Indicators on Urban Air Quality

A review of current methodologies

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Abstract

To follow the development of the air quality in European urban areas, several sets of indicators have been developed over the years. At the European level, Eurostat, the European Commission and EEA use each a different set. This report discusses the similarities and differences in objectives, methodologies, assumptions made in calculating the indicator values and in input data between the three main indicators at the European level (Structural Indicator, Urban Audit indicators and the Core Set of Indicators).
Recommendations on streamlining the input requirements of the indicators and on harmonisation of calculation procedures are given. A possible extension of the indicator with $PM_{2.5}$-results is recommended. An additional indicator giving more directly information on the health impacts of air pollution is presented.

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1. Introduction

Indicators have been widely introduced to provide information in support to the development and implementation of environmental policies. Once these policies are developed and agreed, the progress of their implementation needs to be monitored by comparing key quantities to objectives and targets. At the European level, various international organisations, including the European Environment Agency (EEA, 2009) as well as the European Commission (EU, 2009) have developed a set of indicators for this purpose. Mainly the indicators are used for communications to a wider range of stakeholders and should therefore (1) be simple and easy to interpret, (2) provide a clear, representative picture of environmental conditions, pressure on the environment or society's responses and (3) be enable to show trends over time. Trends in indicator value give insights in what is happening in the environment and whether it is improving.

The European Commission evaluates the implementation of the EU strategy on sustainable development in its annual synthesis report on the basis of a number of headline indicators. At the Barcelona Spring Council in 2002 a set of so-called structural indicators was presented (Eurostat, 2009). In this limited set two indicators describe urban air quality; the indicators show the trends in urban population exposure to PM_{10} and ozone as the most risky air pollutants to human health[1].

The EEA is developing and updating indicators as a basis for their major reports like the State and Outlook reports, the annual Environmental Signals reports and the sectoral environmental reports on transport and energy. For five topic areas (air and climate, water, waste and material flow, terrestrial environment, nature and biodiversity) and for three sectors (energy, transport and agriculture) a core set of indicators has been defined as common basis for these reports. Focussing on air quality, the air pollution core set initially included indicators on the exceedance of limit and target values for the protection of human health for all pollutants for which such values has been defined in the Air Quality Directive (EC, 2008) and the pollutants listed in the fourth Daughter Directive. However, not all indicators have been developed. A preliminary analysis indicated that for benzene, arsenic, cadmium, nickel and benzo(a)pyrene the availability of data was too low to be representative for the EEA area (Barrett *et al.*, 2008). For two pollutants (CO and lead) the limit values have - with the exception of some hot-spot situations – largely been realised; for these pollutants there might be a need for a locally representative indicators rather than for a European wide indicator. For the remaining four (sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3) and particulate matter (PM_{10}, particles with an aerodynamic diameter of less than 10 μm)) indicators on exceedances have been developed.

The European Urban Audit, initiated by Directorate-General for Regional Policy, collects comparable statistics and indicators for European cities. Started in 2003 for the then 15 countries of the European Union it now involves 321 European cities in the 27 countries of the European Union, along with 36 additional cities in Norway, Switzerland and Turkey. Under Eurostat coordination, the work of the Urban Audit involves all national statistical offices as well as some of the cities themselves. Among the more than 250 indicators collected under the Urban Audit there are 6 indicators describing the air quality within the Urban Audit city. These indicators, providing information on the concentrations data for PM_{10}, NO_2 and ozone, are prepared by ETC/ACC and EEA. In addition similar data is delivered to the WHO for support to the Environmental Health Information System (ENHIS)[2].

This working paper will discuss the similarities and differences in objectives, methodologies and assumptions for calculation and in input data between the air quality indicators as defined in the Structural Indicators and in EEA's Core Set of indicators. The discussion will

[1] http://epp.eurostat.ec.europa.eu/portal/page/portal/structural_indicators/indicators/environment
[2] http://www.euro.who.int/EHindicators/Methodology/20060201_1

be extended to the possible application for providing detailed information at the urban level within the Urban Audit.

2. The current set of indicators

2.1. Structural Indicators

Objectives

The objective of the *structural indicator* (SI) is to follow trends in health impacts in the urban population attributable to the exposure from air pollution. For the European situation particulate matter and ozone are the most important pollutants in relation to health effects. Current knowledge shows that fine particulate matter ($PM_{2.5}$, particles whose aerodynamic diameter is less than 2.5 µm) is most likely the metric with regards to human health effects. However, monitoring information on $PM_{2.5}$ is still scarce. Links between annual mean PM_{10} (particles whose aerodynamic diameter is less than 10 µm) and health effects in urban environments has been clearly demonstrated in a number of health impact assessment studies (see e.g., the APHEIS study, Ballester *et al.*, 2008). The WHO recommends an air quality guideline for PM_{10} of 20 µg/m^3 as annual mean (10 µg/m^3 for $PM_{2.5}$). These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase significantly in response to $PM_{2.5}$ exposure (WHO, 2006).

Ozone (O_3) is the most important photochemical oxidant in the troposphere. It is formed by photochemical reactions in the presence of sun light and precursor pollutants such as nitrogen oxides and volatile organic compounds. The WHO recommends an air quality guideline of 100 µg/m^3 as daily maximum 8-hour mean. This concentration will provide adequate protection of public health though some health effects may occur below this level (WHO, 2006).

Definition

The indicator is based upon measurements of particulate matter (PM_{10}) and ozone as reported under the Air Quality Directive 2008/50/EC and its predecessors.
According to the recommendations of World Health Organisation (UN ECE, 2003), the annual mean concentration is the best indicator for PM-related health effects. The structural indicator value for PM_{10} is given by:

$$SI_{PM} = \frac{\sum_i C_i \times Pop_i}{\sum_i Pop_i}$$

where C_i is the annual mean PM_{10} concentration averaged over all (sub)urban background monitoring stations in an agglomeration *i* having a population of Pop_i. The summation is over all agglomerations in a Member State or – in the case of the aggregated EU27 Structural Indicator - in the whole EU27.

The principle metric for assessing the effects of ozone on human health is, according to WHO's recommendations (UN ECE, 2004), the daily maximum 8-hour mean. Ozone effects should be assessed over a full year. Current evidence is insufficient to derive a level below which ozone has no effect on mortality. However, for practical reason is recommended to consider an exposure parameter which is the sum of excess of daily maximum 8-h means over the cut-off of 70 µg/m^3 (35 ppb) calculated for all days in a year. This exposure parameter has been indicated as SOMO35 (sum of means over 35 ppb), and is extensively used in the health impact assessments[3], including the Clean Air for Europe (CAFE) Programme leading to the Commission Communication on the Thematic Strategy on Air Pollution.

The ozone structural indicator is given by:

$$SI_{Ozone} = \frac{\sum_i SOMO35_i \times Pop_i}{\sum_i Pop_i}$$

where $SOMO35_i$ the averaged SOMO35 value over all (sub)urban background station in an agglomeration *i* having a population of Pop_i. The summation is over all agglomerations in a Member State or in the whole EU27.

Data collection

Air quality data is collected on an annual basis according to the Exchange of Information Decision (97/101/EC amended by the Commission Decision 2001/752/EC). All data is stored in AirBase, the European air quality database accessible via http://etc-acc.eionet.eu.int/databases. It contains, next to multi-annual time series of measurement data and their statistics for a representative selection of stations throughout Europe, also meta-information on the monitoring stations, their networks and the measured pollutants. The information submitted to AirBase should be in compliance with the data quality objectives as described in the air quality directive; it is assumed that the air quality data has been validated by the national data supplier. Upon delivery by the Member States the European Topic Centre on Air and Climate Change (ETC/ACC) performs a number of quality checks on the data, see Mol *et al.* (2009) and references cited therein for further details on the contents of Airbase and the applied QA/QC procedures. In case in these procedures questionable data or information is found, the national data supplier is asked for action (that is, confirm, correct or delete the data).

Information on agglomerations has been extracted from the annual reporting under the Commission Decision 2004/461/EC of 29 April 2004 laying down a questionnaire to be used for annual reporting on ambient air quality assessment under Council Directives 96/62/EC and 1999/30/EC and under the Directives 2000/69/EC and 2002/3/EC of the European Parliament and of the Council. A preliminary report evaluating the questionnaire for the reporting year 2007 has prepared by de Leeuw and Vixseboxse (2008); analyses of earlier years are given by van den Hout (2006) and Vixseboxse and de Leeuw (2008).

In an ongoing process the ETC/ACC is, in cooperation with the national data suppliers, improving the quality of the information in AirBase. In the 2007 data submission cycle, corrections to previous submitted data and additional historical data covering years before 2007 has been received. To assure that the structural indicator is based on the most recent information, indicator values for all previous years (1999-2006) have been recalculated. This may introduce small changes in values compared to the indicator values calculated earlier for the period 1999-2006.

Compilation of national & European aggregates

The Structural Indicators are presented at the European level[4] and at the national level[5]. According to the Air Quality Framework directive each EU Member State has to divide its territory into zones and agglomerations. Information on agglomerations as defined by the

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[3] The general methodology has been endorsed in the Summary report prepared by the joint Task Force on the Health Aspects of Air Pollution of the World Health Organization/European Centre for Environment and Health and the Executive Body of the UN Convention on Long Range Transboundary Air Pollution: http://www.unece.org/env/documents/2004/eb/wg1/eb.air.wg1.2004.11.e.pdf

[4] see: http://ec.europa.eu/environment/indicators/pdf/leaflet_env_indic_2009.pdf

[5] see: http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsien100 (ozone data) and http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsien110 (PM10 data)

Member States is obtained from the Questionnaire used for annual reporting under the Framework Directive (2004/461/EC). For all EU27 Member States the questionnaire over the calendar year 2007 was available. As member of the European Economic Area, Norway and Iceland have voluntary submitted a questionnaire.

The questionnaire provides information of zones and agglomerations (area, population statistics) in the MS. Further, it lists for each zone and agglomeration the monitoring stations used for compliance checking under the framework directive. The stations listed in the questionnaire have been related to the information in AirBase in order to obtain additional meta-information on type and surroundings of the stations. A match between the two sets is made by relating the information in the questionnaire (EoI station code, local station code) with corresponding information in AirBase. Due to erroneous or incomplete information in the questionnaire (incorrect EoI codes, missing EoI station code and/or local station code, non-unique local codes) the link could not be made for a limited number of stations.

Information on agglomerations (population, monitoring stations operational within the agglomerations) has been extracted from the 2007-questionnaire (see de Leeuw and Vixseboxse (2008) for a preliminary analysis of the 2007-Questionnaire).

The 2007 information has been applied for the whole period 1999-2007. As the definition of the zones and agglomerations by the Member States may differ from year to year, (for example, in 2004, 1095 zones and agglomerations have been defined, in 2007 this number was reduced to 919), some uncertainties are introduced here. No attempts have been made to introduce year-specific population numbers.

From AirBase stations fulfilling the following criteria have been selected:

1. stations classified as *urban background* or *suburban background*; the stations classified as "traffic" or “industrial” are influenced by local (traffic) emissions and might not be representative for the concentrations in more residential areas and are therefore excluded from the indicator calculations;
2. stations having a data capture of at least 75% per calendar year (that is with more than 274 valid daily values per calendar year);
3. (sub)urban background stations used for compliance checking under the FWD (that is, stations for which a positive match is made between questionnaire and AirBase, see above) and assigned to an agglomeration.

After selection, for each agglomeration a representative mean concentration is obtained by averaging over all operational stations within the agglomeration. National and European aggregation is done by using the weighting procedure described above.

Data availability

All EU-27 member states provide PM_{10} and ozone air quality data which comply with the data quality objectives set in the directive. In addition air quality data is available in AirBase for eight non-EU countries (Mol *et al.*, 2009). However, due to the stringent selection criteria applied in the preparation of this indicator, not all countries could be included in the final calculations. PM_{10} data fulfilling all criteria is available for 17 MS since 2001 and for 23 MS since 2004. Ozone data fulfilling all criteria is available for 17 MS since 1999 and for 23 MS since 2004.

