Progressing to cleaner air

Evaluating attainment areas

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Front page picture:
Many measures which have been implemented or are planned to be implemented in order to improve the urban air quality, are related to transport. A number of frequently taken measures are illustrated here: the introduction of congestion charging in London, promotion of e-cars by free parking and free charging points in Rotterdam and three Dutch post stamps (issued in 2008) promoting hybrid cars, car sharing and the introduction of particle filters.

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1. Introduction

In a previous ETC/ACM technical paper (de Leeuw et al, 2012) the progress of air quality (AQ) in "non-attainment" areas was discussed. Following the AQ Directives[1], "non-attainment" areas were defined as those areas where the EU air quality (AQ) objectives (limit and/or target values) are not met during a longer period of time. In a more operational way a non-attainment area was defined as an area where in the past five years the limit or target value has been exceeded in at least three years; to ensure that the area is still in exceedance, it is further required that during one of the two last years an exceedance has been observed.

In the previous report non-attainment areas have been identified with respect to the PM_{10} and NO_2 limit values and the O_3 health related target value; a general discussion on the degree on non-attainment and a possible trend over the past years has been presented. The report further included a more in-depth discussion on air quality assessments in a number of cities selected for the Air Implementation Pilot (EEA, 2013).

This paper will focus on the *attainment areas*, i.e. those areas where exceedances of the limit or target values have not been observed during a longer period of time. In Chapter 2 the definition of an attainment area and the methodology to assess attainment zones is discussed. In Chapter 3 an evaluation is given on the probability that the status of the area changes from attainment into non-attainment. This evaluation is based on a short-term (five years) and long-term (ten years) trend in air quality.

[1]Framework Air Quality Directive 96/62/EC, developed by the 4 Daughter Directives (1999/30/EC, 2000/69/EC, 2002/3/EC and 2004/107/EC). The Framework Directive and its first three Daughter Directives have been replaced by Directive 2008/50/EC on ambient air quality and cleaner air for Europe.

2. How is *attainment* and *non-attainment* defined and assessed?

In the previous study (de Leeuw et al, 2012), a non-attainment area has been defined as:

> *an area (either an AQ management zone as defined under the AQ Directives or an administrative unit like a city) where in the past five years the limit or target value has been exceeded in at least three years. To ensure that the area is still in exceedance, it is further required that at least one exceedance of a limit or target value is observed during the last two years*.

Complementary to this, an attainment area can be defined as:

> *an area (either an AQ management zone as defined under the AQ Directives or an administrative unit like a city) where in the past five years the limit or target value has not been exceeded in at least three years. To ensure that the air quality in the area is still in compliance, it is further required that at least not more than one exceedance of a limit or target value is observed during the last two years*.

The attainment status of an area is evaluated when valid data is available during at least four of the past five years. Given the definitions of (non)-attainment areas and the criteria on data availability, two additional cases have to be considered:

- insufficient data: valid data is available for less than four years;
- the attainment status is undefined; the development of the air quality does not fulfil the criteria set in either of the two definitions. This is, for example, the case when in the first three years the concentrations are above the limit value (LV) or target value (TV) and during the two most recent years below the LV/TV.

As discussed in the previous report (de Leeuw et al, 2012), an assessment on the attainment status could be obtained (i) from the information on the Air Quality (AQ) management zones reported under the AQ Questionnaire (EC, 2004)or (ii) from AirBase data. The first approach has the advantage that official reported data is used. However, as in various Members States the designation of the AQ management zones changes over time, it is not possible to trace back in time the air quality in all the zones designated in 2011. The second method has the disadvantage that the official national submissions are not used. However, the advantage is that a more complete assessment can be made by evaluating the historical concentrations reported for the monitoring stations within a zone. A second disadvantage is that this approach relies fully on monitoring data; in a few MS the compliance situation is (partly) based on modelling (see below).

In order to get an as complete as possible picture, method (ii) is used in this paper to evaluate the attainment status. In more detail, the following procedure has been applied:

- the assessment is limited to the three environmental objectives having the largest number of non-compliance zones: PM_{10} daily limit value, NO_2 annual limit value and the ozone target value set for the protection of human health;
- the assessment is based on the designation of zones as defined for 2011, see Jimmink et al (2013) for further details on the 2011-delivery. In addition to the EU-27 Member States[2], the zones designated by Iceland and Norway have been included in the analysis;
- in the assessment of the attainment status, the five year period 2007-2011 is considered;
- the connectivity table between zones and AirBase stations is based on (i) the reported list of stations in the Forms 3 and 4 of the 2011-questionnaire, (ii) by combining the spatial

[2] Only the EU Member States are obliged to submit the AQ Questionnaire under (EC, 2004). Nevertheless, other countries submit it under voluntary basis. In 2011, EU consisted of 27 MS.

information of the 2011 zone designation and the geographical coordinates of all AirBase stations;
- relevant indicators (for PM_{10}, the 90.4 percentile value of daily mean, for NO_2 the annual mean, and for ozone the 94.2 percentile of the daily maximum 8h-mean) have been collected for all stations having an annual data coverage of more than 75%;
- for each year in the period 2007-2011 the highest concentration measured at any of the stations within a zone has been collected (note that in this way different stations might be selected for each of the five years); the attainment status is evaluated on the basis of these five annual maxima.

