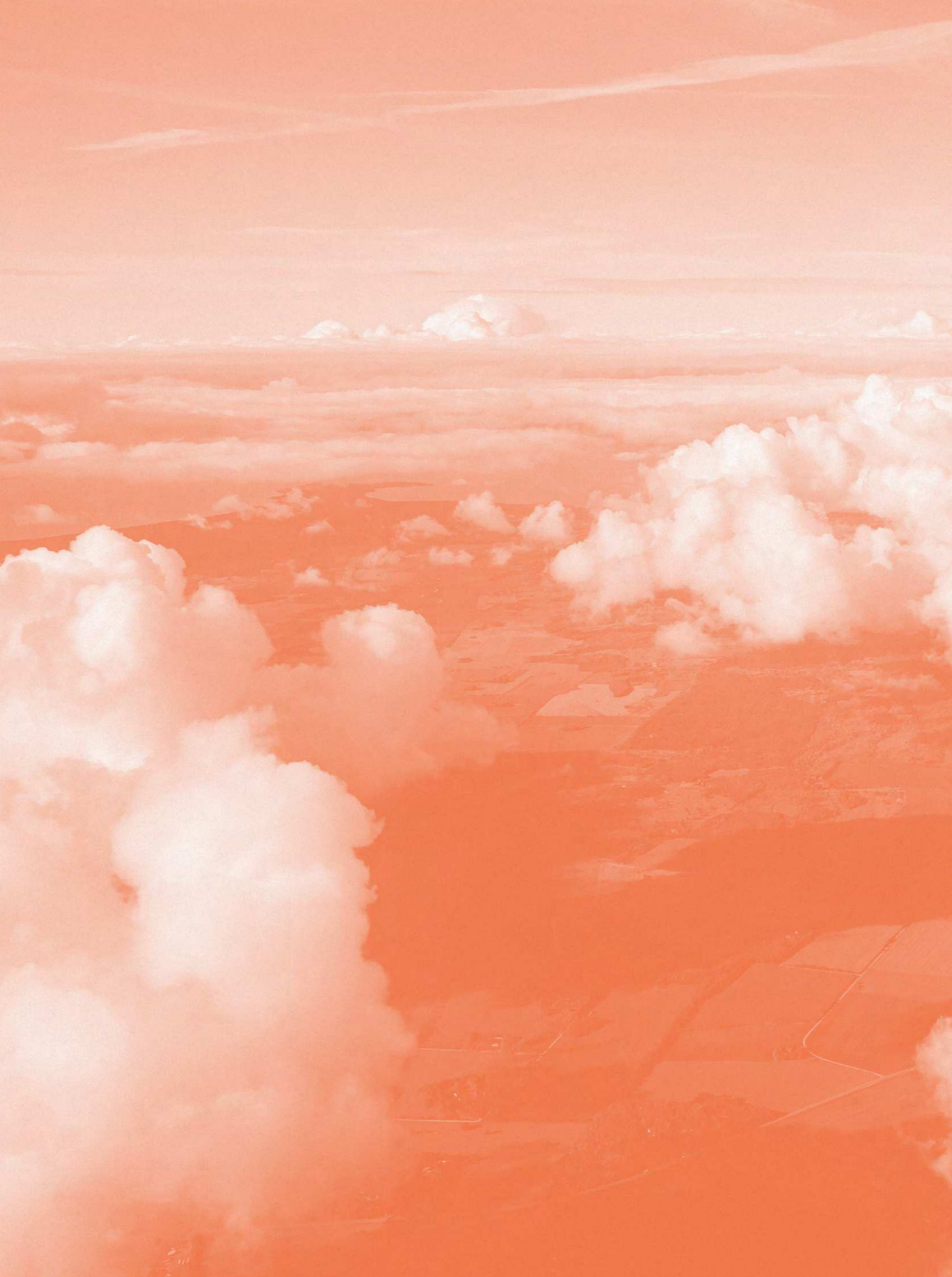


2

Air Quality

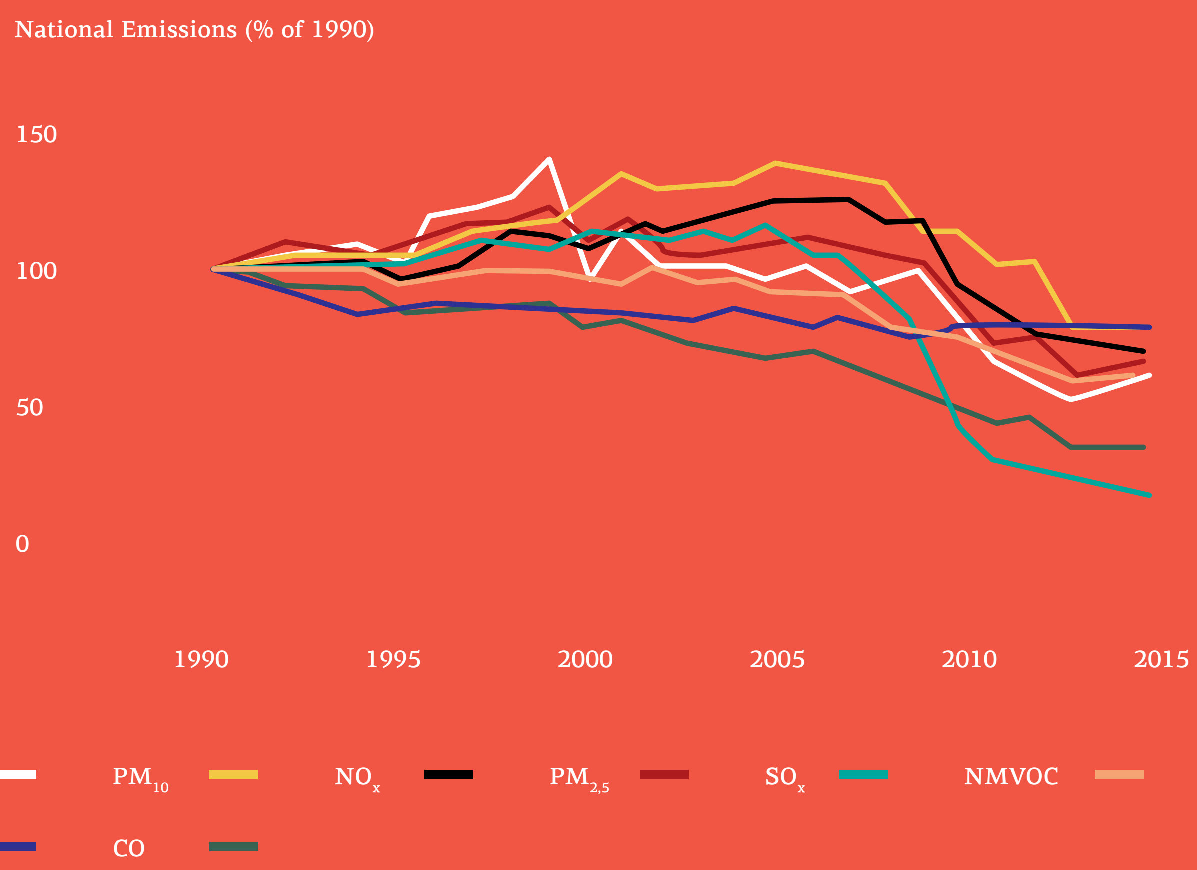
Air pollution is a complex environmental and social issue at the European and international levels. It poses a high risk to human health as it is related to cardiorespiratory disease and cancer. At the same time, it impacts the economy, adding to the health expenditure and reducing productivity. Air pollution also has important effects to the natural environment affecting ecosystems, soil and water quality and vegetation. Moreover, it interacts with the climate, since several main pollutants behave as climate forcers.