Reasons for not including a Member State in the structural indicator are (situation for 2007):

- no agglomeration defined within a Member State (Cyprus, Luxembourg);
- no operational (sub)urban background stations in the agglomerations or the data is not fulfilling the current criteria (Ireland (ozone only), Latvia).

Uncertainties

This indicator covers the population in the larger urban agglomeration as defined under the Air Quality Directive. Air quality data fulfilling all the stringent criteria set here is not available in each of the agglomerations. The PM_{10} agglomerations as defined in the AQ questionnaire on 2007 data are shown in Figure 1. The map illustrates the different approaches chosen by the Member States in designating the agglomerations. It further suggest an incorrect qualification of zones in Bulgaria and parts of Italy. In most of the zones (sub)urban background station are operational.

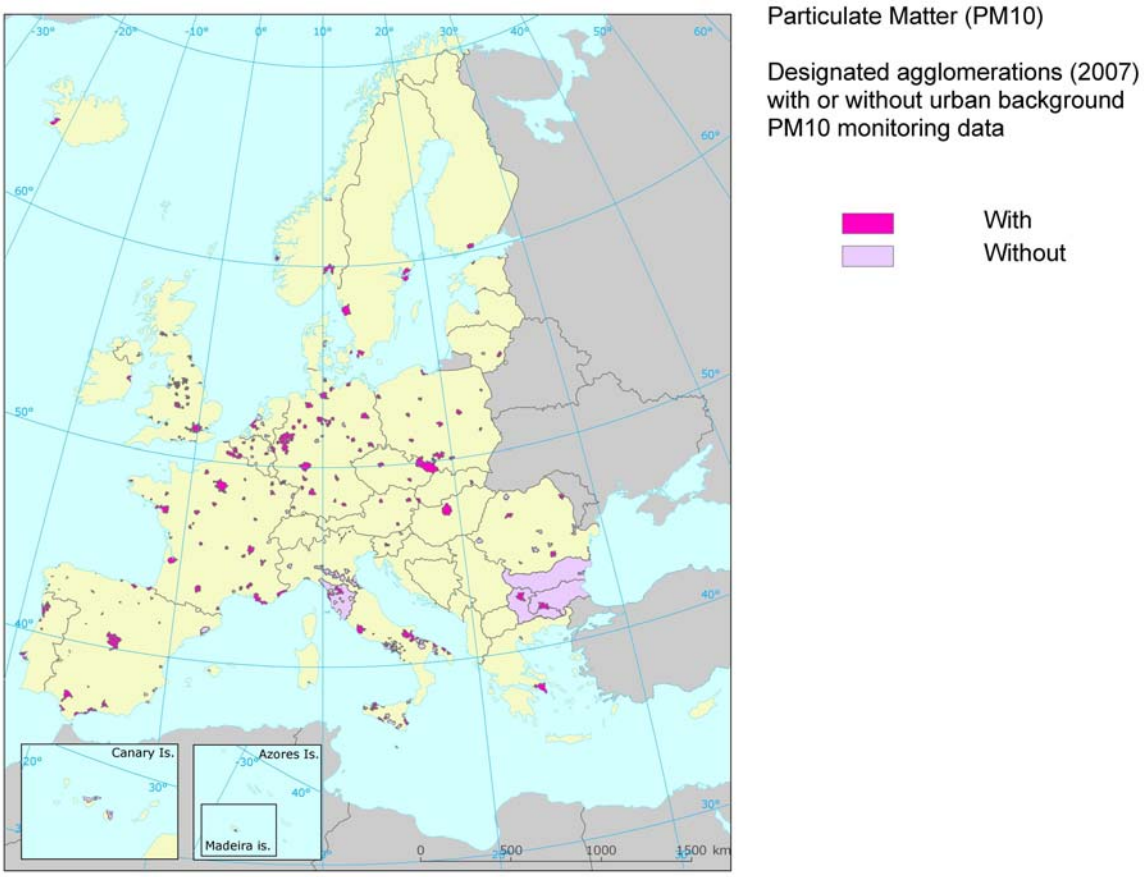

Figure 1. Designated agglomerations for PM10 (reference year 2007) with and without having one or more operational (sub)urban background monitoring stations. Note that four Italian regions (Abruzzom Basilicata, Lombardia, Veneto) could not be shown due to missing GIS information. In these regions 5 agglomerations have been designated; three of them have operational (sub)urban background stations and are included in the calculations.

The fraction of the total population living in agglomerations (177 million, de Leeuw and Vixseboxse, 2008) for which ozone data is available is steadily increasing from 70% in 1999 to 91% in 2006. In 2007 the coverage is reduced to 77% mainly caused by a strongly reduced reporting by Spain. Also in the United Kingdom, Latvia and the Netherlands less data on agglomerations is available over 2007. PM_{10} data is available for a population fraction increasing from 54 % (2001) to 86% (2006) which is in 2007 reduced to 80%. In the year 1999 and 2000 for 27% and 34%, respectively PM_{10} data is available. The indicator values for these years should not be seen as representative.

The rural population and the population living in smaller town and villages is not included. As PM_{10} tends to be higher and ozone tends to be lower in urban areas, the PM_{10} level will be an overestimation and the ozone level an underestimation of the total population.

The uncertainty in the individual air quality measurements is assumed to be within the quality objectives set in the Daughter directives (for PM_{10}: 25%, for ozone: 15%). However, different methods are in use from the routine monitoring of PM_{10}. Some of these methods are very sensitive for measuring artefacts. The air quality directive states that when a non-reference method is applied, equivalence with the reference method has to be ensured, if necessary, by applying a correction procedure. However, it can not be excluded that incidentally the data obtained by a non-reference method has not been or is not properly corrected prior to submission to AirBase. This may lead to a systematic underestimation for the stations concerned, see Box 1.

For interpretation of the air quality data it is essential to have information on the direct surroundings of the station as local sources may influence the concentrations. Although guidance is provided on how to classify the stations, difference in the interpretation of the guidance within the countries can not be ruled out. This might introduce differences between countries.

Comparability between countries

There are no harmonized rules for the designation of agglomerations. The number, size and the fraction of the total population living in agglomerations differs widely from one country to the other (see Figure 1 and the reports on analysing the reporting questionnaire of the air quality directive, Vixseboxe and de Leeuw (2008) and references cited therein). This will affect the comparability between countries.

The different monitoring strategies the national monitoring station networks might affect the comparability across countries. The air quality directive prescribes the use of a reference measuring method which ensures the comparability across countries. Comparability is further enhanced by selecting only data from urban and suburban background stations.

Comparability over time

Up to the first half of the 90ties, the information in AirBase is relatively low and mainly restricted to the EU15 countries. After 1996/1997 the number of stations increases strongly and a reasonable to good coverage of the whole EU27 is realised for ozone in 1999. Systematic monitoring of PM_{10} started even later; the realisation of PM_{10} monitoring networks started in many countries around in 1998 and was more or less completed in 2001.

Air quality levels strongly depend on the meteorological conditions. Figure 1 gives the best available estimate for the potential exposure of the urban population to air pollution but a possible long-term change in concentration might be less visible due to the meteorological induced year-to-year fluctuations.

Results

Figure 2 shows the population weighted mean concentrations of PM_{10} and ozone in urban agglomerations, averaged over the EU27 Member States. Over the years the PM_{10} concentrations show variations between 27-31 $\mu g/m^3$, that is, more than 50% above the WHO recommended guideline. Urban concentrations below the WHO-guideline are observed in 2007 in Norway, Sweden Finland, Estonia, and Ireland. Urban concentrations close to or above the current EU-limit value (40 $\mu g/m^3$) are observed in agglomerations in Bulgaria and, Romania. Although the emissions of primary PM and of the precursors are declining, the concentration data do not indicate any upward or downward tendency.

In the period 1999-2007 the ozone SOMO35 values vary between 3000 and 6000 ($\mu g/m^3$).day. The strong increase in ozone levels in 2003 has to be accounted to the weather condition: 2003 was a year favouring ozone production in the most parts of Europe (EEA, 2003). Ozone precursor emissions are steadily decreasing over the years. This is, however, not reflected in the ozone level: the population weighted mean does not show a clear increasing or decreasing tendency.

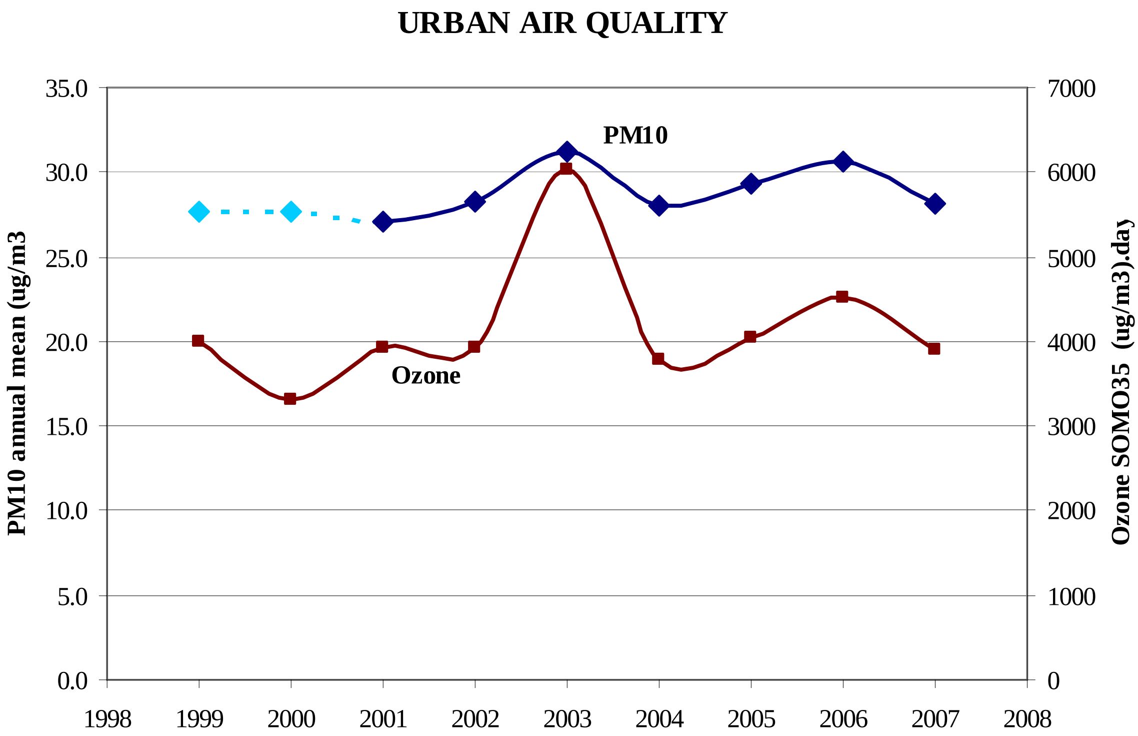

Figure 2. Population weighted concentrations of PM_{10} and ozone in urban agglomerations in EU27.

In Figure 2 the temporal variation of the spatial averaged indicators is shown. Not depicted in this graph is the spatial variation in indicator values over the EU27 area. This information is given in tabulated form (see the data sheets[4] at the Eurostat web site) but could also been included in the summarizing figure. In Figure 3 the range of 10- and 90 percentile values are given; 80% of the urban population is exposed to concentration within this range. Although slightly more complex, Figure 2 provides the reader in one glance a temporal and spatial summary of the indicator. Compared to Figure 3 the advantage of Figure 2 is a more simple structure of the figure and the combination of both pollutants in one figure.