While testing this approach inconsistencies were noted in the Italian deliveries of the AQ Questionnaire: in Form 9a (providing information on the compliance situation with respect to the TV and long-term objective (LTO) of ozone) a larger number of zones are listed than in Form 2 (providing information on the designation of zones). In the routine QA/QC procedure of the reported AQ Questionnaires (Jimmink et al, 2013) the reporting countries are a.o informed on this type of inconsistencies in their reports. However, as on this point no reply has been received from Italy, the more complete set of zones as listed in Form 9a are considered here.

At some points the procedure sketched above deviates from the way compliance checking is done in the Air Quality Questionnaire:
- according to the AQ Directive the compliance check for PM_{10} and ozone is based on the number of exceedances of daily values. When evaluating the distance to non-attainment and trends the use of exceedance numbers is not advisable; it is recommended to use the 36th (PM_{10}) and the 26th (ozone) highest daily value (or the corresponding percentile values) as these are statistically more robust indicators. The percentile values are used here as they allow a lower data coverage (>75%) than required in the AQ Directive (>90%) without a significant increase in uncertainty (de Leeuw, 2012). The data coverage used (>75%), lower than the data coverage required according to the AQ Directive (>90%), allows to include a larger set of stations (and therewith possibly a larger set of zones). The percentile values are systematically slightly larger than the corresponding 36th/26th highest value; this will cause a slight bias towards more non-attainment situations;
- the compliance check is based on the raw data as reported to AirBase; no correction for the contributions of natural sources or for winter sanding and salting has been applied. Derogation for PM_{10} or NO_2 limit values is not considered. This will introduce a slight bias towards more non-attainment;
- all operational stations, also those not assigned by the MS as compliance stations, are used in the analysis. This might introduce a slight bias towards more non-attainment situations;
- it is known that in two Member States (United Kingdom, the Netherlands) the exceedance of the limit values of PM_{10} and NO_2 is (partly) based on model results. In a number of zones the attainment situation based on the observations is in conflict with the situation based on the AQ Questionnaire; in these cases the attainment situation has been adopted according to the official national delivery in the AQ Questionnaire.

The results have been summarised in Table 1 and Figures 1-3. The numbers on population and area have been based on the national 2011 deliveries of the AQ Questionnaire. Although for health-related environmental objective, the zones have to cover the whole territory and therewith the total population of a country, a complete coverage was not reported in the 2011-deliveries (see the white coloured regions in the maps of Figure 1-3). This and the fact that some of the (voluntary) data on population and area is missing explain the small differences in grand totals for population and area for the different pollutants.

From the collected information the following conclusions can be drawn:

- With respect to number, population and area the fraction of zones with an undefined attainment status is less than 5%; an undefined status is most frequently found for a non-agglomeration and for PM_{10}. Given this low fraction, the definitions of attainment and non-attainment areas seem robust and there is no reason to revise the adopted definitions.
- Insufficient data for assessing the attainment status is a larger problem, especially – again – for non-agglomerations, see Figures 1-3. Missing values play a lesser role when looking at population data. For 6-8% of the total population, the attainment situation of the zone in which they are living cannot be assessed. In terms of number of zones and area, for a fraction of 13-19% (number) and 8-16% (area) insufficient information is available. One of the reasons of having insufficient monitoring data might be that the concentrations in the zone are below the lower assessment threshold (LAT); in these situations fixed measurements are not mandatory and the assessment of air quality might be based on modelling or objective-estimation techniques. We have compared the zones having insufficient data with the information provided in Form 10 of the AQ Questionnaire (providing information on the assessment regime). As the LAT is 50-65% of the limit value and the information in Form 10 is also based on a five year period, we can safely conclude that zones with levels below the LAT are attainment areas. From this comparison it is concluded that in 66 of the 92 NO_2 zones with insufficient data, concentrations are below the LAT; for PM_{10} in 18 of the 134 zones with insufficient data, levels are below the LAT. In case of ozone, fixed measurements are not required when the long-term objective has not been exceeded during any of the previous five years of measurement. However, this information is not provided in the AQ Questionnaire which precludes a further analysis of the ozone zones with insufficient data.
- 21- 28% of the area is marked as being in non-attainment; 50% (NO_2), 45% (PM_{10}) and 35% (O_3) of the population lives in these non-attainment areas. This population is potentially exposed to levels above the TV or LV during at least three years in the past five-year period. Note that this will be an upper estimate of the exposed fraction. The air quality status in a zone is determined by the highest observed or modelled concentration irrespective whether the area in exceedance covers the whole zone or just a few hundred square meters.
- The attainment areas cover more than 50% of the total area of the reporting countries (EU-27 plus Iceland and Norway) for all three selected pollutants. The majority of the population (57%) lives in zones where ozone concentrations are generally (that is, at least three out of five years) below the target value; 43% of the population is exposed to concentrations of NO_2 and PM_{10} which are generally below the respective LVs. However, it should be noted that with exposure to concentrations below the LV or TV, adverse effects may still occur. The Air Quality Guidelines for PM_{10} and O_3 as recommended by the WHO (2006) are substantially lower than the EU LV or TV: 20 $\mu g.m^{-3}$ as annual mean (PM_{10}) and 100 $\mu g.m^{-3}$as maximum daily 8h mean (ozone). The NO_2 LV equals the WHO AQG.
- NO_2 is largely a problem in densely populated agglomerations; a large number is recognizable in the map. About 80% of the population living in an agglomeration resides in a non-attainment area while the surface of the non-attainment agglomerations covers less than 40% of the total agglomeration surface. In non-agglomerations the majority (56%) lives in an attainment area.
- PM_{10} exceedances are more widely spread, urban agglomerations are still recognized in the map but the difference between agglomerations and non-agglomerations is less extreme.
- Due to the chemical quenching by freshly emitted NO, ozone tends to be lower in urban regions than in the more rural regions. This behaviour is directly reflected in the Figure 3. The ozone non-attainment areas are both in number, in population as well as in area, biased towards non-agglomerations.