The European Union has specified as a long-term target the achievement of ambient air quality levels that don't have important adverse effects for human health and the environment. To reach this objective, European legislation follows a two-pronged approach, with the promulgation and implementation of air quality standards, and with the control and reduction of anthropogenic emissions. In the case of Greece, high levels of pollutants are a perennial cause of concern. Their management and mitigation are priorities for the protection of public health, not discounting their considerable importance for the environment. Greece is a characteristic example where the need of systematic observation of both primary emissions and actual air quality indicators is emphasized, since the distinct geographical and climatological conditions of the region convolute the processes that the atmospheric mixture undergoes along the path from the point sources to the receptors. An understanding of the state and also the tendencies which affect ambient air quality in the country, is an important first step towards addressing the issue. The present study reviews the current conditions and the trends of primary emissions from sources and of ambient pollutant concentration levels in large urban centers in Greece.

1. Emissions of air pollutants

Systematic inventorying of main pollutant emissions in Greece is conducted according to the provisions of the Geneva Convention on Long Range Transboundary Air Pollution and of the European Union's legislation on National Emission Ceilings. The available data, which cover the period between 1990-2015 and now incorporate a wide range of gaseous and particle pollutants, can highlight trends in anthropogenic contributions to air pollution and indicate the efficacy of implemented strategies and measures for control of emissions. The inter-annual variability of emissions for main pollutants, with respect to the base year (1990), is shown in Graph 2.1. Reductions in the range of 20-80% are observed for all pollutants in 2015. A detailed account of emission levels, their trends and the contribution of various activity sectors is provided in this report, focusing on pollutants for which reduction targets are stipulated in the (EU) 2284/2016 directive, which sets the year 2005 as the reference year for required reductions.

Graph 2.1.
National emission trends between 1990-2015

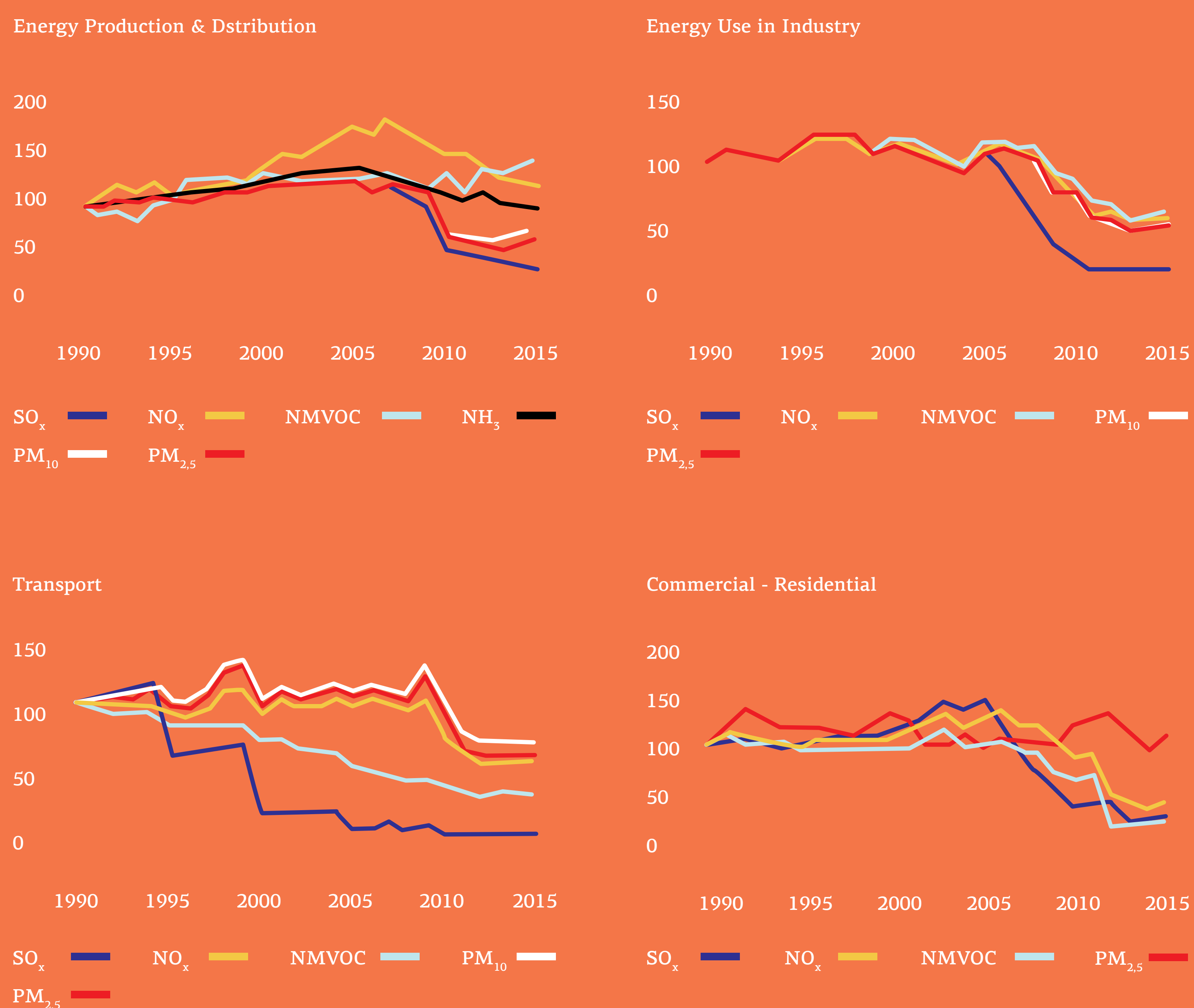


In Greece, 2015 emissions of sulfur oxides (SO_x as SO_2) are reduced by 80% and 83% in comparison to 1990 and 2005, respectively. Since the energy sector produces almost 80% of SO_x emissions, observed reductions mainly reflect the modernization of conventional older power plants and the operation of new units using natural gas. European fuel legislation, during the last decades, has imposed successive reductions in the sulfur content of petrol and diesel, leading to important cuts of SO_x emissions from the road transport sector. While 2015 emissions of nitrogen oxides (NO_x as NO_2) have also diminished (31% and 43% since 1990 and 2005, respectively), the grade of reduction is not comparable to that of sulfur oxides, while its major part mainly occurred during the beginning of the recession period. The main factor for observed reductions is the transport sector, whose emissions, as well as those of the residential-commercial sector, have shrank by 40%, during 2009-2015. Comparable reductions (37% and 33% for 2015 since 1990 and 2005, respectively) have been also recorded for emissions of non-methane volatile organic compounds (NMVOCs). These are related to emission controls in new-technology vehicles (Euro emission standards) as well as to the reduction of emissions from solvent use - the sector with the highest contribution in total emissions.