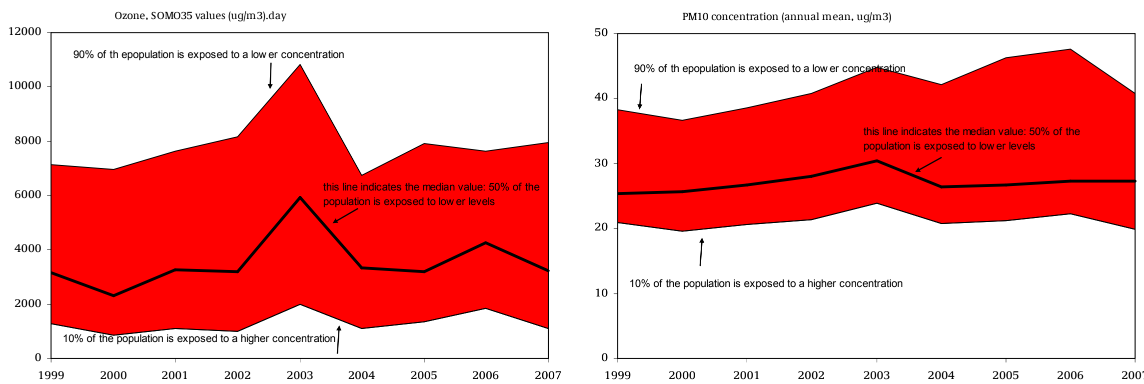

Figure 3. Alternative presentation of the structural indicator showing the spatial variability.

Box 1. Uncertainties caused by using non-reference methods for PM_{10}

PM mass is measured with different methods and instrument across Europe. The prevailing methods are:

- Gravimetry (sampling on filters with subsequent filter weighing in the laboratory), according to, or similar to, the CEN reference method.
- Automatic instruments using the beta ray absorption method (referred to as BAM method)
- Automatic instruments using the tapered element oscillating method (referred to as the TEOM method).

All methods require that acceptable QA/QC procedures are applied by the operating institution to provide quality data according to the requirements to accuracy set in the first Daughter Directive (EC, 1999). It is also established that the automatic instrumental methods need to be compared with the reference sampling method in order to provide comparable results, and that in most areas in Europe, results from the automatic methods need to be corrected.

Most countries have been or are investigating the correction factors (CF) to use for their PM mass measurements, according to the CEN 12341 standard methodology. Full information on the respective CFs used in different countries has not yet penetrated into AirBase, although many countries have already reported corrected concentration values to the database. Overviews of the CFs in AirBase are summarised in ETC/ACC Technical papers (see Buijsman and de Leeuw, 2004) and de Leeuw, 2005) and vary largely between 1.0 and 1.3. Many countries have station-specific CFs. The TEOM CFs are typically somewhat higher than the BAM. These differences in monitoring methods will hamper the comparability of the data between countries and are introduce an additional source of uncertainty.

In comparison to its neighbouring countries the concentration in France are relatively low in the PM10 concentration map given in Figure B.1 (Horalek *et al.*, 2007). It can not be excluded that these low levels to the fact that these data are not corrected despite they were obtained by non-reference measuring configurations (85% TEOM, 15% BAM) (de Leeuw, 2005). In their analysis of the France network, Aymoz *et al.* (2007) reported on the problems in demonstrating the equivalence of the French monitoring data with the reference method. In course of 2006 a nation-wide system to correct the non-reference has been introduced. The first results over 2007 have been reported (MEEDDAT, 2008). Although the correction procedure uses time and place dependent factors, national annual averaged correction have been deduced by comparing the corrected and uncorrected data for 2007. In a sensitivity run we tested how this new French correction method might effects the current findings. The averaged 2007 correction factors are assumed to be representative for 2005 as well; after correcting the French PM_{10} data, the mapping procedure and health impact assessment were repeated. This newly created map in shown right in the Figure; the increased concentrations in France are clearly visible. The population weighted average concentration increases from 19.1 to 24.8 $\mu g.m^{-3}$; this increase is in agreement with the 6.5 and 7 $\mu g.m^{-3}$ increase seen at urban and traffic sites after correction of the 2007 data (MEEDDAT, 2008).

By October 2008 France has for the first time submitted corrected PM_{10} data (reference year 2007) under the EoI. So far, corrected data for the previous years has not been delivered. This will introduces artefacts when analysing possible trends in PM_{10} concentrations, see Figures B.2 and B-3.

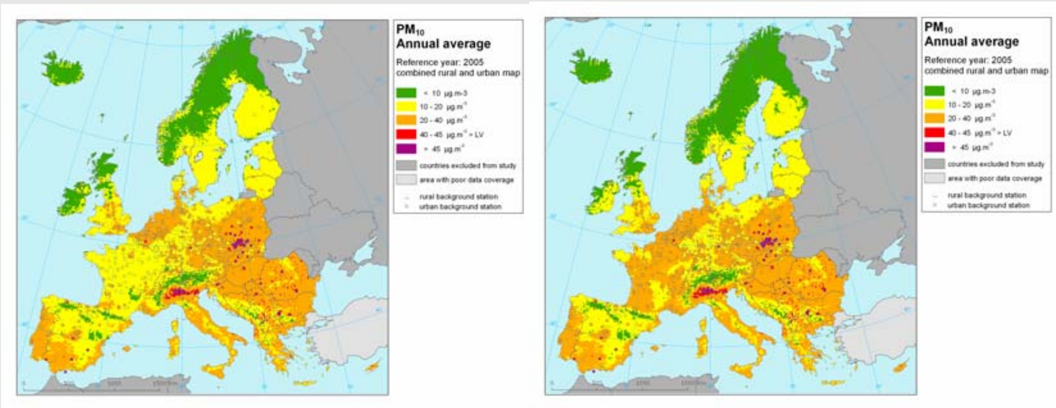

Figure B.1. Combined rural and urban concentration map of PM_{10} – annual average, year 2005 (left) based on PM_{10} measurements data as reported to AirBase. Spatial interpolated concentration field and the measured values in the measuring points. Units: µg.m-3. The same PM_{10} annual mean map (right) after correcting of the French stations using correction factors deduced from MEEDDAT (2008).

Figure B.2. Recent trend in PM_{10} stations in France and neighbouring countries (all available stations). While in the neighbouring countries the PM_{10} levels tends to be lower in 2007 compared to 2006, the French data shows a strong increase in concentration. This increased must be ascribed to the newly introduced correction for non-reference methods (MEEDDAT, 2008).

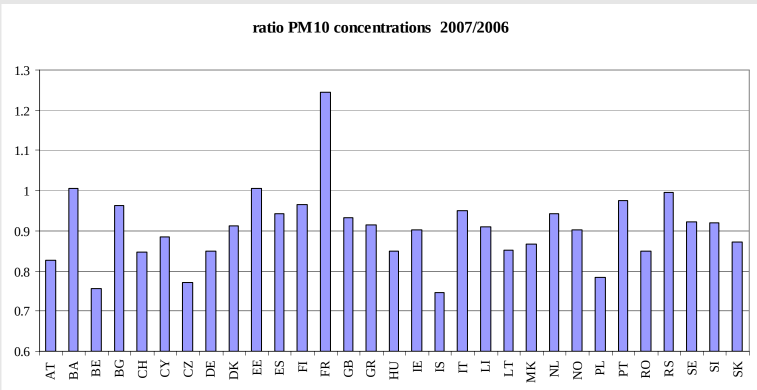

Figure B.3. Ratio of PM_{10} concentrations in 2007 and 2006 (all available stations) per country. While in whole Europe the ratio is less than one, the French data shows an opposite behaviour with an increase of about 25%. The lower levels in 2007 compared to 2006 rather indicate better dispersion and removal conditions in 2007 than a strong decrease in emissions.

The annual averaged correction factor has been applied to all French data over the period 2001-2006. As the PM_{10} Structural Indicator is only presented at a EU27 aggregated level, the sensitivity for this correction is relatively small: after correction the PM_{10}-SI is about 4-6%. The sensitivity of the SI averaged over the French agglomeration is of course much large over the period 2001-2006 the population weighted mean increases with 34% after correction. After correction the 2007-value is in line with the previous years.

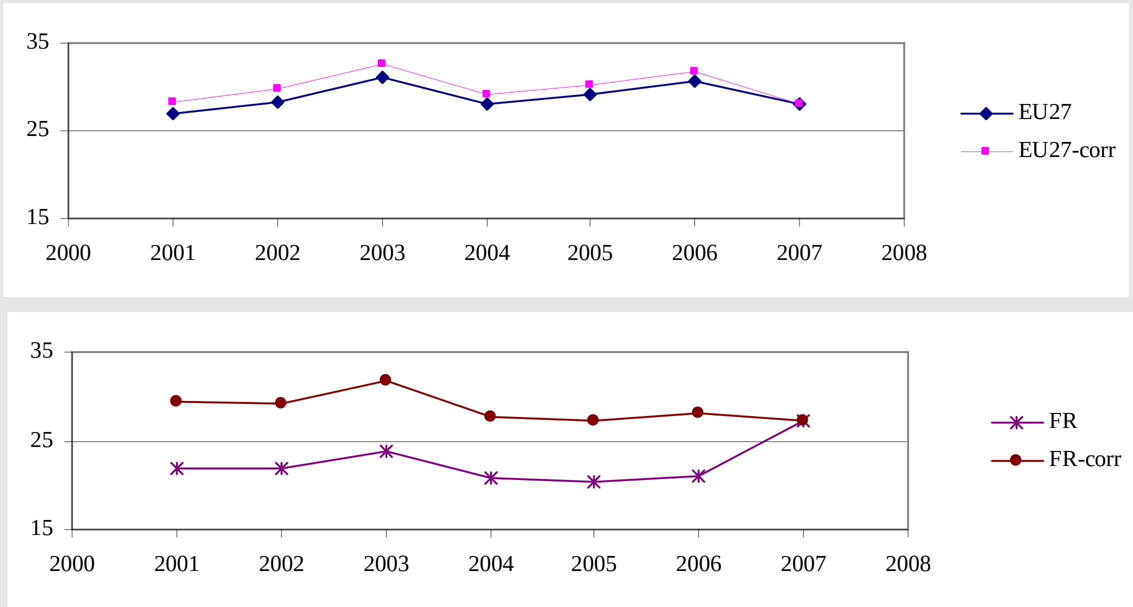

Figure B.4. Structural Indicator: population weighted PM_{10} concentrations before and after a first order correction of the French data (period 2001-2006) for non-equivalence monitors.

2.2. Core Set of Indicators

Objectives

The urban air quality indicator (labelled CSI04) shows the fraction of the urban population that is potentially exposed to ambient air concentrations of pollutants in excess of the EU limit value set for the protection of human health.

Definition

The indicator shows the fraction of the urban population that is potentially exposed to ambient air concentrations of pollutants in excess of the EU limit value set for the protection of human health.

In the Air Quality Directive 2008/50/EC health related limit or target values have been set for a number of pollutants. For SO_2, NO_2, PM_{10} and $PM_{2.5}$ more than one limit/target value has been set for different time scales. Evaluation of recent measurements (e.g in Mol *et al.*, 2009) indicates that the limit values set for one pollutant are in general not equivalent when two limit values have been. The most stringent limit values have been included in the core set indicator, that is, for:

- Sulphur dioxide (SO_2): the daily limit value (not more than 3 days/year);
- Nitrogen dioxide (NO_2): the annual limit value;
- Particulate matter (PM_{10}): the daily limit value;
- Ozone (O_3): the target value.

Note that monitoring data for $PM_{2.5}$ is still not widely available over Europe (Mol *et al.*, 2009) and therefore it is not yet possible to include a $PM_{2.5}$ indicator. Following the air quality directive $PM_{2.5}$ networks representative for the population exposure in urban areas with more than a 100 000 inhabitants have to be operational on 1 January 2009 the latest.

Data collection.

As is the case for the Structural Indicators all air quality data needed to calculate the indicators is extracted from AirBase (see above).

Information on cities and urban population is taken from the Urban Audit data set, see the description given below.

Compilation of European aggregates

The urban indicator CSI04 is not presented at the national level but only at the European level[6].

Similar to the procedure under the SI, from AirBase (sub)urban background stations having an annual data capture of at least 75% have been selected. A connectivity table between AirBase station and the Urban Audit core cities is made by overlaying maps of the city boundaries and AirBase stations.