In an excel file accompanying this report, the results are summarized. The file contains a list of the 2011 zones with their attainment status; the zones which are currently (2011) in attainment or have an undefined status but which are at risk (see below) of becoming a non-attainment zone have been identified. The zones with insufficient data and with concentrations below the lower assessment threshold (which would mean attainment, see below) have also been identified.

Table 1. Summary of the attainment status of NO_2, PM_{10} and ozone zones; for the designation of zones the reporting year 2011 has been selected. The attainment status is based on information over the years 2007-2011.

	agglomerations			**Non-agglomeration**		
NO_2 annual LV	Number of zones	Total population	Area (km^2)	Number of zones	Total population	Area (km^2)
attainment	77	31940875	131982	277	176468670	2534342
insufficient data	14	3122240	3377	78	21657316	689561
non-attainment	149	136648491	85921	89	108158559	853895
undefined	7	1643353	1953	11	10111951	78062
Grand Total	**247**	**173354958**	**223233**	**455**	**316396496**	**4155860**
PM_{10} daily LV						
attainment	96	48329258	28666	205	163218160	2188672
insufficient data	23	9408081	5635	111	29587207	656464
non-attainment	117	110412132	184804	117	109979735	1052989
undefined	9	4652587	3868	24	13431480	182756
Grand Total	**245**	**172802057**	**222972**	**457**	**316216582**	**4080881**
Ozone TV-health						
attainment	152	106108879	98568	167	173247946	2598264
insufficient data	22	4634840	5500	81	22240530	353713
non-attainment	61	54662418	79634	147	119163928	1115198
undefined	6	6320194	37767	15	3959451	51628
Grand Total	**240**	**171538330**	**221359**	**409**	**318546116**	**4117930**

