO_X, SO_2, PM	Local/Regional, through inspections of plants and AQ monitoring	EU/international by providing the underpinning technical framework; National, by setting out the requisite regulations
S12	Exhaust gas treatment in large and medium-sized installations	Regulation	National	NO_X, SO_2, PM, VOC	Local/Regional, through inspections of plants and checking emission data from operators	EU/international by providing the underpinning technical framework; National, by setting out the requisite regulations
S13	Switch to clean fuels/energy for residential heating and for industries	Funding Regulation Taxation	National	NO_X, SO_2, PM, CO_2	Local/Regional	National, by setting up supportive funding schemes, if necessary
S14	Combined heat and power generation, expansion of district heating	Infrastructure Funding Regulation Taxation	Local/Regional	NO_X, SO_2, PM, CO_2	Local/Regional	National, by setting up supportive funding schemes, if necessary
S15	Enhance energy efficiency in buildings	Funding Regulation	National	NO_X, PM, CO_2	Local/Regional	National, by setting up supportive funding schemes
S16	Precipitator retrofit programme for small installations to control PM emission	Funding Regulation	Local/Regional	PM	Local/Regional	National, by setting out the requisite technical regulations and funding schemes

C) Measures on urban planning and on behavioural change

No.	Measure/intervention	Policy type(s)	Spatial scale of implementation	Targeted emissions (AQ or GHG)	Main governance level in charge of implementation and enforcement	Requisite support from other governance level
Planning measures						
P1	Co-implementation of various measures through sustainable urban mobility planning, such as pedestrian zones, low or car free traffic neighbourhoods, superblocks to reduce motorized traffic	Funding Taxation Infrastructure Regulation Guidance/Info	Local	NO_X, PM, CO_2	Local	National, by providing funding for requisite investments and by removing regulatory barriers
P2	Green infrastructure – urban vegetation	Infrastructure	Local	PM	Local	
P3	Green public procurement of clean fuels, low emission combustion equipment, low/zero emission vehicles	Taxation Regulation	Local	NO_X, PM, CO_2	Local	National/EU by providing the requisite regulatory framework on public procurement
Measures to change behaviour						
P4	Clean Air day	Guidance/Info	Local	NO_X, PM, CO_2	Local	
P5	Public engagement, citizens science, etc	Guidance/Info	Local	NO_X, PM, CO_2	Local	
P6	Exposure reduction programmes targeting especially sensitive parts of the population	Guidance/Info	Local	NO_X, PM, CO_2	Local	
P7	Air Quality alerts and information based on indices	Regulation Guidance/Info	Local	NO_X, PM, CO_2	Local/Regional	National, by setting harmonized AQ indices including concerted advice to relevant population groups and providing forecast tools

Annex 2: How to develop a successful multi-level air quality plan

The success of an air quality plan depends on: 1) the political process; and 2) the availability of relevant knowledge.

Political elements for success are:

1. Political support from the highest-ranking decision maker, e.g. the mayor or the (prime) minister;
2. Input from independent scientists in problem assessment (air quality monitoring, emission inventory, dispersion modelling, health impact assessment);
3. Involvement of relevant departments and consultation of key stakeholders in problem framing, target setting, timing and prioritization of measures;
4. Citizens awareness and public participation in problem framing;
5. Availability of funding;
6. Agreement on enforcement, monitoring and review procedures of the plan.

An integrated approach would make policies more effective. Horizontal integration requires coordination of air quality managers and managers from sectors such as transport, energy, industry and finance. Vertical integration requires coordination with different policy levels (local, regional, national, international).

This annex will focus on how to organize the knowledge needed for an air quality plan. All other (political) elements will vary strongly from case to case and is difficult to write a general guideline for.