After selection, for each city a representative mean concentration is obtained by averaging over all operational stations within the city. European aggregation is done by assigning the population in each city to one of the four exposure classes (see Figure 5).

Data availability

Within the Urban Audit project no cities have been defined in the Balkan countries (Albania, Bosnia-Herzegovina, FYR of Macedonia, Montenegro, and Serbia) and in Iceland and Liechtenstein (see section 2.3 on a more detailed discussion on the Urban Audit). To improve the coverage of the CSI04 indicator, the larger cities in these countries for which (sub)urban background stations are available in AirBase have been added. Information on city population has been taken from national statistical bureaus or from http://www.citypopulation.de/Europe.html. Note that the web-based presentation[6] of CSI04 is limited to the EEA32 member countries.

In the aggregation step the number of countries for which data is available depends on the year and on the component. Limiting the discussion to EEA32 member countries, for all four pollutants data at the national level is missing for Cyprus, Lichtenstein, Luxembourg and Turkey either because there is no air quality data is available in AirBase or there is no AQ data for (sub)urban background stations in the selected UA cities.

The extended UA city database covers 595 cities with a total population of 183 million in the EEA32 member countries. Excluding Turkey for which so far did not submit any air quality data to AirBase, reduces these numbers to 569 cities and a population of 157.7 million. The coverage of the indicator varies over the years (see Figure 5 below) with increasing coverage up to 2006 and a decrease in 2007. In 2006 the indicator covers 63-69% of the theoretical maximum.

Uncertainties

The uncertainty related to the air quality measurements and related to the station classification has been discussed above.

The population numbers have been provided by the Urban Audit and are (for most cities) representative for 2004. In the CSI04 application the 2004 data has been used throughout the full period. Scattered information on population numbers for other years is available from the Urban Audit. For a sensitivity test the population for each year in the period 1999-2007 has been estimated by exponential inter- or extrapolation for those cities for which at least for two years data is present. When data for only one year is available, the national urban growth rate data (UN, 2006) is used to estimate year specific population numbers. The total population of the cities included in CSI04 increases with 3.4% from 117.8 M in 1997 to 121.9 M in 2007. As results for CSI04 are only presented at an EEA32 aggregated level, the results are hardly different when a fixed (2004) population is chosen or when actual population numbers are used.

[6] See: http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20080701123452/IAssessment1219309276318/view_content

Comparability between countries

As results are presented at a European level comparability between countries is not an issue for CSI04.

Comparability over time

Criteria concern the minimal coverage in terms of member countries or in terms of covered population has not been defined. If one selects an arbitrary criterion of a coverage of at least 33% of the total UA population, the 1997-data for ozone and the PM_{10} data for 1997-2000 has to be disregarded.

Results

In EEA32 member countries during the period 1997-2007 (Figure 4):

- 20-50% of the urban population was potentially exposed to PM_{10} concentrations in excess of the EU limit value set. The fraction varies strongly during the period.
- 15-41% of the urban population was potentially exposed to NO_2 concentrations above the EU limit value. There was a slight downwards trend in the beginning of the period but levels are almost invariant during the last four years.
- 15-60% of the urban population in Europe was exposed to ambient ozone concentrations exceeding the EU target value. 61% of the urban population exposed to ambient ozone concentrations over the target value was recorded in 2003, which was the record year. As in the case of PM_{10}, the fraction varies strongly during the period reflecting the importance of meteorological variations.
- the fraction of the urban population that is potentially exposed to ambient air concentrations of sulphur dioxide in excess of the EU limit value set decreased from 11% to less than 1%, and as such the EU limit value set is close to being met in urban background areas.

Figure 4 shows the distribution of the population over various exposure classes combined with information on the size of the covered population.

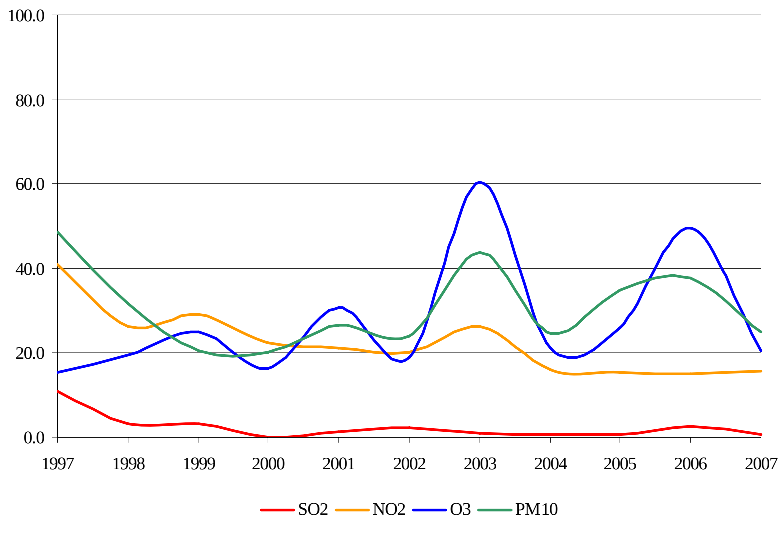

Figure 4. Percentage of the urban population resident in selected urban areas where pollutant concentrations are higher than selected limit or target values, EEA32 member countries.

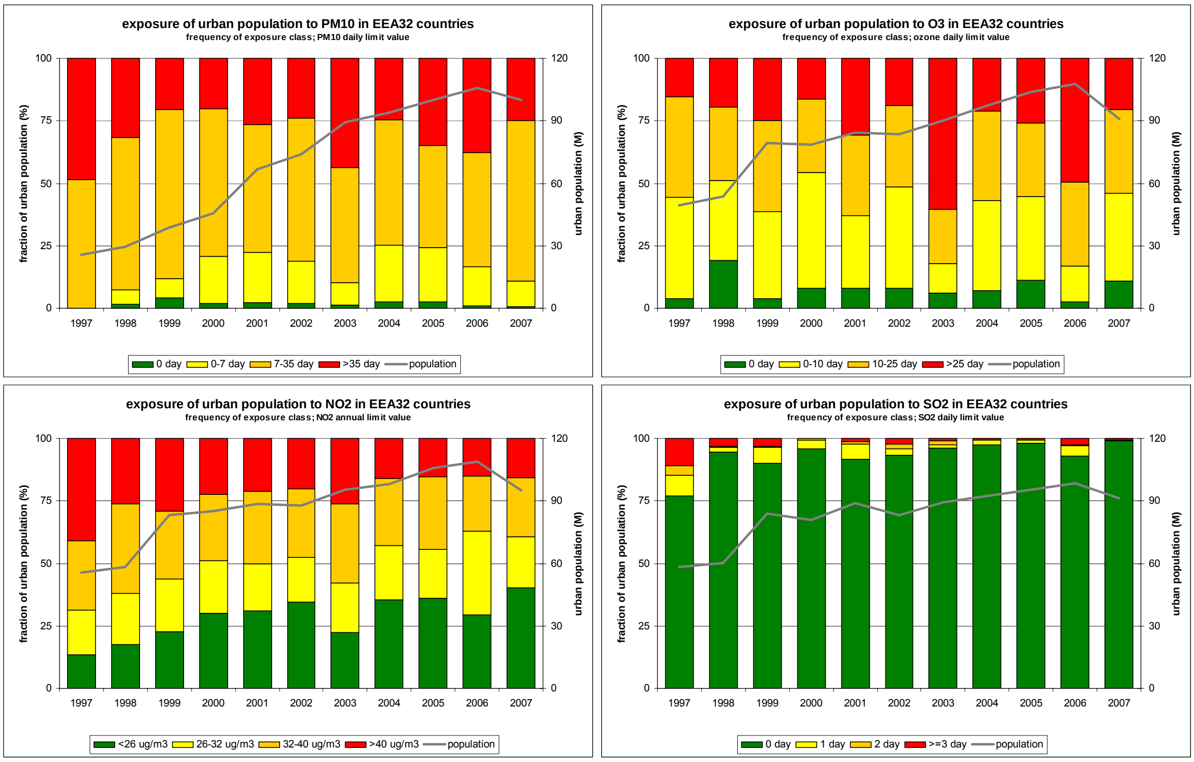

Figure 5. Percentage of population resident in urban areas potentially exposed to PM_{10} concentrations exceeding the daily limit value, ozone concentrations over the long-term objective for protection of human health, NO_2 concentration levels exceeding the annual limit value and SO_2 concentration levels exceeding the daily limit value, EEA32 member countries.

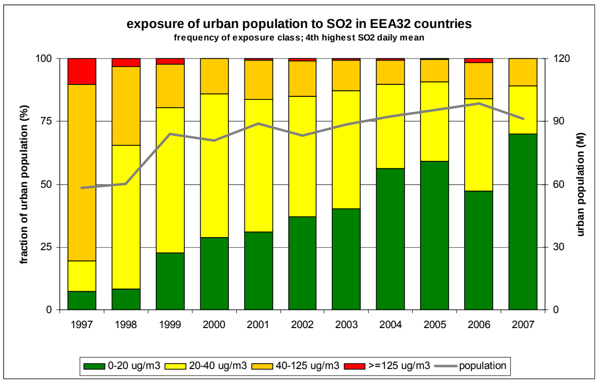

Figure 6. Alternative presentation of the SO_2 indicator, see text.

The SO_2 indicator is not very informative; Figure 4 shows a flat line just above zero, Figure 5 shows that during the last decade in almost all agglomeration the daily mean SO_2 concentration does not exceed the limit value of 125 µg/m3. The fact that SO_2 concentrations are still declining (Mol *et al*., 2009) is seen. When for SO_2 not the number of days but the 4^{th} highest daily mean is given (there is compliance when the 4^{th} highest value is below the limit value of 125 µg/m3), the figure shows the information on both aspects: no exceedance and still decreasing concentrations (see Figure 6). To be consistent a figure on the 4^{th} highest value for SO_2 should be combined with corresponding figures for ozone (26^{th} highest value) and PM_{10} (36^{th} highest daily mean). Such a change will not influence Figure 4 nor the size of the red bars (the fraction exposed to level above the LV/TV) as shown in Figure 5.

2.3. Urban Audit

Introduction

The Urban Audit (http://www.urbanaudit.org/) aims at a balanced and representative sample of cities in Europe. To obtain such a selection, a few simple rules are applied:

1. Approximately 20% of the national population should be covered by the Urban Audit.
2. All capital cities were included.
3. Where possible, regional capitals were included.
4. Both large (more than 250 000 inhabitants) and medium-sized cities (minimum 50 000 and maximum 250 000 inhabitants) were included.
5. The selected cities should be geographically dispersed within each Member State.

The selection of cities was prepared in close collaboration between the Directorate-General for Regional Policy, Eurostat and the national statistical institutes. To ensure that large and medium-sized cities are equally represented in the Urban Audit, in some of the larger Member States not all large cities could be included. Figure 6 shows the final set of cities used in this study.

The Urban Audit works with three different spatial levels: the city, the larger urban zone (LUZ) and the sub-city district (SCD). Here as well as for CSI04 only the city level is considered, which is the most important level. To ensure that this level is directly relevant to policy makers and politicians, political boundaries were used to define the city level. In many countries these boundaries are clearly established and well-known. As a result, for most cities the boundary used in the Urban Audit corresponds to the general perception of that city. Due to the highly diverse nature of political boundaries in the European Union, for some cities the political boundary does not correspond to the general perception of that city. In a few cities, Dublin for example, the political boundary of the city is narrower than the general perception of that city.

Objective & definitions

Objective of the Urban Audit indicators is to provide information on the air quality at the city level in relation to the limit and target values as defined in the Air Quality Directive. Currently the following UA-indicators have been defined:

- Indicator EN2002V[7]: The number of days when the maximum daily 8-h mean concentration of ozone exceeds 120 µg/m^3. This agrees with the long-term objective set for the protection of human health. As target value, to be met in 2010, the number of exceedance days may not be greater than 25 days per year.
- Indicator EN2003V[8]: The number of hours when the hourly NO_2 concentration exceeds the limit value of 200 µg/m^3.
- Indicator EN2005V: The number of days when the daily averaged PM_{10} concentration sexceeds 50 µg/m^3.
- Indicator EN2026V: Annual average concentration of NO_2.
- Indicator EN2027V: annual average concentration of PM_{10}.