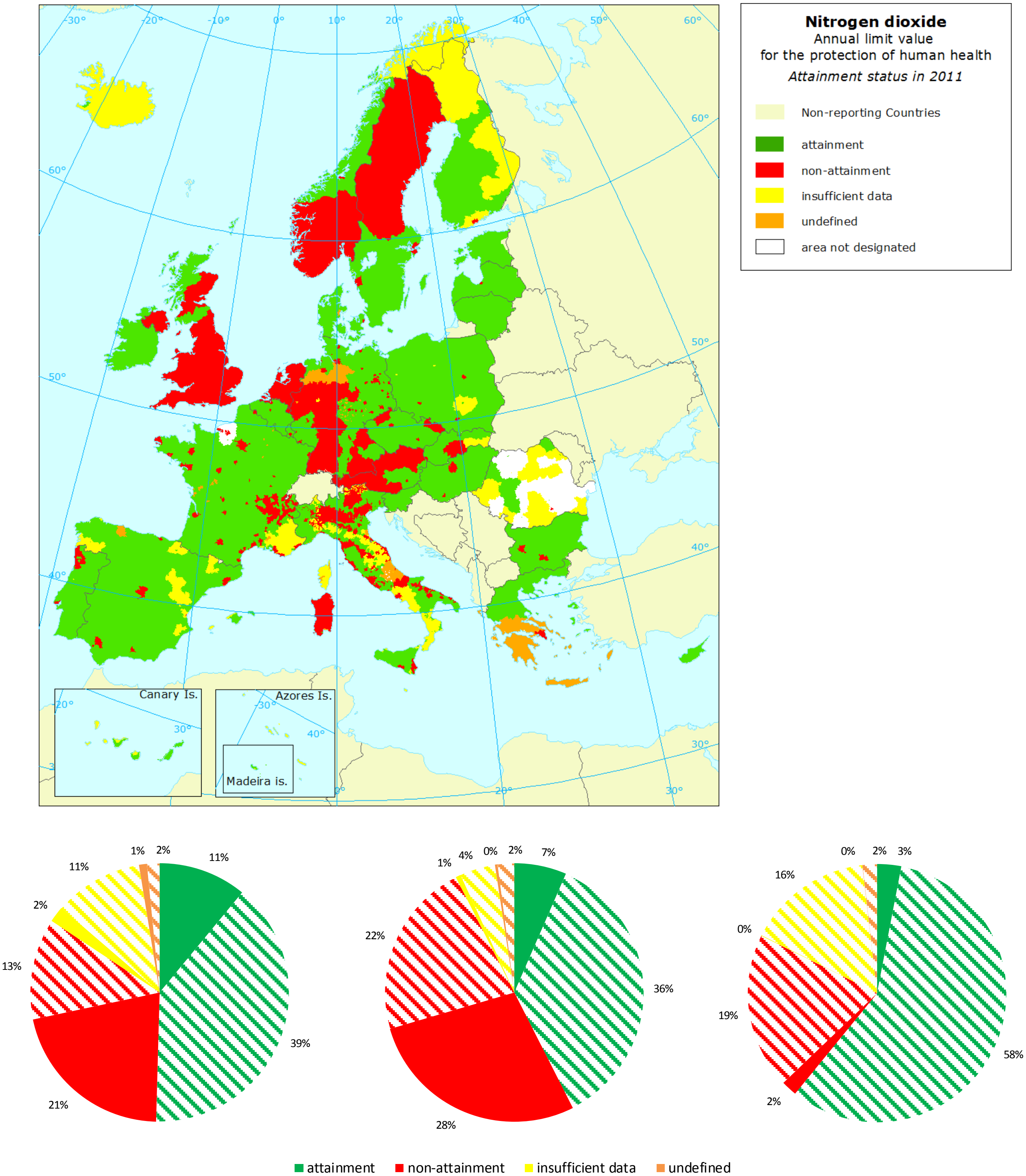


Figure 1. Attainment status of the 2011 NO_2 air quality management zones based in the period 2007-2011; distribution of number (left), population (middle) and area (right) of agglomerations (solid fill) and non-agglomeration (shaded fill).

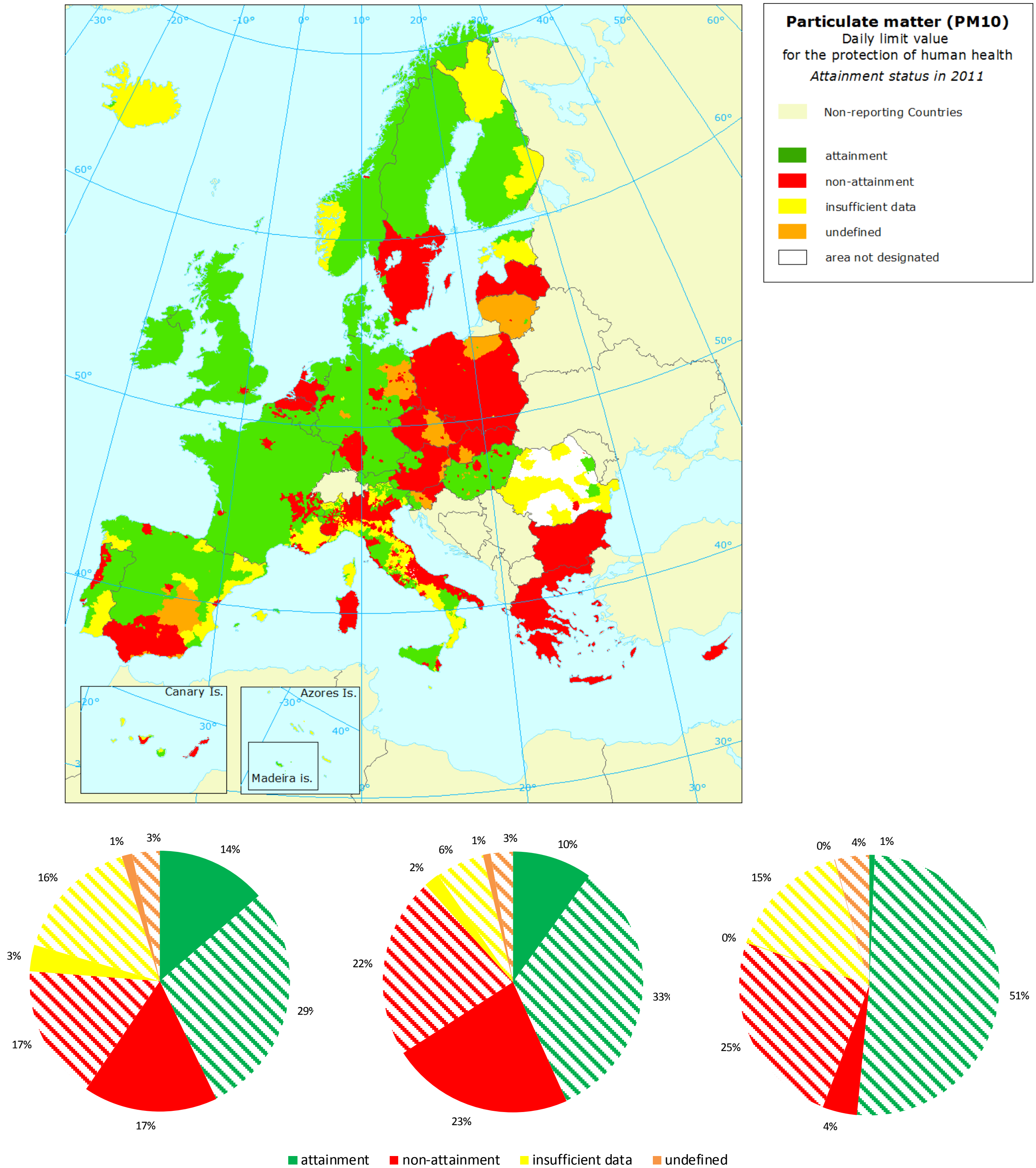


Figure 2. Attainment status of the 2011 PM_{10} air quality management zones based in the period 2007-2011; distribution of number (left), population (middle) and area (right) of agglomerations (solid fill) and non-agglomeration (shaded fill).