Emissions of ammonia (NH_3) originate mainly from agricultural activity and their decline has been of lesser magnitude (22% and 7% for 2015, since 1990 and 2005, respectively). These reductions are mainly attributed to the decreased use of synthetic fertilizers and to the spread of organic farming practices.

The energy sector appears to have a critical contribution to emissions for the majority of pollutants; through energy production, its use in industry, fuel use for transport and use in the residential and commercial sector. Changes of emissions from energy related sectors are presented in Graph 2.2.

Graph 2.2.
Changes of emissions (% of 1990) from energy related source sectors, between 1990-2015



A characteristic deactivation of the transport sector - especially road transport - as a source of any significance for SO_x emission is obvious, as a result of legislation on the sulfur content of fuels. The European legislation on vehicular emission control is also leading to the gradual decline of NMVOC emissions.

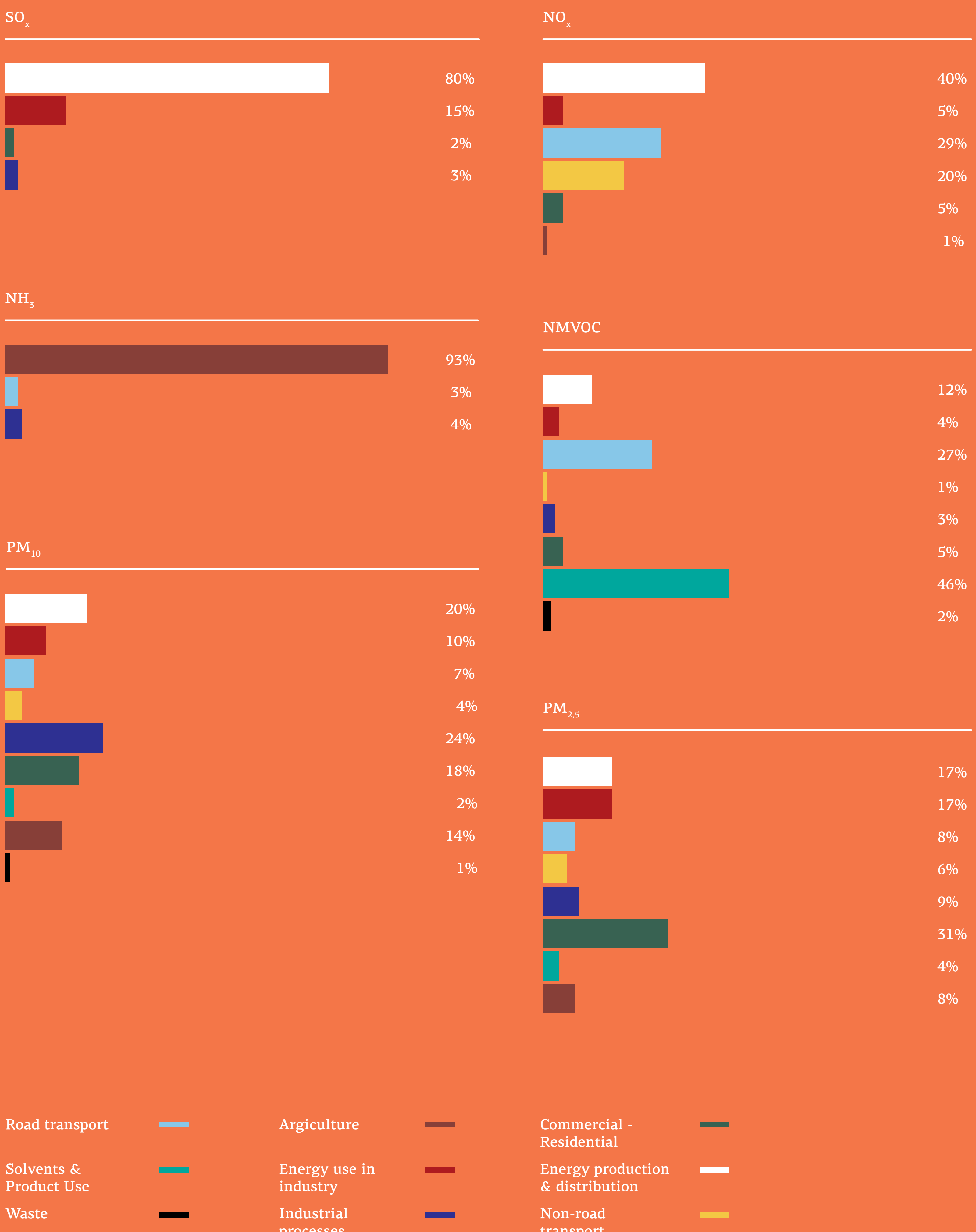
The important reductions which were recorded in most cases during the last decade, regardless of the implementation of appropriate policies and measures, are expected to be influenced to a certain degree by the general decrease in energy demand, related to the recession (for example in the secondary, tertiary and residential sectors). In 2015, the main exceptions to the general reduction of emissions since 1990, are NO_x and NMVOC emissions from the energy production sectors and ambient particles from commercial and household uses.

The contribution of the main activity sectors (energy production and distribution, energy use in industry, road and non-road transport, industrial processes, commercial and residential uses, solvent and product use, agriculture and waste) to the national emission total for 2015 is displayed in Graph 2.3.

The energy production sector is still the highest contributor to SO_x and NO_x. Since NO_x emissions from energy have remained comparable to 1990 levels, while those from transport have decreased significantly, the relative contribution of the sector (40%) is higher than in 1990. This is also the case for its contribution to SO_x emissions (80%), whose decline from the energy production sector, although significant, occurred at a lower rate, in comparison with the energy use in industry sector. The transport sector records the higher contribution to NO_x (49% combined), NMVOC (28%, almost exclusively from road transport) and PM (11-14%) emissions. Its share in NH_3 emissions, although small is measureable (3%), due to emissions from catalytic converters. The monitoring of variations and relative contributions of NO_x emissions from the sector is of particular importance, given the observed discrepancies between actual on-road vehicular emissions and those determined in laboratory tests assessing compliance with the EU regulations. The industry-related sectors (energy use in industry and industrial processes) appear to have a substantial contribution to particle emissions (26-34% combined, for $PM_{2.5}$ and PM_{10}, respectively). Particle emissions receive also a noteworthy contribution from the commercial - residential sector (18-31%, for PM_{10} και $PM_{2.5}$, respectively).