[7] Indicator code as used by Urban Audit is given as reference.
[8] In the Urban Audit this indicator has been defined as the number of days when the hourly averaged concentration of NO2 exceeds at least once the limit value of 200 µg/m^3. Here we have adopted this definition to bring it in line with the requirements of the Air Quality Directive.

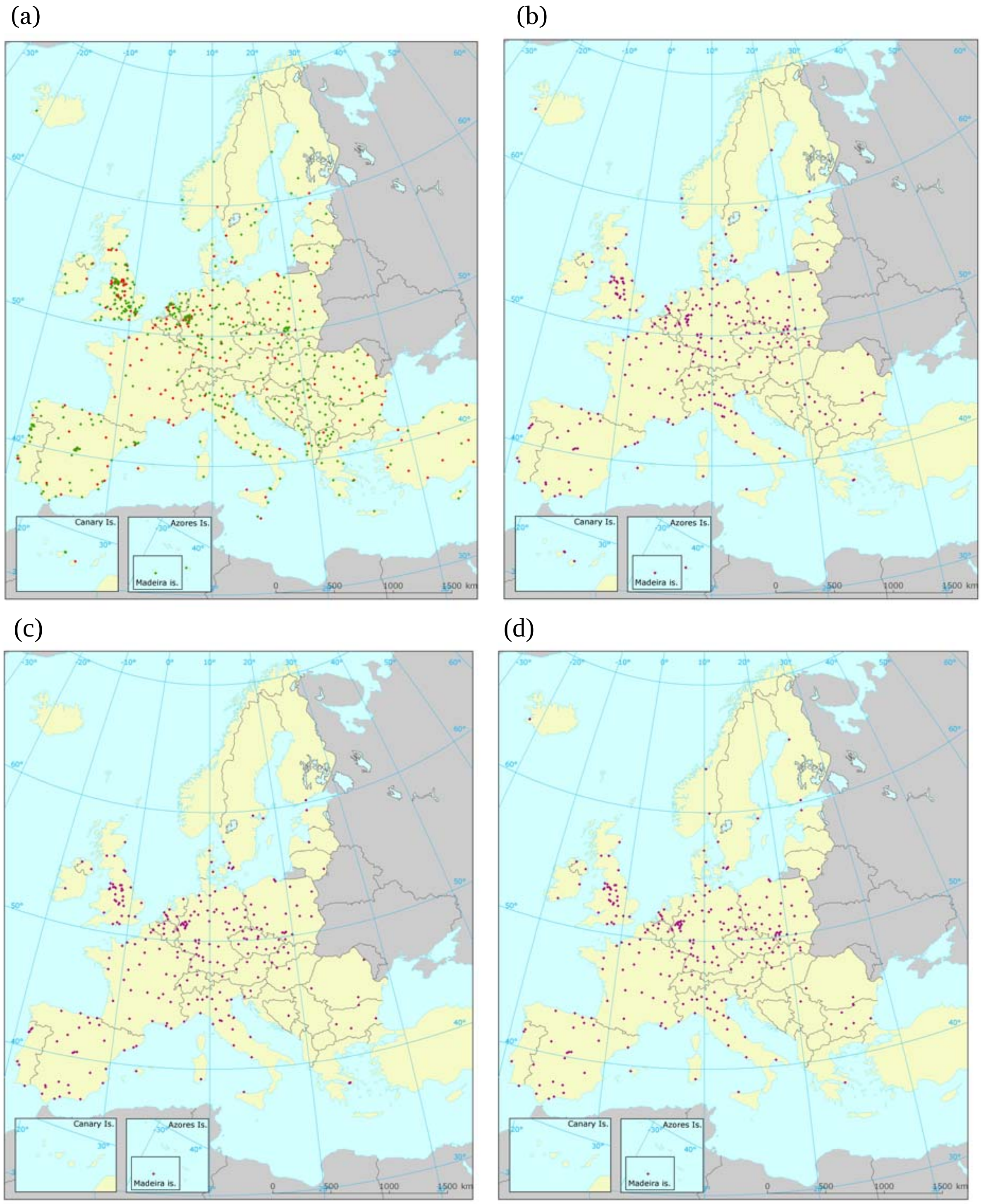

Figure 6: (a) Cities participating in the Urban Audit; cities having operational (sub)urban background stations for NO_2 (b),ozone (c) and PM_{10} (d).

In addition to these indicators related to compliance with the air quality limit or target values, an exposure indicator has been defined:

- Indicator EN2037V: Ozone SOMO35 value.

Data collection

The information in AirBase covers the data needs for the listed air quality indicators. No additional data is needed.

Compilation of city aggregates.

Similar to the procedure under the SI and CSI04, from AirBase (sub)urban background stations having an annual data capture of at least 75% have been selected. A connectivity table between AirBase station and the Urban Audit core cities is made by overlaying maps of the city boundaries and AirBase stations.

After selection, for each city a representative mean concentration is obtained by averaging over all operational stations within the city. The Urban Audit indicators are presented at the city level only; aggregates at the national or European level are not presented.

Data availability

For a number of cities no air quality data at (sub)urban background station is available in AirBase. In Figure 6 the cities available from AirBase have been indicated.

Uncertainties, Comparability between cities, Comparability over time

The uncertainty related to the air quality measurements and related to the station classification has been discussed above. Whereas in the SI and CSI04 indicators (random) errors may partly cancelled out when aggregating the results at national or European level, this is nit the case for the Urban Audit. Comparability between cities will be hampered by different approaches in station classification, network design etc. Changes over times might be influenced by changes in the number of operational stations or by relocation of stations. From Figure 6 it is clear that not in all cities within Urban Audit all pollutants are measured.

Results

Some results have been given in Table 1 and Figure 7. Table 1 gives the 30 most polluted cities for each of the six indicators for the reference year 2007. No attempt has been made to give an overall ranking of the cities as not all six indicators are available for all of the cities. Figure 7 shows examples of changes over time of the six indicators in selected cities. In selecting the cities pragmatic criteria have been used: (*i*) cities should preferably be listed in the top-30 of most polluted cities, (*ii*) they should have data for 10 or 11 years in the period 1997-2007 and (*iii*) the cities should be located in different countries. The selected cities will therefore not be representative for the full set but some observations can be made:

- In the ozone data the peak in 2003 illustrates the impact of the extreme heat waves during summer 2003. Over the eleven years there seems not to be a clear trend. In SOMO35. In all three cities the number of exceedance days is above the target value of 25 days; in Freiburg there is a tendency of decreasing but in Ljubljana of increasing numbers.
- The annual NO_2 concentration shows a very slow decrease; current concentrations are around the limit value of 40 $\mu g/m^3$; the number of exceedance hours of the short term limit value has been decrease and is now below the allowable 18 hours per year.
- The annual PM10 concentrations in Rotterdam show a very small decrease, in Ostrava tend to increase until 2003 when a decrease started and concentrations are now back to the levels at the end of the 20th century. In Krakow annual averages are increasing. A similar behaviour is seen in the graph of number of the exceedance days.

Table 1. The 30 most polluted cities for each of the six indicators. From left to right, top to bottom the following indicators are presented: ozone, SOMO35 in (μg/m³).day; ozone, number of exceedance days of a maximum daily 8-h ozone mean of 120 μg/m³; NO_2 annual mean concentration in μg/m³; NO_2, number of exceedance hours of the hourly NO_2 limit value of 200 μg/m₃; PM_{10} annual mean; PM_{10}: number of exceedance days of the daily PM_{10} limit value of 50 μg/m³.

cc	City	SOMO35	cc	City	O3-days	cc	City	NO_2 year
IT	Novara	11082	IT	Novara	100	IT	Napoli	67.6
RO	Craiova	10604	IT	Bergamo	88	IT	Modena	55.9
IT	Reggio nell Emilia	9828	RO	Craiova	88	IT	Brescia	54.0
BG	Burgas	9659	IT	Reggio nell Emilia	82	IT	Roma	53.9
GR	Athina	9407	BG	Burgas	80	IT	Padova	52.5
IT	Bergamo	9163	IT	Brescia	78	IT	Torino	48.9
IT	Torino	8775	IT	Torino	71	IT	Trento	48.5
IT	Padova	8513	IT	Padova	70	IT	Milano	44.6
IT	Bologna	8419	IT	Milano	61	GB	Manchester	44.5
IT	Brescia	8271	GR	Athina	59	GB	London	42.5
IT	Livorno	8188	IT	Bologna	58	PT	Matosinhos	42.4
MT	Valletta	8156	HU	Budapest	54	IT	Firenze	40.8
IT	Palermo	7904	IT	Cremona	53	FR	Toulon	39.7
IT	Pescara	7886	AT	Graz	49	IT	Verona	39.4
IT	Trieste	7731	IT	Modena	48	GB	Glasgow	39.3
FR	Toulon	7684	IT	Livorno	47	IT	Cremona	39.0
HU	Budapest	7671	IT	Trieste	45	FR	Marseille	38.8
PT	Faro	7480	IT	Firenze	45	IT	Novara	38.6
FR	Nice	7185	IT	Trento	45	DE	Frankfurt am Main	38.5
IT	Cremona	7153	SI	Ljubljana	43	IT	Vicenza	37.8
IT	Napoli	7150	FR	Toulon	42	GB	Leeds	37.3
FR	Ajaccio	7140	AT	Wien	39	FR	Lyon	37.2
IT	Milano	7111	CZ	Brno	39	NL	Rotterdam	37.2
AT	Graz	7037	SK	Žilina	39	IT	Ravenna	36.9
PT	Vila Nova de Famalicão	6920	IT	Prato	38	IT	Trieste	36.8
IT	Ravenna	6857	FR	Aix-en-Provence	38	FR	Paris	36.5
IT	Modena	6630	IT	Pescara	37	RO	Cluj-Napoca	35.6
IT	Firenze	6628	IT	Ravenna	37	DE	München	35.5
SI	Ljubljana	6514	IT	Venezia	36	ES	Pamplona/Iruña	34.8
FR	Aix-en-Provence	6476	FR	Nice	35	IT	Venezia	34.6

cc	City	NO_2 hour	cc	City	PM_{10} yr	cc	City	PM_{10} day
RS	Beograd	48	BG	Plovdiv	67.8	BG	Plovdiv	204
RO	Bucuresti	41	BG	Sofia	59.6	BG	Sofia	154
IT	Roma	17	PL	Kraków	57.3	RO	Timisoara	147
IT	Brescia	10	PL	Rybnik	50.7	PL	Kraków	140
BG	Sofia	9	RO	Timisoara	50.7	ES	Zaragoza	126
IT	Milano	9	PL	Nowy Sacz	50.2	ES	Torrejón de Ardoz	125
IT	Modena	6	PL	Bytom	49.3	IT	Cremona	120
IT	Genova	5	RS	Beograd	46.8	RS	Beograd	114
IT	Torino	4	ES	Torrejón de Ardoz	46.5	PL	Bytom	111
GB	London	4	ES	Zaragoza	46.0	IT	Bergamo	110
RO	Cluj-Napoca	3	PL	Zabrze	45.7	PL	Zabrze	110
FR	Paris	3	BG	Stara Zagora	45.4	PL	Rybnik	110
GR	Athina	3	IT	Cremona	45.2	PL	Nowy Sacz	108
BG	Plovdiv	2	IT	Bergamo	43.9	ES	Córdoba	101
IT	Bergamo	2	RO	Bucuresti	43.7	IT	Venezia	100
NO	Stavanger	2	ES	Jaén	43.3	RO	Bucuresti	100
SE	Västerås	2	ES	Córdoba	43.2	BG	Stara Zagora	98
GB	Leicester	2	IT	Venezia	43.1	PL	Dabrowa Górnicza	98
FR	Toulon	2	RO	Iasi	42.2	RO	Iasi	91
IT	Prato	2	RO	Suceava	41.8	ES	Jaén	87
FR	Lens - Liévin	2	PL	Dabrowa Górnicza	41.4	RO	Cluj-Napoca	85
PT	Lisboa	2	PL	Katowice	41.2	PL	Katowice	84
FR	Nancy	1	ES	Toledo	41.2	SK	Žilina	83
RO	Calarasi	1	RO	Cluj-Napoca	40.6	RO	Suceava	81
SE	Göteborg	1	PL	Bielsko-Biala	40.1	PL	Bielsko-Biala	79
GB	Glasgow	1	ES	Granada	39.8	PT	Matosinhos	73
FR	Saint-Etienne	1	BG	Pleven	39.5	CZ	Ostrava	73
BE	Bruxelles / Brussel	1	SK	Žilina	38.6	ES	Granada	70
FR	Limoges	1	ES	Albacete	38.5	BG	Ruse	67
FR	Marseille	1	ES	Jerez de la Frontera	38.5	ES	Toledo	66

Figure 7. Examples of time series of Urban Audit indicators: top left, ozone SOMO35, top right: ozone, number of days when the maximum 8-h mean concentration of ozone exceeds 120 µg/m³; middle left: NO_2 annual mean; middle right: number of hours when the hourly NO_2 concentration exceeds the limit value of 200 µg/m3; bottom left: PM_{10} annual mean; bottom right: number of days when the daily averaged PM_{10} concentration exceeds the limit value of 50 µg/m³.