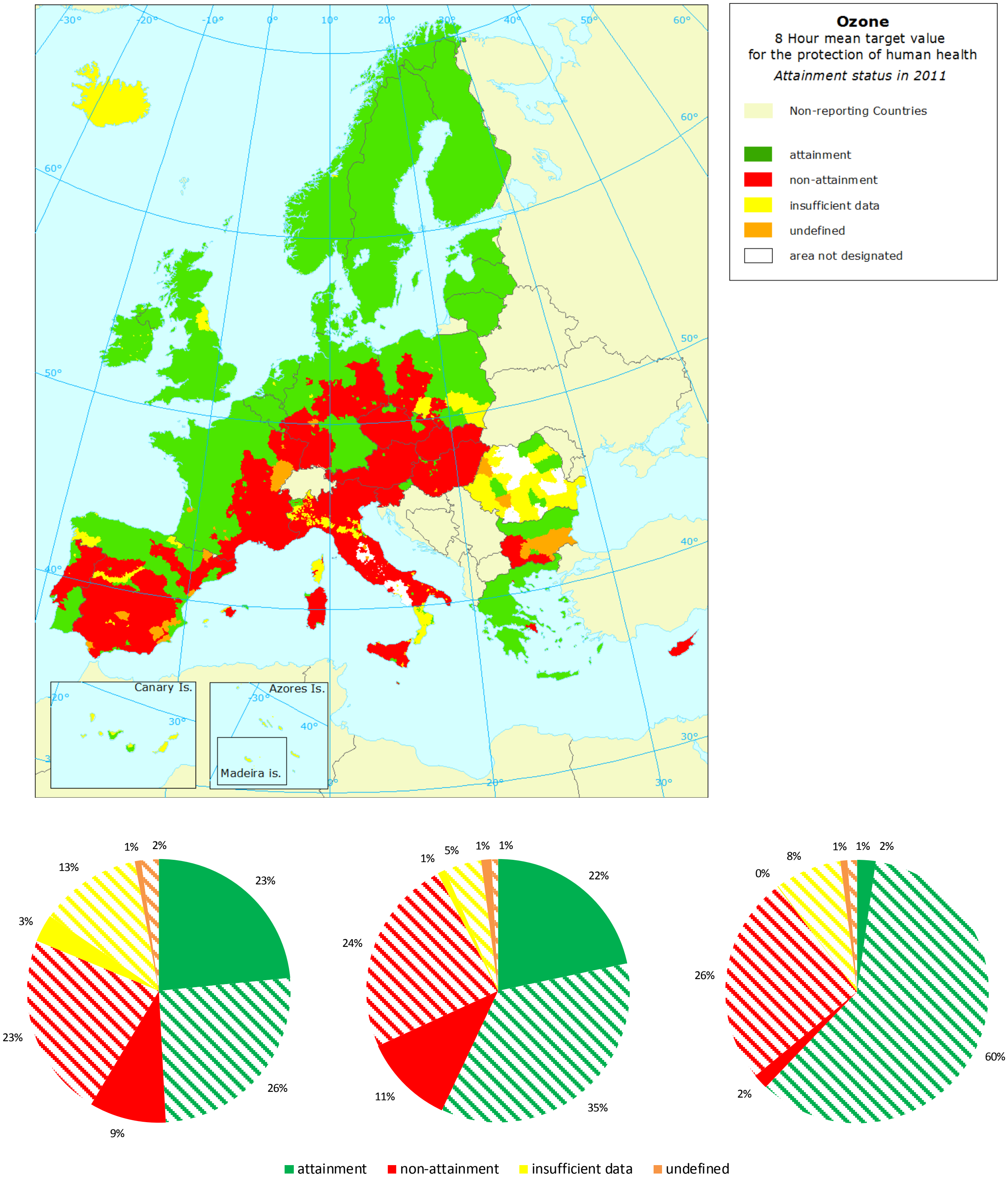


Figure 3. Attainment status of the 2011 ozone air quality management zones based in the period 2007-2011; distribution of number (left), population (middle) and area (right) of agglomerations (solid fill) and non-agglomeration (shaded fill).

3. Are attainment areas at risk of becoming a non-attainment area?

At the European level various measures have been defined to reduce the emission of air pollutants, for example the introduction of the EURO standards for road traffic, the NEC directive and the revised Gothenburg protocol. It is expected that by these and similar measures air quality will generally improve. However, at the local level it might be that, for example by increased economic activities or by (building) new infrastructure, the pollution levels (temporally) increase. Deterioration of air quality may result in a shift from attainment to a non-attainment area. The year-to-year fluctuations in concentrations caused by meteorological variability may form another reason for a shift in attainment status.

In this chapter, we will try to identify those zones which have a high risk to become a non-attainment area. An early detection of “zones at risk” may initiate an early planning of mitigation programs.