Knowledge needed for an air quality plan

Starting point for problem framing are the measurements of air quality and the models to relate these measurements with the emission data. However, a plan is by definition forward looking and would also require modelling of future emissions, concentrations and impacts. Together, measurements and models would enable to answer the relevant policy questions:

1. What are the main sources of air pollution?
   - What do urban sources contribute to concentrations and what is the contribution of sources outside the city?
   - What is the additional contribution of local sources to areas with high concentrations (hotspots), i.e. the impact of traffic on air quality along busy roads?
2. What future changes in emissions and concentrations are expected with existing policy?
   - What happens to emissions and concentrations, when no additional local measures are taken?
   - What effect do existing climate policies have?
   - What will be the future "distance to target" (the gap between projected concentrations and the air quality limit values, average population exposure targets or meeting WHO-guideline levels)?

- What reduction in average population exposure is needed and how much reduction in concentration is needed at hot spots?

3. Which options are available to further reduce concentrations?
    - Which additional measures can be taken at the city level (e.g. clean busses or banning certain types of vehicles in busy streets)?
    - Are such local measures sufficient to meet air quality targets?
    - What would be the impact of additional measures at regional scale (e.g. speed limits on motorways) or at (inter-)national scale (e.g. emission limit values for vehicles or industries)?
    - What would be the most (cost-) effective combination of measures? Is it possible to achieve synergies between air quality policies and other relevant policies, such as climate policies?

There are various methodologies and tools (models) available to answer the questions above. Below we present tools for the different steps in the DPSIR-framework: Drivers and Pressure (= emissions and projections), State (= concentrations), Impact (= health impact) and Responses (= selection of measures to improve air quality). Drivers (= projections for sectoral development) are used to extrapolate pressures and impacts to future years.

The level of complexity of these modules of the DPSIR framework could differ from easy (level-1) to complex (level-3) tools.

Emissions and projections

Insight into emissions (the first ingredient to be evaluated, to test emission reduction scenarios) can be created using the EMEP/EEA CORINAIR guidebook (EMEP/EEA, 2023), which provides detailed information on different level of complexity (Tier levels) that can be used for emission modelling. In this annex we explain, as an example, what can be done for traffic emission modelling, a typical driver for future emissions and air quality at the city level.

The tools to model future emissions (both for the base case and for policy scenarios) can vary between simple spreadsheet-models to the use of various kinds of traffic models. Traffic emission models can be less or more complex, depending if and how behaviour of travellers is included.

The level-1 approach for traffic emission scenario modelling (spreadsheets) would include a linear extrapolation of trends in car use, fuels used, in modal split and in replacement pace of older vehicles by new ones. Furthermore, a spreadsheet could calculate the effects of exogenous changes (or desired policy outcomes) on emissions. Spreadsheet models normally do not include changes in the spatial distribution of traffic over time. Changes in circulation patterns would have to be built in exogenously.

The level-2 approach would entail more explicit spatial traffic circulation patterns and would be able to “predict” how traffic flows would change if certain streets would be closed or downgraded.

The level-3 approach would include behaviour of travellers, where the choice of travel modes and routes is driven by the desire to use the fastest or cheapest way to come from A to B. Such a model would enable to assess the impacts of investments in public transport, or in the use of economic instruments (such as road pricing or parking fees).

For non-traffic sources such as domestic heating, shipping, agriculture or industrial sources, projected emissions can be related to proxy variables (e.g. growth in population, GDP or sectoral production) multiplied by an average emission factor. The more detailed the sectoral split is, the more data on the applied technology will be needed. Emission factors would ideally depend on the age of the installations and end-of-pipe abatement measures already applied of in the pipeline.

An important element for emission projections used in an air quality plan is to ensure the consistency with climate and energy plans. E.g. how are climate and energy plans affecting the share of electric vehicles, residential heating or the use of fossil fuels in industry?

Concentrations

After having computed emission projections, one can evaluate how emission changes will affect concentrations. For estimating the impact of emission reduction on local concentrations, different tools can be used.