3. Discussion

A summary of the three sets of indicators is given in Table 2. The three indicators have in common that they rely fully on measured data; gap filling procedures for correcting for missing neither additional or surrogate data nor information from atmospheric dispersion models is used in calculating the indicators.

Table 2 Comparison between the three sets of indicators.

	SI	CSI04	UA
Objective	population exposure	support to compliance checking	support to compliance checking; population exposure
Pollutants & selected statistical parameter	▪ PM_{10} annual mean ▪ ozone, SOMO35	▪ PM_{10} exceedance days ▪ ozone exceedance days ▪ NO_2 annual mean ▪ SO_2 exceedance days	▪ PM_{10} annual mean ▪ PM_{10} exceedance days ▪ Ozone SOMO35 ▪ Ozone exceedance days ▪ NO_2 annual mean ▪ NO_2 exceedance hours
AQ data	Airbase, (sub)urban background stations, coverage >75% Stations selection from questionnaire	Airbase, (sub)urban background stations, coverage >75% Stations selection based on GIS-overlay	Airbase, (sub)urban background stations, coverage >75% Stations selection based on GIS-overlay
City selection and population data	Agglomerations from questionnaire AQD	Urban audit	Urban audit
Aggregation level	population weighted aggregation at EU27 and national level	population weighted aggregation at EEA32-level	No aggregation , only city level

The **structural indicator** focuses on population exposure to the most risky air pollutants; the indicator variables (PM_{10} annual mean, ozone, SOMO35) have been selected following the recommendations of the WHO and are assumed to be the best proxy for estimating health impacts. It is now commonly accepted that the finer fraction of particulate matter ($PM_{2.5}$) is even a better proxy for health impacts than PM_{10}. Currently, monitoring data on $PM_{2.5}$ is less widely available than for PM_{10}. The number of monitoring stations will increase the coming years. It is recommended to include $PM_{2.5}$ in all three indicators in the near future.

Following the DPSIR-chain it could be argued that a structural indicator should not (alone) express the **state** of air quality but **impact,** in particular adverse helath effects of exposure to ambient air pollution levels.. The dose-response functions generally used in health impact assessments are linear in the ambient concentrations, see, for example Pope *et al.* (2002; 2006): for every 10 μg/m^3 change in $PM_{2.5}$ concentration there is a change of 6% in the number if incidences (e.g. premature deaths, years of life lost). Given this linear relation, the health impact assessment of current ambient concentrations will results in an indicator which mimics the concentration indicator almost perfectly; minor modifications will be introduced due to differences in baseline incidences and demographical differences between the countries or cities. The temporal behaviour and relative ranking of countries/cities will be the same for a state and impact indicator. The added information-value of such an impact indicator compared to the state indicator should be discussed. Alternatively, the impact indicator could be expressed in a *distance-to-target* way: what would health benefits be when the concentration in each city/country is reduced to the air quality guideline value of the WHO. For $PM_{2.5}$ the WHO (2006) recommends an AQG of 10 μg/m^3 as annual mean level. This is the lowest level at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to $PM_{2.5}$ (Pope *et al.*, 2002). Using $PM_{2.5}/PM_{10}$ concentration ratios typical for the European urban environment (de Leeuw and Horalek, 2009) 10 μg $PM_{2.5}$ per m_3 corresponds to 14-18 μg PM_{10} per m^3.

Main objective of **CSI04** is to evaluate current urban AQ levels in relation to limit/target values. As only (sub)urban background stations are included in the procedure, the air quality assessment is not conform the criteria stipulated in the directive for compliance checking. In principle, limit values have to be met at any location accessible to the general public that means, also at e.g traffic hot spot situations. More strictly speaking, CSI04 is a combination of compliance checking and estimation of long-term population exposures.
In the four daughter directives of the air quality framework directive cover in total 11 different pollutants for which in total 14 limit/target values have been set for the protection of human health. In the new air quality directive three additional $PM_{2.5}$ target/limit values have been defined. Four LV/TV have been selected to be included in CSI04. When for a pollutant two health related limit values have been defined the most stringent (the most widely exceeded) LV has been selected: PM_{10}-daily LV, NO_2 annual LV and SO_2 daily LV. The LV of lead (Pb), carbon monoxide (CO) and benzene are not included for either both or one of the following two reasons: i) scarcity of monitoring data, ii) concentration levels are low, exceedance of LV is only observed at a limited number of hot spots For the same reasons arsenic, cadmium and nickel are not included in the CSI04. For these heavy metals the concentrations are frequently below the lower assessment threshold (Barrett *et al*., 2008). For benzo(a)pyrene the situation might be different. Monitoring data is still scarce (2008 is the first reporting year under the 4th DD) but the available data indicates relatively large numbers of exceedances in central and eastern Europe. It might be considered to study the need and feasibility of including B(a)P in CSI04. Similar to the SI including $PM_{2.5}$ has to be considered.

The **UA-indicators** are a mixture of partial compliance checking and population exposure. The parameters covered by the UA are largely the same as in SI and CSI04; unique for UA is the indicator for exceedance of the hourly NO_2 LV. Similar to the SI including $PM_{2.5}$ has to be considered.

The calculation methodology is similar for the three indicators: after selection of the stations a city or agglomeration representative value is calculated by averaging the results of all (sub)urban background stations within the city/agglomeration. A higher aggregation (national, EU27, EEA32 level) is given as a population weighted average.

Differences between the indicators are found in the selection of stations: CSI04 and UA use the same set of AirBase stations. As a first step, a connectivity table between AirBase station and the Urban Audit core cities is made by overlaying maps of the city boundaries and AirBase stations. Out of this set the (sub)urban background station shaving a data coverage of 75% or more are selected. In the SI a different approach is used: the connectivity table between AirBase and the agglomerations is now extracted from the FWD-questionnaire. Differences are also found in the source of the population numbers: the SI extracts population numbers directly from the FWD-questionnaire where the MS provide this information on a voluntary basis. The Member States are free to define their agglomerations; in principle each year the agglomerations might be redefined which seriously hampers the construction of a consistent time series. This was not foreseen in the development phase of the Structural Indicator. As the Urban Audit project was in that time not yet started, agglomerations were judged to be the best available urban database. This argument has weakened over time and the use of UA-information has to be considered.
The CSI04 and UA use the population numbers from the UA database. *Note that the city-averaged values in UA (presented as final results) and CSI04 (seen as intermediate results, not presented but used as input for aggregation at EEA32 level) are identical.*

Selecting the target population

Table 3 gives the coverage of the indicators, both with respect to the total population as well as the urban population. The coverage of the indicator varies from year to year and from pollutant to pollutant. In Table 3 the highest coverage per country in the period 2005-2007 is given, the numbers refer to ozone as this pollutant generally has a better coverage than PM_{10}.
A comparison of Figure 1 and 6 shows that for EU Member States, Norway and Iceland, the agglomerations cover all UA cities with more than 250 000; smaller cities (100 000 to 250 000 inhabitants) and all cities outside the EU27 are not included in the agglomerations.
In the Air Quality Directive the concept of "average exposure indicator" (AEI) is defined. The AEI is a country-wide averaged level determined on the basis of measurements at urban background locations in urban areas in excess of 100 000 inhabitants; it should reflect the population exposure. In the AQ Directive the AEI-concept is used to estimate PM2.5 exposure but it can be applied to any pollutant. In principle, the use of air quality data and population numbers from the UA set will be a better way to estimate the AEI than an AEI based on agglomeration data. However, the lack of background data especially in the smaller UA cities will introduce uncertainties in the national AEI estimates. It might be necessarily to develop procedures for generalisation or gap filling.
The structural indicator extracts part of its input from the AQ Questionnaire and is therefore limited to the EU27 Member States plus Norway and Iceland The population coverage varies widely: from zero (Ireland having one agglomeration without any urban background station, Luxembourg which has no agglomerations defined) to 68% (Malta). About one third of the total population in the EU27 (46% of the urban population) is covered by this indicator. The population coverage by the CSI04 and the UA indicator is lower -for the EU27, 23 and 31% of the total and urban population, respectively – but more countries are included. The geographical size of an agglomeration tends to be larger than the core city and includes a number of smaller but still highly populated neighbouring cities. This explains the larger population coverage in the SI.

Table 3. Total population and urban population (in thousands, source: UN, 2006) and the maximum fraction (in %) of total and urban population, respectively, covered in the structural indicator and in the CSI04.

country	Total population	Urban population	SI % of tot pop	SI % urb pop	CSI04 % of tot pop	CSI04 % urb pop
Austria	8189	5404	25	39	28	42
Bosnia and Herzegovina	3907	1787	0	0	10	21
Belgium	10419	10129	23	24	22	22
Bulgaria	7726	5409	26	37	24	34
C zech Republic	10220	7513	28	38	26	36
Germany	82689	62171	35	47	24	32
Denmark	5431	4649	23	27	21	25
Estonia	1330	919	31	44	30	43
Spain	43064	33039	43	56	28	36
Finland	5249	3207	19	31	11	18
France	60496	46402	42	55	25	32
United Kingdom	59668	53534	41	46	31	34
Greece	11120	6558	32	54	9	15
Hungary	10098	6695	24	36	20	30
Ireland	4148	2508	0	0	1	2
Iceland	295	273	67	72	39	42
Italy	58093	39277	40	59	18	27
Lithuania	3431	2284	16	24	20	29
Latvia	2307	1565	31	46	32	47
Luxembourg	465	385	0	0	0	0
Malta	402	383	68	72	92	97
Netherlands	16299	13072	25	32	15	19
Norway	4620	3574	5	6	5	7
Poland	38530	23907	23	38	22	35
Portugal	10495	6047	42	72	13	23
Romania	21711	11650	15	28	14	26
Sweden	9041	7610	31	37	21	24
Slovenia	1967	1004	14	27	14	27
Slovakia	5401	3036	12	22	18	32
Switzerland	7252	5450	0	0	9	11
TFYR Macedonia	2034	1401	0	0	0	0
Serbia	7380	3838	0	0	15	29
EU27	487987	358354	34	46	23	31
EEA	500154	367652	33	45	22	30

Figure 8 illustrates the relation between agglomeration and the UA cities for the Netherlands. The Netherlands has defined 6 agglomerations in the west and southern part of the country. In five agglomerations urban background stations are located but in The Hague, Amsterdam and Utrecht the representativity of these station might be disputable. In total there are 35 cities in the UA data set of which 4 have more than 250 000 inhabitants and eight are below 100 000 inhabitants. Although the UA cities are mostly located in the western and southern part of the country, a better geographical spread is seen than in the case of agglomerations. This example for the Netherlands will be representative for the situation in other countries as seen by comparing figure 2 and 6. The agglomerations cover the more densely populated parts of the country; the UA cities are more representative for the total urban population within a country.