Emissions from agriculture and solvent and product use contribute the most to emissions of NH_3 and NMVOC, respectively. NMVOC emissions from solvents in 2015, even though they don't differ much from those in 1990, are largely reduced since the middle of the last decade due to legislative action towards the limitation of the volatile organic compound content in organic solvents and the control of emissions from their use.

Graph 2.3.
Contribution of main source sectors
to national emissions in 2015



Overall, regarding the national emission reduction targets, set by the directive (EU) 2284/2016 on national emission ceilings, it is expected that for SO_x, NO_x and NH_3 compliance with the required reductions will be achieved at the first stage (2020-), while for NMVOCs additional cuts will be necessary. Primary $PM_{2.5}$ emissions are on track to meeting the target, however they have to be closely monitored, given the slight uptick (2.7%) that has been observed between 2013-2015.

It is also important to assess the aggregate effects of pollutant groups, involved in physicochemical processes that are linked to serious environmental issues. Typical examples are the acidification of water and soils and the atmospheric formation of secondary pollutants. Sulfur and nitrogen oxides, along with ammonia, are the main pollutants related to ground and water acidification, an environmental issue that has caused great concern in the past. The reduction of SO_x emissions has led to the decline of the total acidification potential (57% for the period 1990-2015). The effectiveness of international action for combatting acidification is rather visible at the European level, where the issue, nowadays is much less of a concern than in the past, as opposed to the issue of eutrophication, a major ecological problem especially in the Mediterranean area.

Gaseous SO_x, NO_x and NH_3 are precursors of sulfate, nitrate and ammonium particles. These secondary particles constitute a large portion of PM mass (especially in the fine fraction). Therefore, controlling the precursor emissions can help lowering ambient particulate levels. In fact, the decline of emissions of primary PM_{10} since 1990 has been less pronounced (20%), in comparison with the decrease (51%) of the secondary particle emission potential.

Nitrogen oxides and NMVOCs are the main pollutants - especially within the urban environment - which participate in the secondary ozone formation cycle. As a result, cuts in their production - mainly from combustion sources - have led to corresponding reductions of the total tropospheric ozone formation potential (38% since 1990).

2. Ambient Air Quality

In Greece and especially in urban areas inhabitants are exposed to a composite mixture of air pollutants, which have numerous and diverse emission sources. During the last decade, a gradual amelioration of air quality has been recorded, mainly as the result of primary pollutant emission reductions. Notwithstanding the observed decrease of pollutant releases - a combined effect of European legislative action and the recession - exceedances of limit values set for the protection of public health are still being observed.

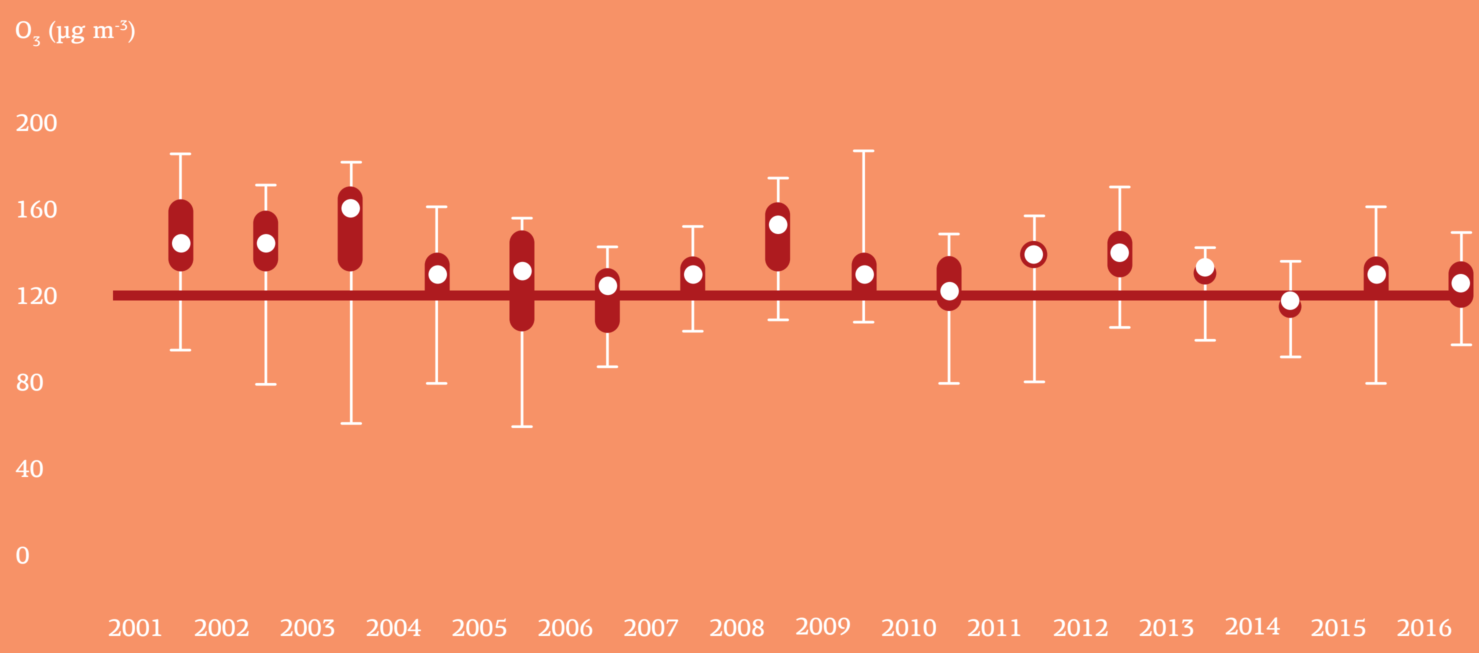
Air quality is routinely recorded at monitoring stations which operate under the oversight of the Ministry for Energy and the Environment (MEEN) and the regional authorities of the country. Systematic monitoring at the national level was initiated in 2001 with the operation of the National Network for Air Pollution Monitoring (NNAPM), which included stations in major urban agglomerations, continuously recording pollutant concentrations according to the provisions of the European legislation (directives 2008/50/EC and 2004/107/EC). Even though the results from recorded pollution levels during the first period of the network's operation were rather concerning, a gradual decline has been observed since. In 2016 (most recent reporting year), exceedances of the European air quality standard continue to occur for ozone, PM_{10} and NO_2.