As mentioned in Chapter 2, AirBase data has been used to collect the highest observed concentrations for each year in the period 2007-2011. The year-to-year variability and the measurements uncertainties contribute to the total monitoring uncertainty. Velders and Matthijsen (2009) found variations (1 sigma) in the annual average concentrations of about 9% for PM_{10} and 5% for NO_2 due to the meteorological fluctuations. At a European level the interannual variation in annual means ranges from 3% for ozone, 5% for NO_2 and 9% for PM (Andersson et al 2007). The year-to-year variation in ozone peak values will be larger than the 3% found for the annual mean. Solberg et al (2009) showed that the meteorological variability in the ozone indicator AOT40 has a decreasing gradient from north-west (50% for AOT40 in UK) to south-east Europe (10% for AOT40). A similar pattern with lower values was found for the SOMO35 indicator. These variabilities are not transferable to the 94.2 percentile value used in this study. Both SOMO35 as well as AOT40 have a cut-off level that makes them more sensitive for small variations. Here we assumed a 9% interannual variation for all three pollutants. With increasing uncertainties, the probability that an attainment area is at risk for exceedance increases (see below). By adopting the high-end value a conservative estimate of the number of areas at risk will be made.

The standard deviation due to the measurement uncertainty is, in the Dutch monitoring network (RIVM, 2013), estimated to be about 13% (NO_2), 6% (PM_{10}), and 8% (ozone); similar uncertainties have been assumed for the networks in the other Member States. Since both sources of variance are uncorrelated, the overall standard deviation is 16%, 11% and 12% for NO_2, PM_{10} and ozone, respectively.

When we assume that the concentrations are normal distributed, a simple approach can be taken to estimate the probability of having an exceedance of the LV or TV. The normal distribution is defined by the averaged concentration (here, the averaged maximum concentration in a zone over the past five years) and a standard deviation (here, the pollutant dependent total uncertainty given above), see Figure 4. We further assume that the zone is potentially at risk of becoming a non-attainment zone when the probability for exceedance is more than 15%, that is, the averaged concentration is less than roughly one standard deviation away from the LV/TV.

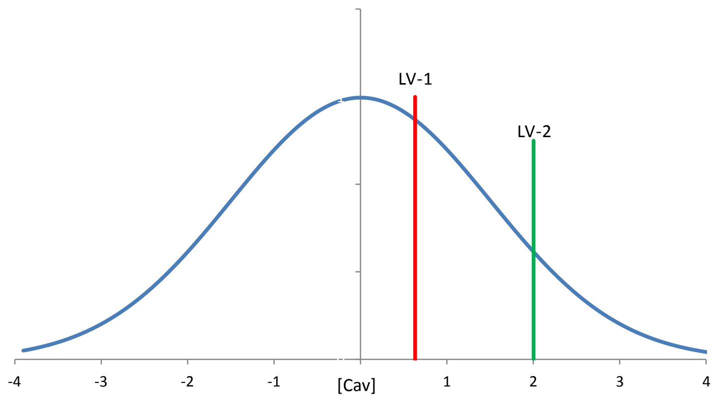


Figure 4. Normal distribution demonstrating the criterion for defining a “zone at risk”. When the difference between LV and average concentration (Cav) is more than 1σ, for example, the value LV-2, the probability of having a concentration larger than {Cav+LV-2} is less than 15%; in this case the zone is seen to be not at risk. However, when the probability is 15% or more (for example, the situation sketched by LV-1) the zone is indicated as “at risk”. The probability is more than 15% when the difference between averaged concentrations and LV is less than about 1σ.

In a second test the temporal changes in concentrations are considered. When concentrations in a zone at risk are declining, the probability of an exceedance will decrease over time. Zones at risk showing a significant trend on a five- or ten-year period are judged as being “save”. To evaluate the changes over the past five years, a possible trend in the maximum concentrations observed in the zone is evaluated by computing the Mann-Kendall S-statistic (Gilbert, 1987); the trend is marked as significantly downwards when $S \leq -6$.

In estimating the ten-year trend in air quality, the concentrations observed at an individual station during the period 2002-2011 are considered. Trends are calculated when the station is operational (defined as a data coverage of 75% or more) during at least 8 years. After evaluating the trend at each station within a zone, a zone-average trend (including a 2σ uncertainty range) is calculated. Zones having a significant downward trend (that is, the slope is negative and its absolute value is larger than 2σ) are judged as being “save”.

When these rules are applied on the PM_{10} attainment areas, this results in 76 zones which are potentially at risk. In 33 zones the short-term (5 years) and/or long-term trend is significantly downwards remaining 43 zones at risk. Of these 43 zones, 16 are labelled as agglomerations. The area of both agglomeration as well as non-agglomeration is in general small (less than 1000 km^2), which might indicate that the zones are designated around a known hot-spot area. If we apply the same rules on the zones for which the attainment status could not be determined (“undefined”), 20 “undefined” zones are considered to be at risk. Not surprisingly, this is a large fraction of the number of undefined zones. Again it concerns in general rather small (<1000 km^2) zones.

In the case of NO_2, in 30 of the 48 attainment zones with an exceedance probability of more than 15%, a statistically downward trend is observed. 18 zones at risk are remaining. In addition, 5 out of the total 18 zones having an undefined status are at risk. Similar to PM_{10}, the zones at risk have mostly a size of less than 1000 km^2.