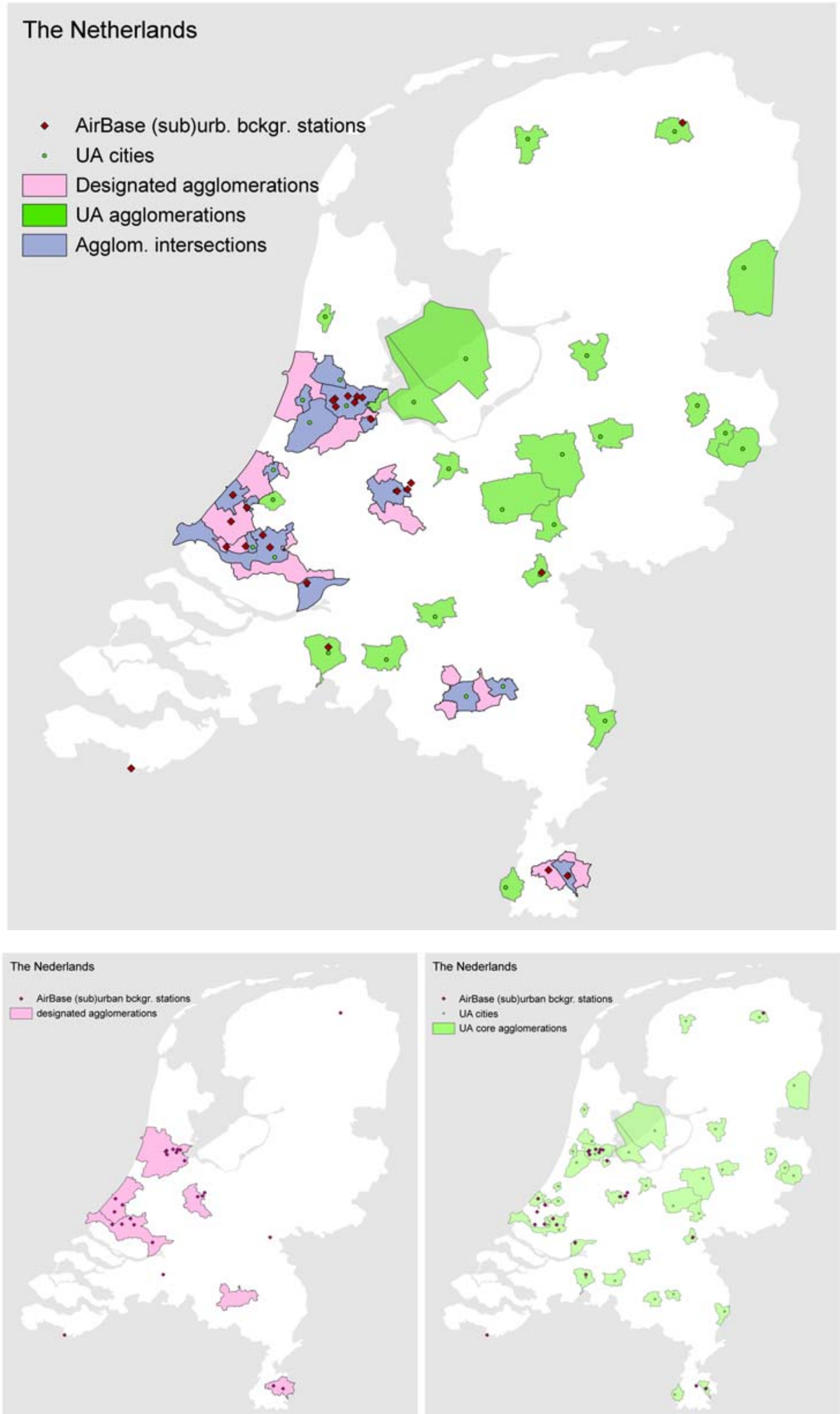

Figure 8. Overlay between agglomerations (bottom left) and UA core city (bottom right) in the Netherlands. The monitoring stations shown are all stations for which data is available in AirBase; some of them are not longer operational.

A population weighted averaging of the CSI04 (or UA) SOMO35 and PM_{10} data results in a indicator value similar to the SI. Differences are caused by the differences in population coverage (Table 3). A comparison is given in Figure 9 and 10. The variation over time are very similar although the SI is systematic a few percent higher, both for ozone as well as for PM_{10}. The data at national level agree well with a slope of nearly 1 and a correlation coefficient of >0.95. There is no difference in the correlation for an extreme year like 2003 or a “normal to low” year as 2007.

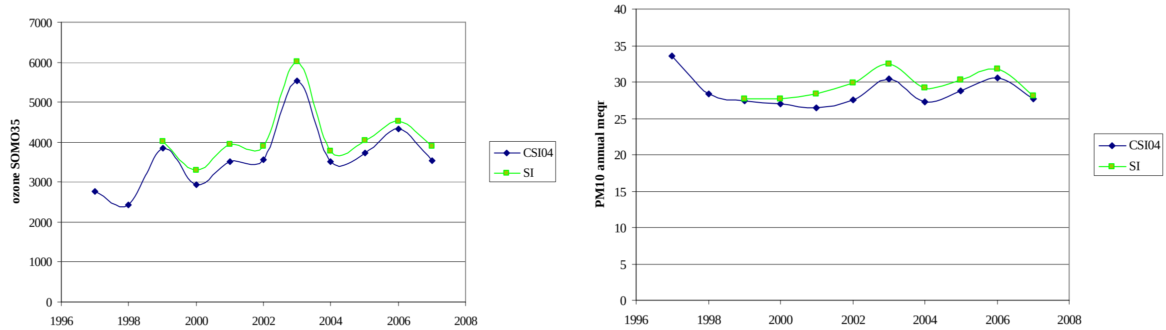

Figure 9. Time series of ozone (SOMO35; left) and PM10 (annual mean; right) calculated as population weighted mean for all cities used in CSI04 and agglomerations in SI.

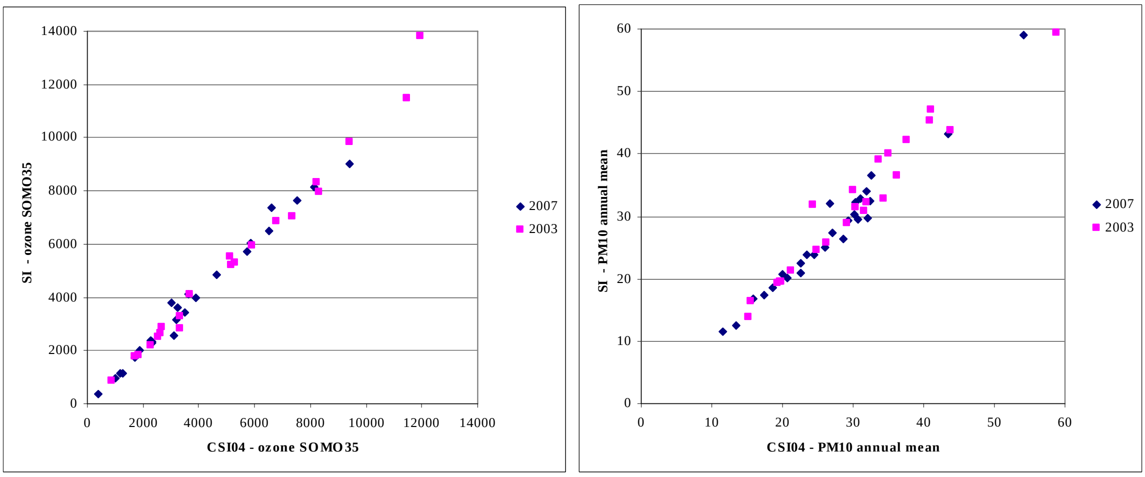

Figure 10. Comparison of ozone (SOMO35; left) and PM10(annual mean; right) calculated as population weighted mean for all cities used in CSI04 and agglomerations in SI, national averaged for EU27 Member States..

For the structural indicator and for CSI04 the target population group is not well defined. The population within an agglomeration may vary three orders of magnitude: from less than 10 000 to almost 10 million inhabitants. The CSI04 indicator now includes as many cities as possible. In view of the discussion above, a clear definition of the target population is recommended. For an *urban* air quality indicator we have three options:

- include as many cities from the Urban Audit list as possible. This is the current practice for CSI04. The coverage may differ from year to year and the development of gap filing procedure to correct fro missing cities is recommended;
- include cities with a population of 100 000 inhabitants and more. This corresponds to the definition of the AEI. When gap filling procedures are applied for missing cities, a well-defined indicator is obtained
- include cities with more than 250 000 inhabitants or more. This corresponds largely to the definition of the SI with the exclusion of the smaller agglomerations. Advantage here is that also urban agglomerations outside the EU27 are included (note that due to lack of AQ data Turkey can not be included); disadvantage is the relatively low coverage of the urban population: this selection covers about one third of the total

urban population (Table 3) and about two third of the population living in the complete UA city list.

A fourth option is to include the *total* population. As Table 3 shows, the indicators by far do not cover the whole population, population living in rural areas, villages and in smaller cities are not included. A country-wide population weighted mean values can be calculated on the basis of the interpolated maps (de Smet *et al.*, 2009 and references cited therein). These maps provide concentrations at a spatial resolution of 10x10 km. National population weighted concentrations of PM_{10} and ozone as obtained from the SI and from the air pollution maps are compared in Figure 10. The correlation between the exposures of total population (map-based) and urban population (SI) is good although the ozone values show some more scatter. Interpolated maps have been produced for 2004, 2005 and 2006; there is no difference in correlation for these years. The (urban) PM_{10} values calculated in the SI is about 30% higher than the values calculated for the total population. This is reflecting the higher concentration in the densely populated agglomerations. For ozone lower values are calculated for the SI than for the concentration maps; due to the chemical reaction between ozone and the local NOx emissions the ozone concentrations are lower in urban areas.

This agreement shows that the development of an exposure indicator for the total population is feasible but requires further study. Maps for the period 1997-2003 have to be prepared and further validation will be needed. A practical point to consider here is the timing of the indicator production. The production of the indicators based on AirBase information only can start as soon as the new data is uploaded in AirBase (1 March), A draft version of the indicators using the AirBase data can be available by June. When the indicators are based on the interpolated maps there is a delay of at least six months. The production of the maps can only start after the final runs of the EMEP dispersion model are available (September).

It can be concluded that a discussion on the target groups of the indicators (population in agglomeration, in cities or total population) in particular the ones aiming at health impacts, should be initiated

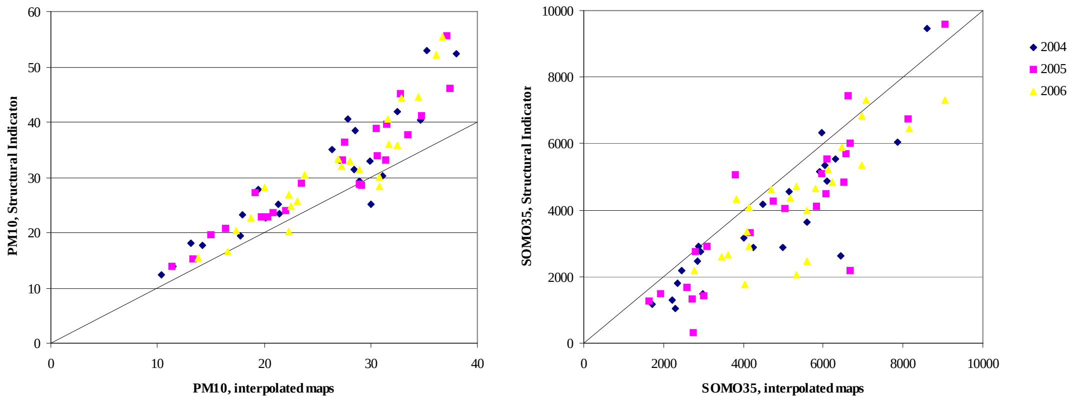

Figure 11. Comparison between the population weighted PM_{10} concentration (annual mean) and ozone concentration (expressed as SOMO35) obtained from the Structural indicator and the weighted PM_{10} and ozone concentrations using the total population based on interpolated concentration maps (de Smet et al. 2009). The line corresponds to the x=y line.

