Evaluation of international air quality standards

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Front page picture: *Comparing international air quality standards is like comparing apples and oranges: Similar size/weight (level/averaging period) but strongly different taste (health protection). ©Frank de Leeuw, 2017.*

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1 Introduction

Successful strategies to improve ambient air quality generally use a dual approach. At one hand emission standards set upper limits on the atmospheric emissions from a specific process or installation or set a ceiling on the emission of a country/region as a whole (e.g. the NEC directive (EU, 2016)). At the other hand ambient air quality standards set a benchmark for what is judged to be an acceptable air quality. At national and regional level considerable efforts are devoted to setting ambient air quality standards. The selection of priority pollutants and the setting of standards for the selected pollutants is in general aiming at the protection of human health but in various cases the effects on vegetation have been considered as well.

Although health protection is the common factor, the standards as set by various countries or international bodies may show a wide range in threshold level, averaging period and the number of allowable exceedances. The different definitions hamper a direct comparison of standards. For example, assume two standards both having a threshold level of 80 µg/m^3 but one is defined as the 98-percentile of daily averaged concentration, the other as a maximum daily running 8-hourly concentration with nine allowable exceedances per year. The similar threshold level suggests that the standards are equivalent but due to the differences in averaging time and statistical indicator, one cannot say by forehand which standard gives the best protection for human health or ecosystems.

Vahlsing and Smith (2012) reviewed the short-term (daily) air quality standards for PM_{10} and SO_2. This review of the literature up to 2010 showed a daily limit value of PM_{10} ranging from 50 to 260 µg/m^3 (data from 68 countries). In most of the countries (35) the standard equals the air quality guideline (AQG) as recommended by WHO (2000, 2006). However, as no information on the allowable number of exceedance days has been given the national standards might be weaker than the WHO-AQG. The reported range in daily SO_2 standards is 50 – 365 µg/m^3; in the majority (63 of 73 reporting countries) the standard equals or exceeds the WHO-Interim Target-1.
Kunzli et al. (2015) have compared global long-term standards for PM_{10} and $PM_{2.5}$; in the majority of countries/regions the current standards (August 2015) are less strict than the guidelines proposed by the WHO.

De Leeuw and Ruyssenaars (2011) analysed the equivalence between the short-term and long-term standards as set in the EU air quality directive (EU, 2008). For the most stringent (that is, the most widely exceeded) standard a systematic comparison was made with the WHO AQG. Using observed data for the period 2006-2008 it was shown that a substantial fraction of the urban population was exposed to levels exceeding the WHO-AQG: SO_2, 70-85%; NO_2, 7-20%; PM_{10}, 80-90%; O_3, more than 95%. According to the most recent analysis (period 2012-2014; EEA, 2016) these fractions are strongly reduced for SO_2 (35-49%), NO_2 (7-9%) and PM_{10} (50-63%) but not for O_3.

For various pollutants, the EU has set both a short-term (on hourly or daily base) and a long-term (annual) limit value. These limit values are in general not equivalent. Applying the most strict (most-widely exceeded) EU limit values as reference, a fraction of the urban population ranging from less than 5% (SO_2) to about 50% (O_3) was exposed to concentrations above the EU standards (period 2006-2008; de Leeuw and Ruyssenaars, 2011) . The most recent update (period 2012-2014; EEA, 2016) showed a reduction in the fraction exposed to levels above the EU standards to less than 0.1 % (SO_2) and 8-17 % (O_3).

In this paper the 2013 air quality in Europe will be evaluated against an extensive set of air quality standards including standards from a selected number of countries (Australia, Canada, China, India, New Zealand and United States), the guidelines set by WHO, and the EU limit and target values.

Although several European countries or regions have set more strict standards than given in the Air Quality Directive (de Leeuw and Ruyssenaars, 2011; Ludok, 2015) only the EU-wide standards will be considered.

The comparison will be performed for all standards set for the protection of human health and which are legally binding for the whole national territory. Standards which have been set by local authorities within the selected countries (e.g. standards set by states within the USA or by Canadian Provinces) or which have to be met in specially designated areas (e.g. China defines (more strict) standards for “class 1” zones which includes natural reserves, scenic spots and other areas that need special protection) have not been included in the comparison.
A summary of the current ambient air quality standards as used in this comparison is presented in Table 1. More detailed information on the standards from the selected countries, the EU and the WHO is provided in Annex A.