For ozone a large number of the attainment areas are at risk. The main reason for this is that the gap between current ozone levels and the target value is small; further, ozone trends are small and in most cases these trends are not significant. Of all zones potentially at risk (having a probability of exceedance of more than 15%), only about 25% have a significant downward trend and 123 zones at risk are remaining. Eleven undefined zones are also at risk. When the meteorological variability is underestimated, more zones will be at risk. When in a sensitivity run the meteorological variability was set to 15%, the number of zones at risk increases from 134 to 159.

Figure 5 shows the location of the attainment area at risk. The18 NO_2 attainment areas at risk are scattered over the map of Europe; this is another indication that NO_2 is in particular a local problem. For PM_{10} we see that a large number of the zones at risk are neighbouring non-attainment areas. These situations could best be described as a relatively large background concentration in combination with a local enhancement. In case of ozone, the zones at risk are neighbouring the non-attainment areas leaving only the NW area (Scandinavia, large parts of the Baltic States, the UK and Ireland) and most of the coastal region of North Sea and Atlantic Ocean as the “persistent” attainment areas. The measurements indicate that Northern Greece is an attainment area; this is in contrast with the general finding, both from measurements as well as modelling, that the highest ozone levels occur in the Mediterranean. It might be that the observations in Northern Greece (on traffic stations) are not representative for the background levels.

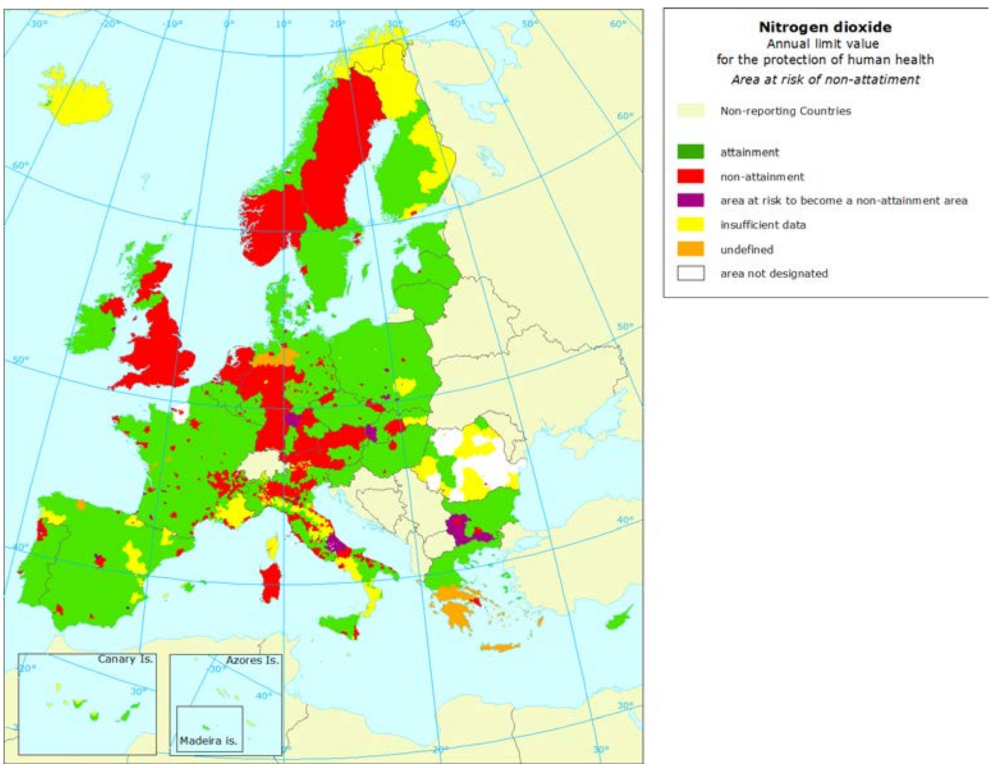
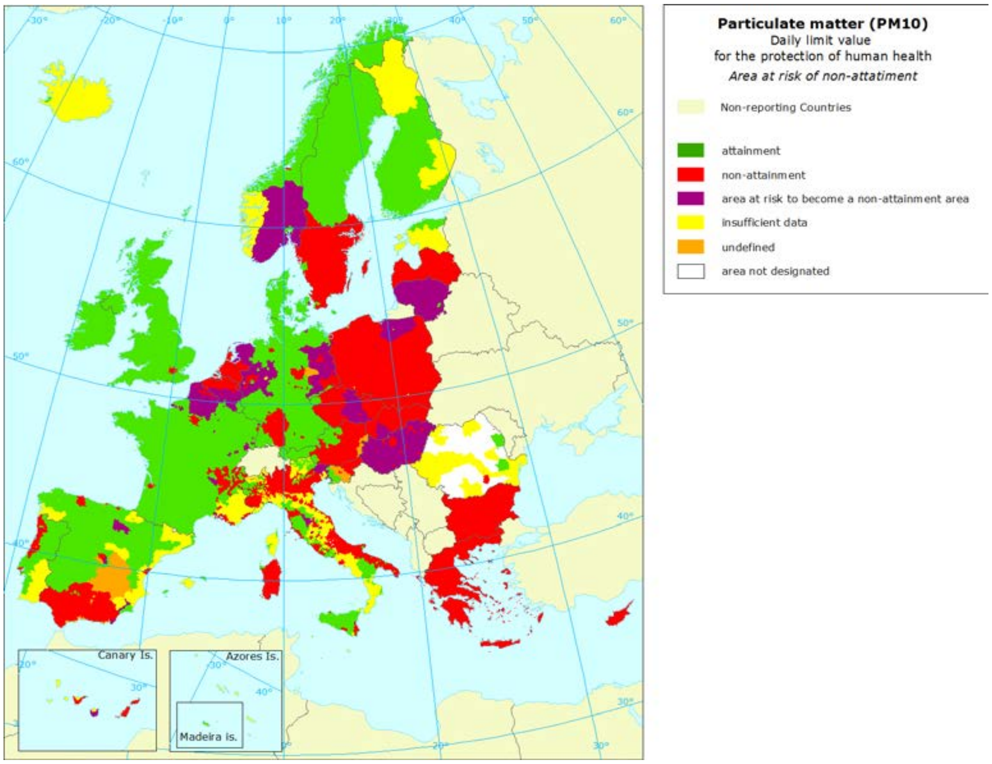