For NO_2, the simplest 'level-1' approach is to assume a linear relationship between the emission reduction from a certain source and the reduced contribution from that source to the average concentration in a city, neighbourhood or street. For the impact on the city level and street increment more advanced 'gaussian' and 'street canyon models' can be applied (level-2). Such models assume certain mixing parameters that take into account traffic density, the shape of the street and the presence of trees (trees could lead to an accumulation of pollution under the tree crown). Some models take into account the chemical process that converts NO-emissions into NO_2-concentrations. To assess the impact of measures on the city background level, more complex atmospheric models will be needed that include meteorology and chemical reactions, such as the formation of secondary particles or ozone (level-3). These models are the Chemical Transport Models, which can be used for urban background pollution estimation.

For $PM_{2.5}$, modelling will be more complex, because the contribution of local traffic is substantially less than for NO_2. Traffic contributes directly to primary PM-concentrations via the wear of tires, brakes and roads, and via tailpipe emissions. However, concentrations related to other PM-sources can differ widely among cities. The contribution from domestic burning of wood or other solid fuels is significant is some cities. In regions with high densities of traffic, industry and livestock, secondary particles (ammonium-nitrate, ammonium-sulfate) create a 'blanket' of high $PM_{2.5}$ concentrations over a large area, which diminishes the possibility of city authorities to substantially reduce $PM_{2.5}$-concentrations. For the assessment of the reduction of $PM_{2.5}$ concentrations it is important to take sources outside the city and the formation of secondary particles into account. In this case the use of Chemical Transport Model (level-3) is suggested (such as regional applications of the EMEP-model, the CHIMERE model, the Lotos-Euros-model or SHERPA (http://aqm.jrc.ec.europa.eu/sherpa.aspx).

Figure 1 shows as an example the source apportionment of the concentrations in Amsterdam and Brussels based on the SHERPA tool (Thunis et al., 2016). Because of the non-linearity of the chemical formation of secondary PM this source apportionment does not always correspond with the effectiveness of measures.