4. Towards a health impact indicator

Within the DPSIR-chain the atmosphere is well described with indicators for driving forces (e.g energy demand), pressure (e.g. air pollutant emissions) and state (e.g. the indicators discussed here). At the moment there is no indicator on impacts of air pollution. The CSI05 indicator describing the exposure and exceedances of critical loads and levels of ecosystems to acidification, eutrophication and ozone is also a state indicator.
Health impact assessments have been published starting either with European concentration maps (Horalek et al. 2007, de Leeuw and Horalek 2009) or with observed urban air quality data (Ballester et al. 2008). This methodology could be applied to come to an estimate of the health impacts in urban areas which could form the basis of a health impact indicator.

A sustainable health impact indicator could provide information of the current health impacts compared to the sustainable situation as set in 6th EAP: *"levels of air quality that do not give rise to significant negative impacts on, and risk to human health and the environment"*. Here we studied the feasibility of preparing such an indicator assuming the following starting points:

(i) It builds on the urban air quality as available from the CSI04/UA indicators (chapter 2.2 and 2.3). The calculation of city-specific air quality data has been discussed above and needs no further explanation.

(ii) It limits to the health impacts of ozone and particulate matter, being the most relevant pollutants as discussed in chapter 2.1;

(iii) Both mortality and morbidity health endpoints are selected. This selection is guided by the CAFE CBA analysis (Hurley et al. 2005).

The WHO (2006) has defined Air Quality Guidelines (AQG) for ozone and particulate matter. For $PM_{2.5}$ a guideline of 10 µg/m³ as annual mean is set. This is the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to $PM_{2.5}$ (Pope et al. 2002). The use of the $PM_{2.5}$ guideline is preferred. For ozone the guideline is set to 100 µg/m³ for the daily maximum 8h-mean. This concentration will provide adequate protection of public health, though some health effects may occur below this level. In the current methodology the ozone SOMO35 value is used in the concentration-response function. From AirBase the SOMO35 is plotted against the maximum daily maximum 8h-mean (Figure 12); the relation between the two parameters differs from year to year but in general one can say that with a SOMO35-value of 500 (µg/m³).day the AQG is most likely not exceeded. This value is therefore used as sustainable concentration.

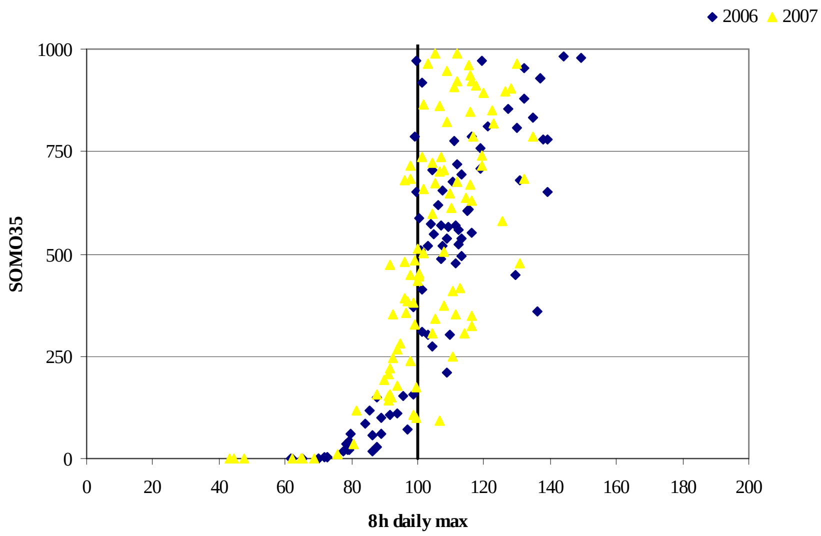

Figure 12. Statistical relation between SOMO35 and maximum daily maximum 8-h mean, reference years 2006, 2007. Source AirBase.

Any health indicator will critically depend on the selected end point and associated concentration-response functions. Next to total mortality, we have selected in this feasibility study a limited number of morbidity health end points. After valuation these end points account for more than 90% of the total valuation of morbidity effects (Hurley et al. 2005). As the end points have very different output (years of life lost, hospital admissions, activity days etc.) valuation is the only option to estimate the total health damage. The values applied here are in agreement with those used in the CAFE cost benefit analysis. A summary of health end points, the applied concentration-response functions and the valuation of end points are given in Table 4 and 5.

Table 4. Mortality relative risk associated with a 10 μg/m³ change in $PM_{2.5}$ or ozone concentration (Pope et al. 2002; WHO 2006a), concentration-response function used in estimation of morbidity health end-points (Hurley et al. 2005; WHO 2006b)

pollutant	Health outcome	Relative risk per 10 μg/m³ (95% CL)
$PM_{2.5}$	Total mortality, adults > 30 year; excluding violent death	1.06 (1.02 – 1.10)
Ozone	Total mortality, adults > 30 year; excluding violent death	1.003 (1.001-1.004)
PM_{10}	New cases of chronic bronchitis , adults > 27 year	26.5 (1.9 - 54.1) new case per year per 100000 adults >27 year
$PM_{2.5}$	Restricted Activity Days (RADs)	902 RADs per 1000 adults at age 15-64
PM_{10}	LRS symptom days , children at age 5-14 year	1.86 (0.92 - 2.77) extra symptom days per child
PM_{10}	LRS symptom days, adults (>15 year) with chronic respiratory symptoms	1.30 (0.15 - 2.43) extra symptom days per adult with chronic symptoms
Ozone	Minor restricted activity days (MRADs)	115 (44 – 186) MRADs per 1000 adults aged 18-64 years
Ozone	Cough and LRS, children aged 5-14 years	0.93 (0.19 – 2.22) cough days and 0.16 (0.43 – 0.81) days of LRS (excl. cough) per child aged 5-14 years

Table 5 Values for use in sustainable health impact indicator: effects of mortality and morbidity

Health outcome	value
VOLY- median	€ 52000 per year lost
VOLY-mean	€ 120000 per year lost
hospital admission	€ 2000 per admission
chronic bronchitis	€ 190000 per new case
restricted activity day	€ 83 per day
MRAD	€ 38 per day
LRS day	€ 38 per day
cough day	€ 38 per day

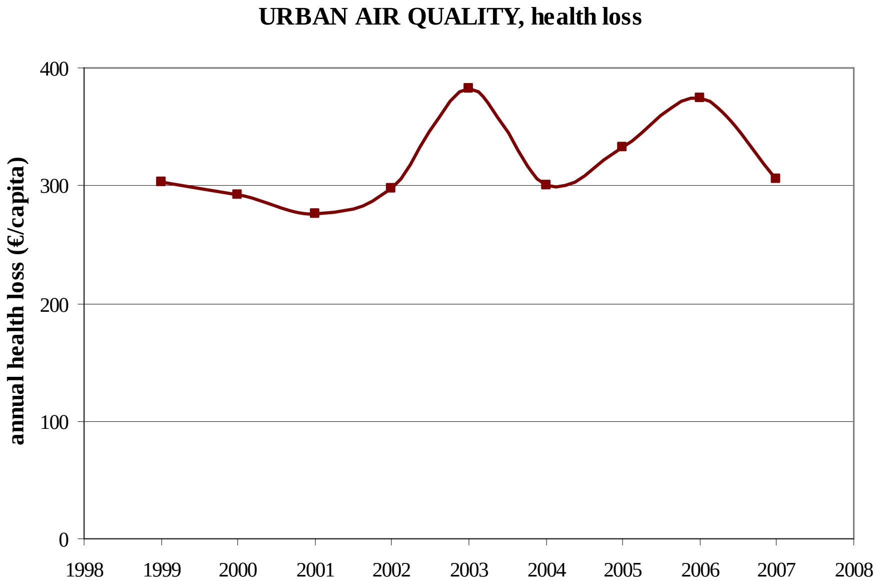

Figure 13. Health loss (in € per capita per year) of current urban air quality compared to the sustainable levels.

In the most recent years about 250 cities are included in the CSI04 indicator. It is evident that the total cost estimates are very sensitive for missing cities. To reduce the sensitivity, we firstly evaluated the cost per capita for each city and in a second step a European wide average was made by a population weighted averaging of the city results. It is recommended to develop more robust gap-filling methods.

Final results are given in Figure 13. The graph resembles the PM_{10} graph of the Structural Indicator; health impacts attributable to the exposure of particular matter are substantially larger than those from ozone. When the sustainable levels would be met, each European city-dweller would have a benefit of 300-400 € per year; a clear upward or downward tendency is not seen over the studied period. Note that the median value of a life year is applied in the calculation. As mortality dominates the total health damage, the use of the mean VOLY (120 000 €) will result in an estimate of health damage which is at least twice as high.

It is concluded that with current knowledge and available data an indicator for the health impact of air pollution in urban areas can be made. Further work on refining the indicator and for reducing the uncertainties is needed.

5. Recommendations

- In all three indicator sets $PM_{2.5}$ (annual mean values) should be included. Restrict the AQ parameters used in the indicator to those being to most relevant for public health (annual means of PM_{10}, $PM_{2.5}$ and ozone-SOMO35) and to those having the largest compliance problems (annual mean NO_2, exceedance days PM_{10}, and ozone). Further work has to be done to evaluate the health relevance of B(a)P at the European level. Possibly B(a)P (annual mean) should be added to the indicator. Monitoring data shows that the limit/target values set in the air quality directive for the remaining pollutants (SO_2, CO, benzene, lead, arsenic, cadmium, and nickel) are still exceeded in Europe. In general, the exceedances have a very local character which makes them less suitable to be included in a European indicator (see e.g. the SO_2 indicator Figure 5).

- Harmonisation of input data of the three indicators: air quality data is selected from AirBase, information on cities and population numbers is taken from the Urban Audit. The use of UA-data enables a regular update of population numbers (once per three year).
- Within the Urban Audit data collection procedures the cities are asked on a regular basis to provide information/data for UA indicators. In this process it is recommended to pre-fill the questionnaire send to the city authorities with the results extracted from AirBase. If air quality data is available at the city level but is missing in AirBase, the cities are encouraged to submit their data to AirBase so that the flow of data is improved in the future.
- It is recommended to open the discussions with stakeholders on the target population:
  - should all cities be included in the indicator,
  - or only cities with more than 100 000 inhabitants (like in the AEI-calculations)
  - or cities with more than 250 000 inhabitants (like in the SI)
  - or should the total population (including those living in small towns, villages and rural areas) be included ?

  In the first three options the indicator could be based on monitoring data only. However, it is recommended to develop gap-filling methods for correcting for missing data (not for all cities air quality data will be available for the full period). In the last option, the density of the monitoring networks is too low to estimate a representative exposure of the total population based on the observations only. A combination of monitoring data with the results of air quality transport models and supplementary information (see the interpolated air quality maps given by de Smet et al 2009 and references citied therein) or model results alone may form the basis for the exposure estimates. The resolution used in the mapping/modelling procedures might be crucial; further work needs to be done here.
- It is recommended to start the discussions with stakeholders on the development of indicators on health impact of air pollution.
- The use of non-reference method for PM monitoring without ensuring equivalence with the reference method may cause an underestimation of the PM-indicator as the example of France showed. When intercomparison studies results in new corrections factors or correction methods the MS have to apply, where appropriate, these newly developed methods for correcting historical data.
- Reconsider the presentation of indicators: uncertainties, spatial variation and change in concentration levels are not always reflected in the final figures.

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