2.1 Ozone

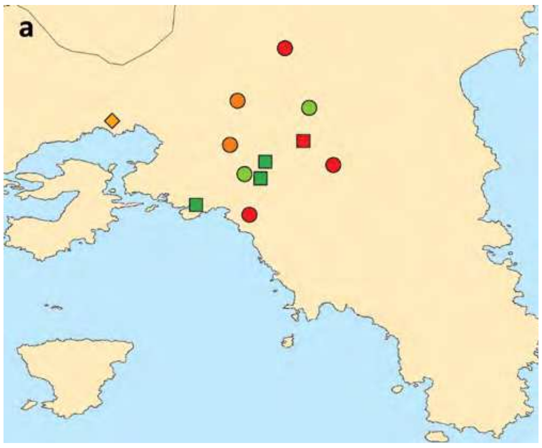
In contrast to the rest of the pollutants which are of exclusive or principal primary character, the long-term improvement in O_3 levels has been less pronounced. This is mainly due to regionally prevailing climatological conditions which favor the appearance of intense high-concentration episodes. The EU standard for O_3 sets a target value of 120 $\mu g\ m^{-3}$ for the protection of public health, as the maximum daily 8-h mean concentration not to be exceeded more than 25 times in a year.

Graph 2.4. displays the variation of the median value, among background stations in Greece, of the 93.2 percentile of maximum daily 8-h mean concentration values, corresponding to the 26th highest value in an annual time-series. It can be seen that the majority of stations exceed the target value, throughout the period 2001-2016. In 2016, the standard was violated in 6 of the 10 background stations of the network.

Graph 2.4.
Median, interquartile range and min-max values for the 93.2 percentile of maximum daily 8-h mean O_3 concentration values, recorded at background stations of the NNAPM



In Athens the mean values of the percentile among urban and suburban background stations is higher than the target value for the entire period 2001-2016. In background stations of Thessaloniki, violations of the standard have also been recorded throughout the years, although more variable and less intense than in Athens. Meteorological conditions in Northern Greece are less favorable for photochemical production of O_3, in comparison with Athens, where intense insolation, higher temperatures and topographic characteristics of the basin increase the frequency of high concentration events. Results for the percentile indicator in Athens and Thessaloniki in 2016 are shown in Picture 2.1.



Picture 2.1.
93.2 percentile of maximum daily 8-h mean O_3 concentration values in 2016, in Athens (a) and Thessaloniki (b)
(circles: background stations, squares: traffic stations, diamonds: industrial stations)