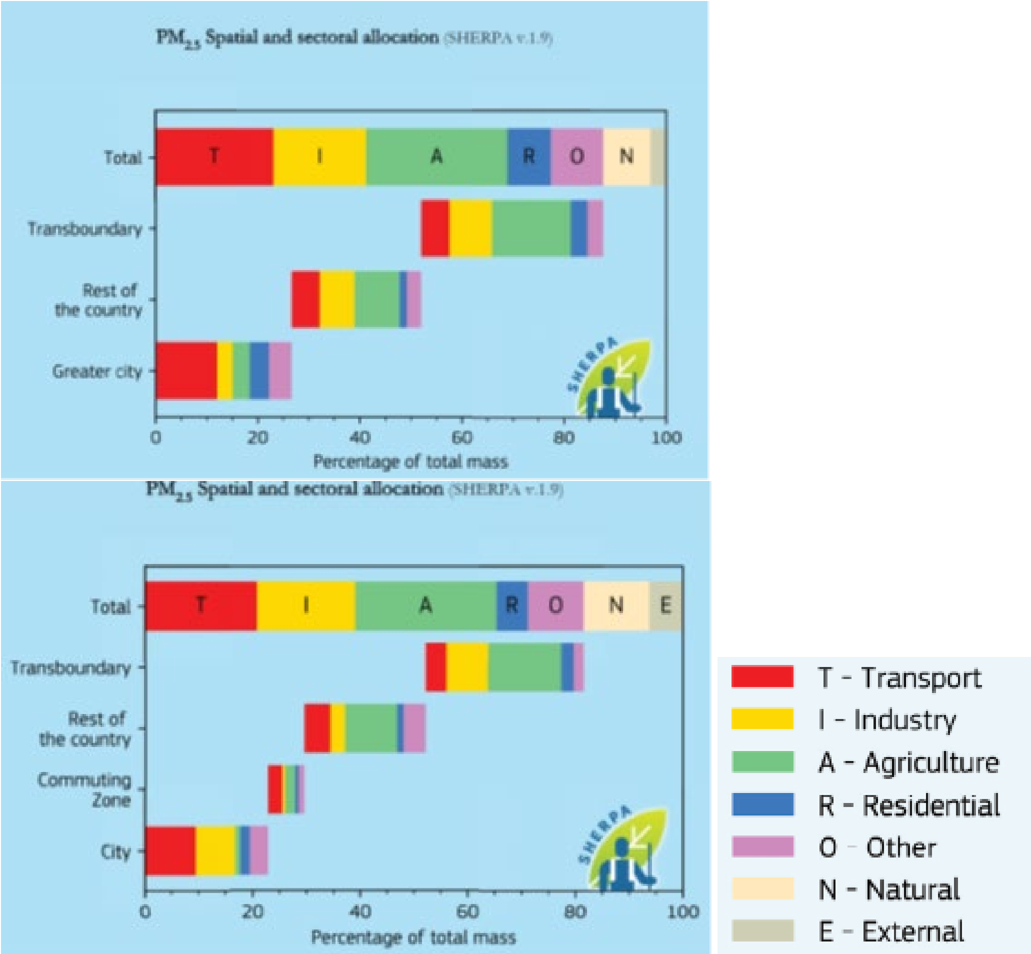

Figure 1: Sources of air pollution in Brussels (top) and Amsterdam (bottom) [source: SHERPA modelling, Thunis et al., 2018].

Impacts

Based on measured and projected concentrations, one can evaluate the changes in health risks due to air quality. To conduct a risk assessment, data are required on: 1) the level of air pollution in base year and target year, 2) the exposed population, and 3) the exposure-response relationship.

Most health impact tools use similar approaches and rely on epidemiological derived concentration-response functions and population weighted exposure estimates to determine the proportion of cases of a particular health effect (e.g. premature deaths or asthma) that can be attributed to air pollution. The assessment can become increasingly complex with a higher spatial resolution (e.g. national, city or street level) and with taking more than one pollutant into account.

The first step of an air pollution risk assessment is to estimate the exposure of the target population. A combination of monitoring data in combination with air quality modelling is often used to estimate differences in exposure for a population and to predict changes in exposure in different policy scenarios. For health impact assessment, data on the (actual or predicted) average exposure in a city, neighbourhood or street is a required minimum input, as well as the number of people that are exposed. For larger groups (e.g. the whole city) the outcomes will be more reliable than for a small group (e.g. a street), in order to reduce the 'noise' from confounding factors, such as the quality of housing and differences in life-styles. However, for larger groups it is required to estimate the 'population weighted exposure', where the estimated air concentrations in a grid cell or neighbourhood are weighted with the population number in that grid or neighbourhood.

The second step is to determine the health risk associated with exposure to air pollution. This requires concentration-response functions based on epidemiological studies.

The third step is to quantify the estimated health impacts (preferably including uncertainty ranges) As the relationship between exposure and different health risks is generally linear, estimated reductions in the annual average exposure can be translated into various health benefits.

The level-1 approach for quantifying the health impact of air pollution would include the AirQ+ tool which is developed by the WHO Regional Office for Europe. It can handle the following pollutants: $PM_{2.5}$, PM_{10}, NO_2, O_3 and black carbon (BC). The AirQ+ tool includes methodologies to assess the effects of long-term and short-term exposure to average ambient air pollution levels in a city. Various health outcomes related to mortality and morbidity, both in terms of acute and chronic conditions can be considered for the calculations.

More complex approaches could be used for assessing spatial differences in health risks across neighbourhoods or even streets (with decreasing statistical reliability for finer spatial scales). Models for combined assessment of stress factors such as various air pollutants, heat, noise and the availability of 'green' are still experimental.