Figure 5. Maps showing the location of the attainment area at risk of becoming non-attainment areas for NO_2 (annual LV), PM_{10} (daily LV) and ozone (health related TV).



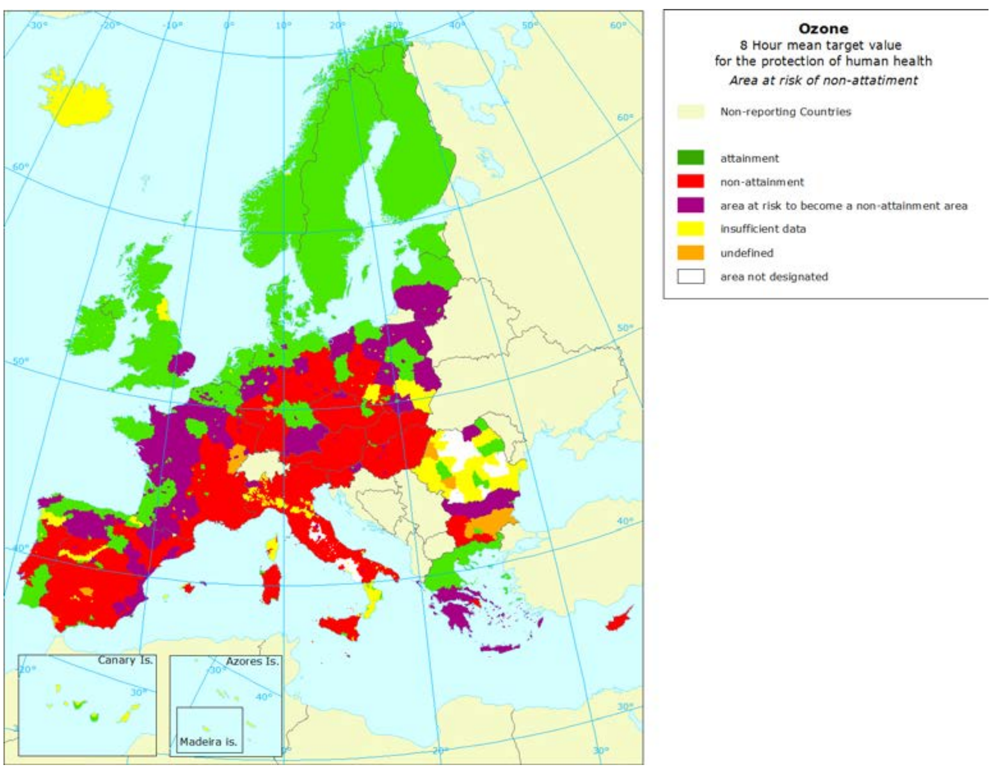


Figure 5, continued.

Summary and conclusions

Definitions for attainment and non-attainment areas have been proposed. Using the AirBase monitoring database these definitions have been applied on the air quality management zones as designated and reported by the Member States for 2011. It is shown that the proposed definitions are workable. Only in a few cases no exclusive result can be given; in these cases the attainment status must be marked as “undefined”. A larger problem is that, for a relatively large fraction of the zones, insufficient monitoring data is available to make any statement on the attainment situation. For NO_2 zones, this could largely be explained by the fact that concentrations in many zones (especially non-agglomerations) are below the lower assessment threshold and no fixed measurements are required. However, for the 134 PM_{10} zones having an “undefined” status only in 18 zones the levels have been reported to be below the lower assessment threshold and can therefore be labelled as “attainment areas”.
Taking into account both the meteorological induced year-to-year variability in concentrations as well as the measurement uncertainty, the probability of having an exceedance of the limit or target value has been estimated for all attainment areas. It was assumed that the attainment area is at risk to turn over into a non-attainment area when the probability of exceedance is more than 15% and there is no significant downward trend in concentrations. A zone “at risk” is still in compliance with the limit or target value and there is no requirement to develop abatement plans and programs. However, as the compliance situation might change in the coming years, it might be advisable to initiate the process of defining abatement strategies.
By this procedure we estimated that 23 of the 372 NO_2 zones now marked as attainment area or as “undefinied” are at risk to become a non-attainment area. For PM_{10} these numbers are 63 and 334; for ozone 134 and 340. The large number of ozone zones at risk is caused by a combination of the fact that there is only a small gap between the current levels and the target level and by the absence of a significant trend at most monitoring stations.

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