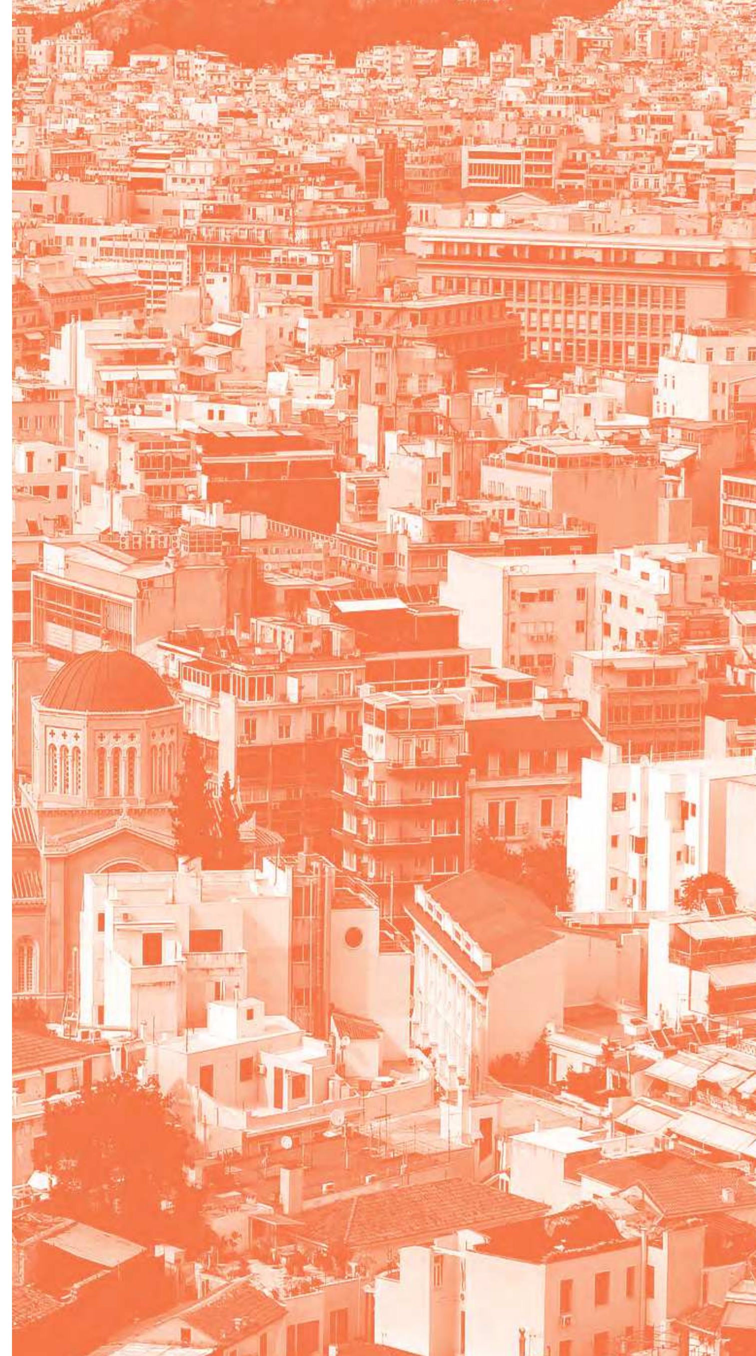
<110

110-120

120-130

>130

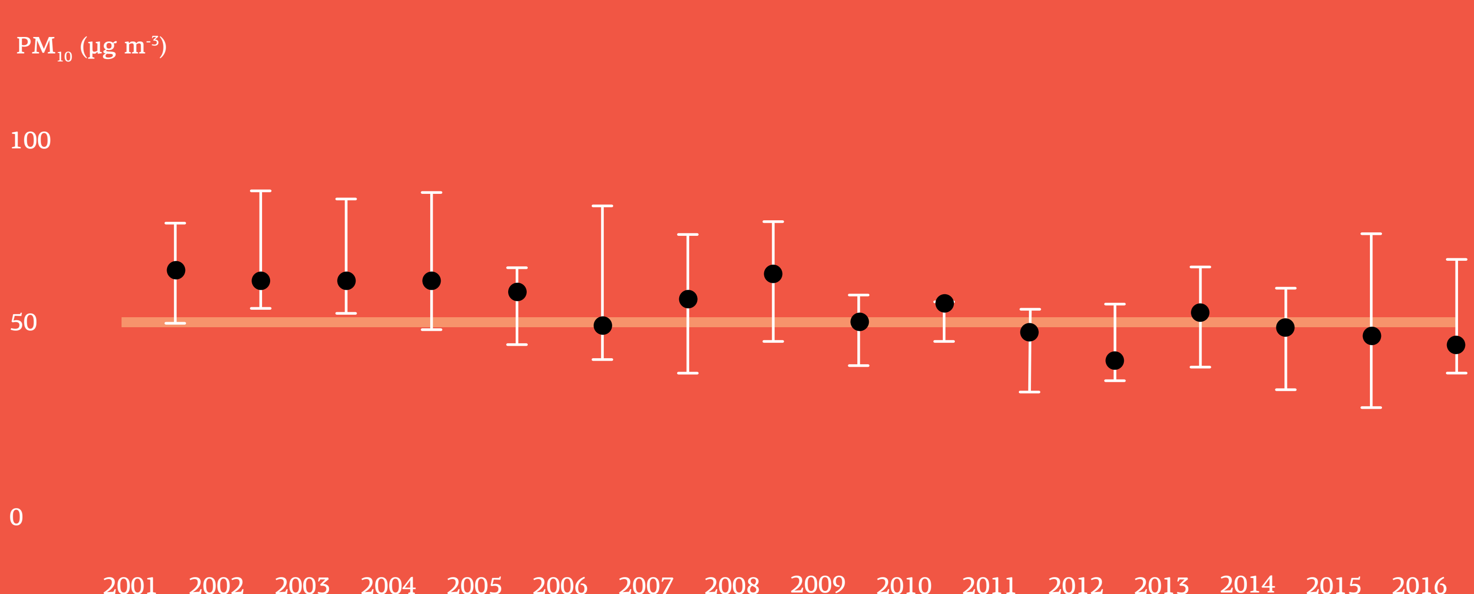
A slow decline of O_3 levels can be deduced, which for Athens and Thessaloniki, in terms of background station average of the percentile indicator, is estimated at 14.5-15.1% between 2001-2015. In the same time period, the decrease of the O_3 formation potential from gaseous precursors is significantly higher (40%). This discrepancy is attributed to the type of the target value, which is designed to track short-term increases of O_3 concentrations, since these are linked to the most adverse health effects. Due to its secondary character, peak ozone levels are rather variable and depend on fluctuations of precursor emissions and on meteorological conditions which in Greece promote the occurrence of episodes, especially during the warm months.



2.2 Particulate matter

Regarding mean annual PM_{10} levels, the improvement over the years is obvious. While 75% of the network's stations breached the annual limit value (40 μg m^{-3}) in 2001, in 2016 such exceedances are observed at only two out of 19 PM_{10} recording stations. However, the daily standard (50 μg m^{-3}, not to be exceeded more than 35 times in a year) was exceeded in 10 out the 19 stations with adequate data coverage. Graph 2.5. presents the variation of the median value, among background stations in Greece, of the 90.4 percentile of daily mean PM_{10} concentrations, corresponding to the 36th highest daily mean in an annual time-series.

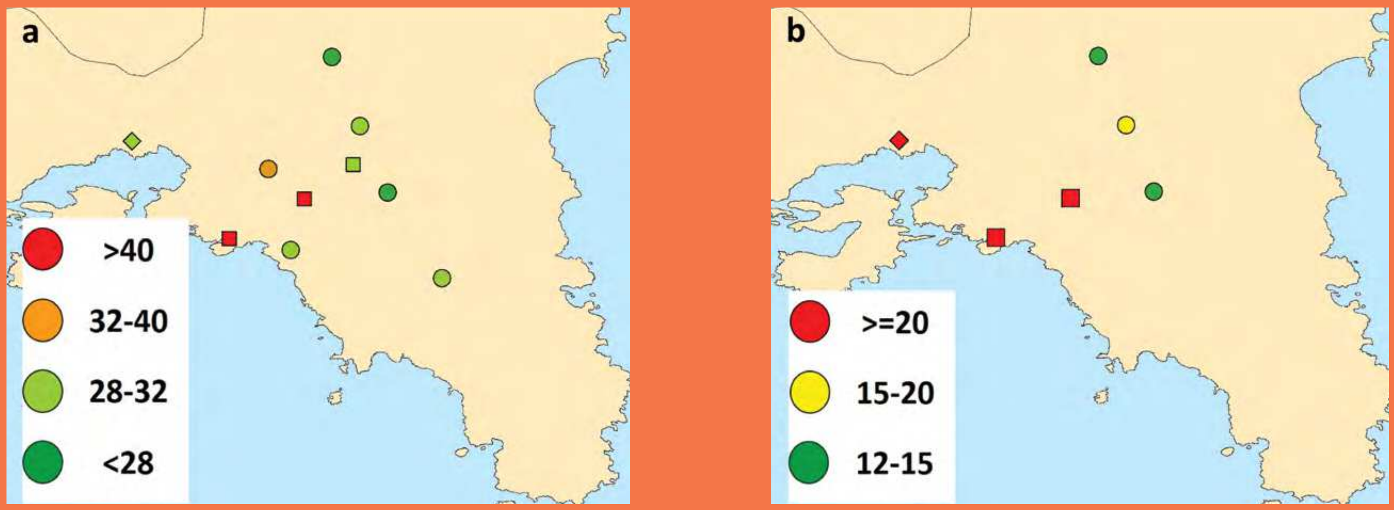
Graph 2.5.
Median and min-max values for the 90.4 percentile of daily mean PM_{10} values, recorded at background stations of the NNAPM



The observed decline of PM_{10} levels is to a certain degree relevant to the decline of respective emissions at a national level, which for the 2001-2015 period reached 54% for primary particles and secondary particle precursors, combined. It is noted, that the number of exceedances is influenced also by particles of natural origin, such as Saharan dust particles and sea salt, which are taken into account in the assessment of the country's compliance with the provisions of European legislation.

An improvement is observed also in the case of $PM_{2.5}$ fine particles. Since 2010, no exceedances of the annual limit value (25 μg m^{-3}) have been recorded. However, all reported mean annual concentrations were higher than 10 μg m^{-3}, which is the guideline value set by the World Health Organization. Special concern should be given to the impact of emissions from extensive biomass burning for residential heating in observed concentrations of PM and their constituents, such as black carbon (BC) which displays rather high levels during the winter period. Results for the annual mean concentrations of PM_{10} and $PM_{2.5}$ at a spatial scale in Athens are provided in Picture 2.2.