Air pollution will also have non-health impacts, such as damage to vegetation (crops, tree growth), biodiversity loss (rapid growth of grasses, nettle and bushes that will crowd out less common plants , butterflies or birds) and materials. Some of these impacts depend on air concentration (e.g. ozone damage to crops or material damage due to sulfur concentrations). Risks of biodiversity loss requires estimates for deposition of nitrogen compounds and the exceedance of critical loads (this is the deposition level that will not lead to chemical and biological changes in the soil).

Last but not least, air pollution could influence temperature and rainfall patterns, and ozone and some forms of particulate matter are identified as short-lived climate forcers. The regional and local modelling of air and weather interactions is still in its early stages.

The impact assessment tool that is being used can be applied both for base-year, the (baseline) projections for the concentrations in future years and for alternative futures that assume further air quality improvement due to additional policy measures (responses).

Responses

To assist decision makers in selecting policy measures the main tools are:

- **Scenario analysis**: in this context, the available policy options will be "translated" in emission and concentration changes (using a multiscale approach to distinguish between measures that will impact the urban background and local measures for e.g. street canyons. Scenarios can include all available policy options showing maximum feasible improvements, or a selection of the available options, e.g. the low-cost measures.
- **Optimization approaches**: in this case the idea is to look for the optimal (best) compromises between air quality improvement and costs of policies. Integrated Assessment Models are fit-for-purpose tools to do so (as i.e. GAINS, Amann, et al, 2011 or RIAT+, Carnevale et al., 2012).

A key aspect for both (scenario or optimization) approaches is to have a full inventory of available emission reduction measures. Several inventories have been made of measures to improve air quality at local scale. Often they are focused at finding a solution to solve exceedances at certain hotspots (see e.g. the JRC catalogue of measures, at http://fairmode.jrc.ec.europa.eu/measure-catalogue/, the JOAQUIN Decision Support Tool, at http://www.joaquin.eu/Knowledge/Decision-

Support-Tool/page.aspx/121 and the list of indicative measures in annex VIII (p5-9) of the AAQD (2024): https://data.consilium.europa.eu/doc/document/PE-88-2024-INIT/en/pdf.

If considering the mobility sector, as an example, we can say that reducing traffic has a greater effect on population exposure than a shift to zero-emissions vehicles (because emissions from tires, brake and road wear will still continue). Stimulating zero-emission vehicles is more effective than a shift from diesel to petrol cars. The effectiveness of low emission zones depends largely on the size of the zone. In assessing the health impacts, one should realize that concentration reductions also occur outside the city, because cities are a net exporter of population and because measures will also cause a shift in vehicle types and modal split in the commuting zone around the city.

Table 2 gives a qualitative indication of the effectiveness of selected local measures for reducing the average population exposure to NO_2.

1.	Less car traffic – more walking, cycling & public transport	+++
2.	Electric vehicles, electric busses & LDVs/HDVs	++
3.	Low emission zones (…diesel ban?)	+
4.	Speed limits	+
5.	Traffic circulation plans, planting trees	+/-

Table 2: Qualitative indication of the effectiveness of local measures

The effectiveness of local measures for the average $PM_{2.5}$ exposure in a city is often limited, because a substantial part of the air quality is influenced by sources outside the city. Table 3 gives an indication of the effectiveness, at city scale, of measures taken i.e. on the agriculture sector.

1.	Reduction of SIA precursors (NH3, NOx, SO2) at international level	+++
2.	Emission reduction from industry, shipping and transport in the region	++
3.	Emission reduction from domestic heating in the region	++/+

Table 3: Qualitative indication of the effectiveness of measures outside the city

The selection of policy measures to be included in an air quality plan requires an interaction between experts and policy makers: Experts can show what is maximum feasible and what the impact is of leaving out certain policy measures. The implementation of the measures that are selected depends on public and political awareness and support, as well as the choice of policy instruments (promotion campaigns, use of economic instruments, regulation and/or infrastructural investments) and the available funding.

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