Picture 2.2.
Annual mean concentrations of (a) PM_{10} and (b) $PM_{2.5}$ in Athens, in 2016 (circles: background stations, squares: traffic stations, diamonds: industrial stations)

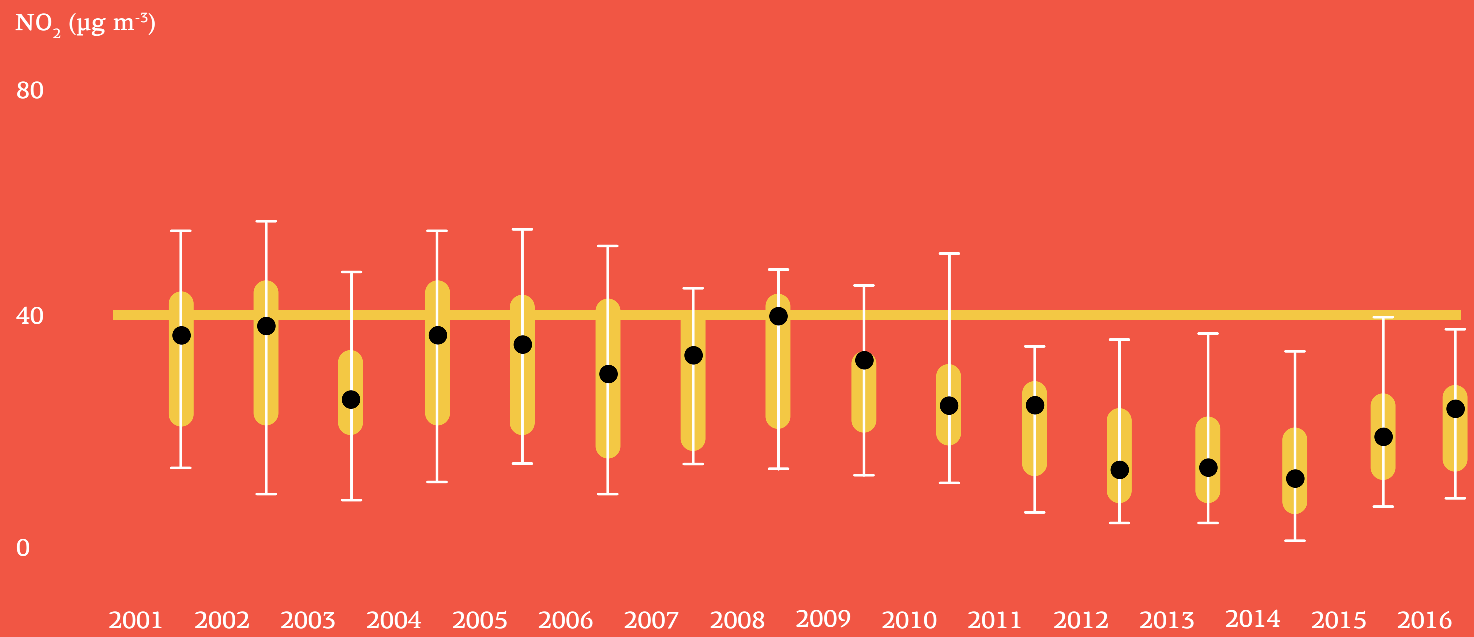


Although PM emissions from road transport on a national level have decreased, the roadside enhancement (difference between traffic and background stations) of mean annual particle concentrations in Athens is large and in 2016 exceeded on average 10 μg m^{-3} for PM_{10}, while the mean annual traffic-background difference in $PM_{2.5}$ reached 6 μg m^{-3}. It is obvious that along with direct fine particle emissions from combustion in vehicles, road traffic also produces coarse particles ($PM_{10-2.5}$) from mechanical and tire wear and from road dust resuspension.

2.3 Nitrogen dioxide

Annual average NO_2 levels display a noteworthy downward trend, which bears resemblance to the declining progress of NO_x primary emissions, especially during the recession period. Graph 2.6. shows the variation of the median value, among background stations in Greece, of the annual mean concentration of NO_2. Notably, following 2010, there have been no exceedances of the annual limit value at background stations, while in 2016, out of all (21) stations, the standard was only breached at 3 traffic locations in Athens.

Graph 2.6.
Median, interquartile range and min-max values for annual mean NO_2 concentration values, recorded at background stations of the NNAPM



The overall reduction of NO_2 levels appears to track the respective reduction of primary NO_x levels, which between 2001-2015 was 40%. A characteristically large decline of levels is observed between 2008-2015, when NO_x emissions from road transport decreased by over 50%.

Results for the annual mean concentration NO_2 at a spatial scale in Athens and Thessaloniki are depicted in Picture 2.3. The observed mean roadside enhancement of concentrations (traffic vs. background stations) in the greater area of Athens is 24 μg m^{-3} in 2016 and has been on the rise since 2014.

2.4 Other Pollutants

Levels of remaining pollutants regulated by European legislation do not pose a reason for concern. Regarding carbon monoxide (CO), during the whole 2001-2016 period, there has been only one exceedance of the 8-h limit value. In the same period, the daily limit value (125 μg m^{-3}) for sulfur dioxide has never been exceeded in NNAPM stations, while only 3 exceedances of the 1-h limit value have been reported. During the examined period, SO_2 levels have decreased drastically, in line with reduced national SO_x emissions of 82% between 2001-2015.

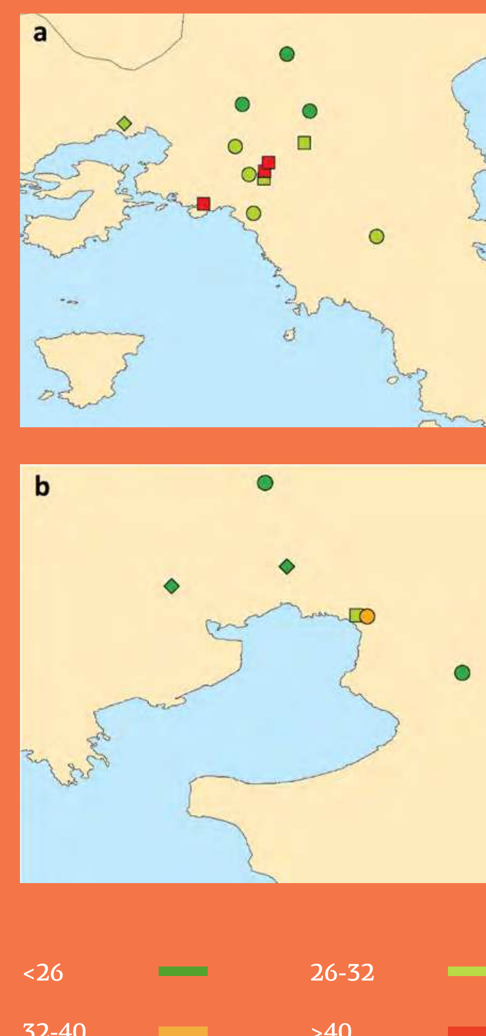
Exceedances of the mean annual limit value for benzene (5 μg m^{-3}) have been reported only at the traffic station of Patission Str. in the center of Athens. Benzene concentrations, since the upgrade of the NNAPM in 2015, are recorded at 3 additional stations in Athens, while measurement equipment has been installed in four other cities. In 2016, for stations in Athens, mean annual concentrations were lower than the limit value, with the sole exception of the Patission station.

Indicative measurements of benzo[a]pyrene (BaP) which have been conducted during 2014-2015 at stations around the country, are suggesting that exceedances of the annual target value of 1ng m^{-3} are probable. Thus, systematic measurement of BaP is necessary to assess the attainment of the target value for the protection of human health.

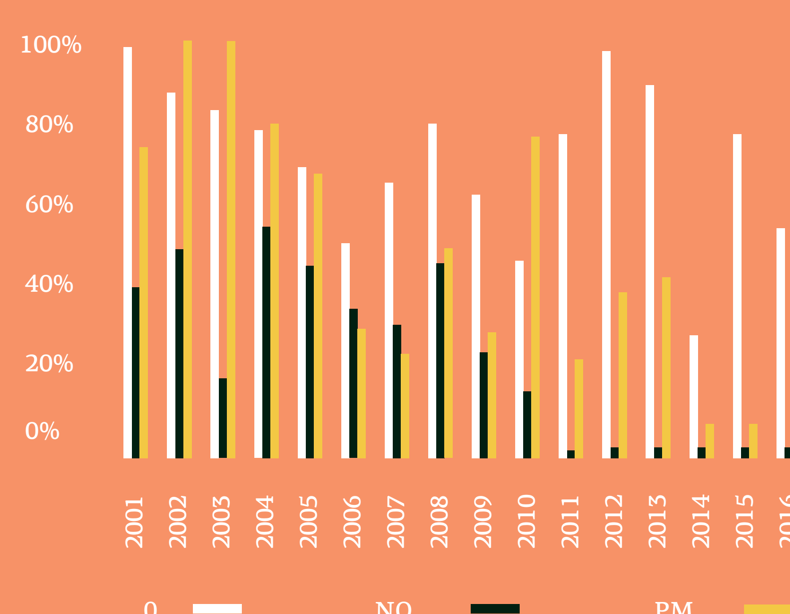
2.5 Population exposure to air pollutants

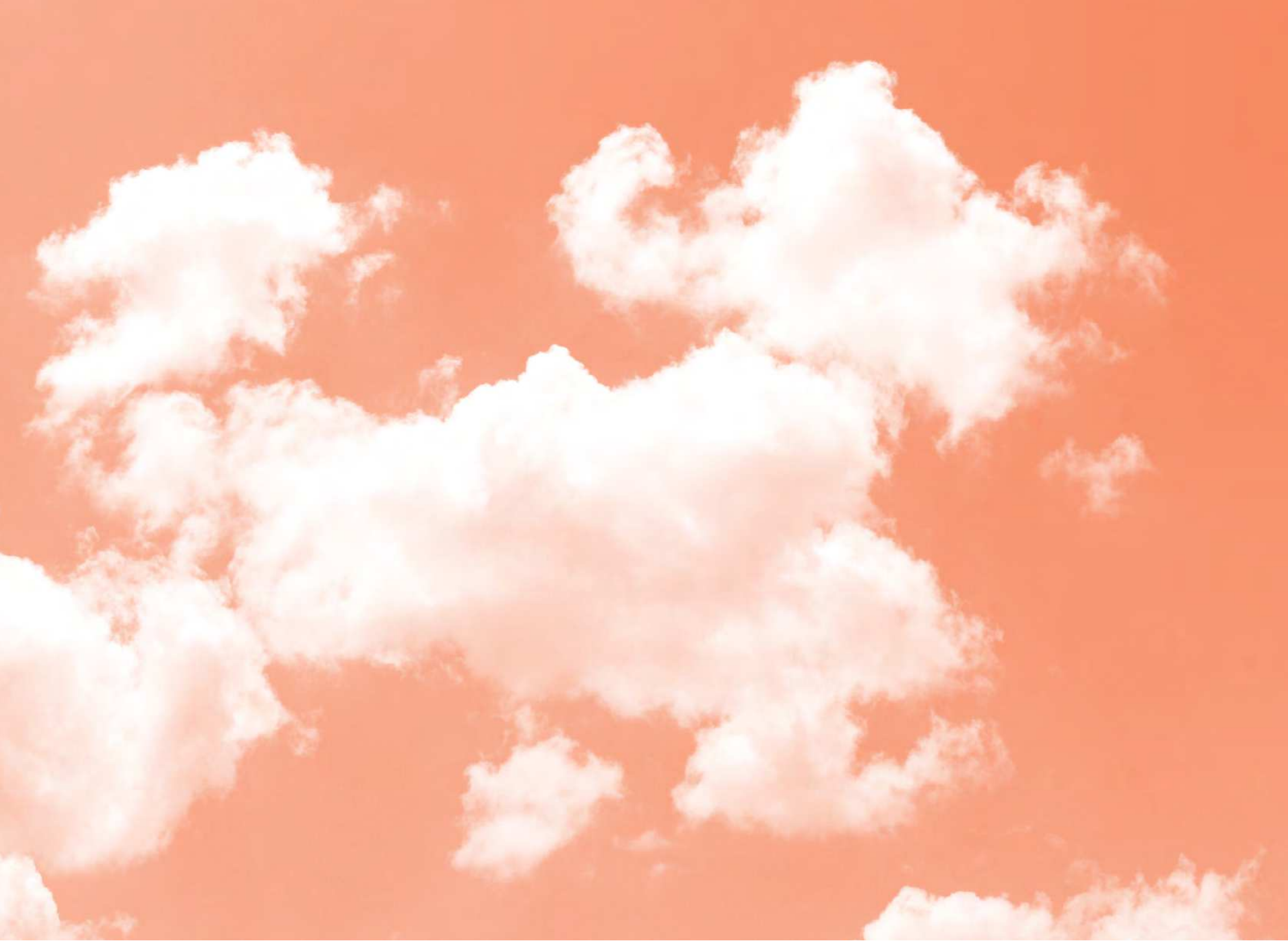
Following the methodology proposed by the European Environment Agency (indicator EEA CSI 004), and utilizing data on monitoring station characteristics, on the recorded exceedances of limit values and on demographic factors, the fractions of the urban population exposed to levels above the EU reference values were estimated. The inter-annual variation of fractions of urban population exposed to levels exceeding the air quality standard, for O_3, PM_{10}, NO_2 is presented in Graph 2.7.

Picture 2.3.
Annual mean of NO_2 concentrations in 2016, in Athens (a) and Thessaloniki (b) (circles: background stations, squares: traffic stations, diamonds: industrial stations)



Graph 2.7.
Fraction of the urban population exposed to concentrations above the European air quality standard (directive 2008/50/EC)





Specifically, for 2016, according to the estimations:

55% of the urban population is exposed to O_3 levels above the EU target value for the protection of health.

2% of the urban population is exposed to NO_2 annual mean concentrations exceeding the EU limit value.

21% of the urban population is exposed during the year to more than allowed exceedances of the EU limit value for daily mean PM_{10} concentrations.

2% of the population in Athens is exposed to annual mean benzene concentrations exceeding the EU limit value.

The urban population is not exposed to $PM_{2.5}$ annual mean concentrations exceeding the EU limit value.

The urban population is not exposed to SO_2 daily mean concentrations exceeding the EU limit value.

There are some inherent limitations in the estimations provided by this indicator, which in the case of Greece are magnified due to the small number of background stations in cities other than Athens. The large upgrade that the monitoring network has undergone in 2015 and the increase of spatial coverage in cities where existing monitoring capabilities are out of service or outdated are expected to provide valuable and spatial representative data for population exposure assessment.