Table 1. Overview of the (inter)national air quality standards. In parenthesis the number of allowable exceedances is given; when the threshold is expressed as a percentile value, the percentile is indicated by the suffix P. Thresholds are given in $\mu g/m^3$ except in the case of CO (in mg/m^3), and BaP, As, Cd, Ni (all in ng/m^3).When the national standards are expressed as a mixing ratio, the levels are converted to $\mu g/m^3$ using the conversion table in Annex B. See for further details the overview of the national and other international bodies' standards in Annex A.

Pollutant *Average period*	PM_{10} daily	PM_{10} annual	$PM_{2.5}$ daily	$PM_{2.5}$ annual	NO_2 hourly	NO_2 daily	NO_2 annual	SO_2 hourly	SO_2 daily	SO_2 annual
Australia [a]	50 (5)				230 (1)[b]		57 (0)	530 (1)[b]	210 (1)	53 (0)
Canada [a]			28 (98P)[e]	10 (0)[e]						
China [a]	150 (0)	70 (0)	75 (0)	35 (0)	200 (0)	80 (0)	40 (0)	500 (0)	150 (0)	60 (0)
India	100 (98P)	60 (0)	60 (98P)	40 (0)		80 (98P)	40 (0)		80 (98P)	50 (0)
New Zealand	50 (1)				200 (9)			350 (9); 570 (0)		
USA	150 (1)		35 (98P)[e]	12 (0)	190 (98P*)		100 (0)	200 (99P*)		
EU	50 (35)	40 (0)		25(0)	200 (18)		40 (0)	350 (24)	125 (3)	
WHO	50 (99P)	20 (0)	25 (99P)	10 (0)	200 (0)		40 (0)		20 (0)	

Pollutant *Average period*	O_3 1 hour	O_3 MDA4	O_3 MDA8	CO 1-hour	CO 8-hours	CO daily	lead daily	lead 3 monthly	lead annual	benzene annual
Australia[a]	200 (1)[b]	160 (1)			10 (1)[d]				0.50 (0)	
Canada[a]			126 (3)[e]							
China[a]	200 (0)		160 (0)	10 (0)		4(0)				
India	180 (98P)		100 (98P)[c]	4 (98P)	2 (98P)		1.0 (98P)		0.50 (0)	5 (0)
New Zealand	150 (0)				10 (1)					
USA			140 (3)[e]	40 (1)	10 (1)			0.15 (0)		
EU			120 (25)[e]		10 (0)[d]				0.50 (0)	5 (0)
WHO			100 (0)	30 (0)	10 (0)				0.50 (0)	1.7 (0**)

Pollutant *Average period*	BaP annual	As annual	Cd annual	Ni annual
Australia				
Canada				
China				
India	1 (0)	6 (0)		20 (0)
New Zealand				
USA				
EU	1 (0)	6 (0)	5 (0)	20(0)
WHO	0.12 (0**)	6.6 (0**)	5 (0)	25 (0**)

Notes to Table 1:
MDAx: maximum daily x-hour mean
* USA: NO_2: 98-percentile of 1-hour daily maximum (MDA1); SO_2: 99 percentile of 1-hour daily maximum (MDA1);
** WHO: estimated reference level, see Annex A for description;
(a) Applicable at (urban) background locations only, see Annex A;
(b) Exceedance allowed during one day per year (MDA1);
(c) Based on running 8-hourly values;
(d) Based on MDA8.
(e) Averaged over three years

2 Harmonisation of the air quality standards

In addition to differences in level, averaging period and statistical indicator, there are differences in the application area. While comparing the international standards with Europe's air quality concentrations, the differences between the implementation of the standards according to the national legislation and the EU legislation have to be considered. The comparison has been made according to the EU practice; below the major differences in approaches are discussed.

In the EU and in New Zealand a temporal derogation of the standards is allowed. The EU directive (see art. 22 in EU, 2008) allowed for derogation for benzene and NO_2 (up to 1 January 2015), and PM_{10} (up to 11 June 2011). In New Zealand breaching of the PM_{10} standard is possible until 1 September 2016 or 1 September 2020 depending on the levels over the period 2006-2011 (see Annex A). In the comparison the option for derogation will not be considered.

According to the EU-regulation there is an option to subtract from the observed ambient levels the contribution of natural sources and/or the contribution of winter sanding and salting before comparing the observation with the threshold levels. When using this option, detailed information on the source contributions, PM-speciation, and meteorology is required. This additional information is generally not routinely available in the air quality data base (EEA, 2015). Observed data (without taken into account any subtraction) will therefore directly be compared against the standards given in Table 1.

The Australian PM_{10} standard allows for five exceedances of the threshold level of 50 $\mu g/m^3$ to account for natural events. As this is a fixed number and does not require any further motivation, it is seen as an inherent part of the standard.

In a number of cases, the standard is defined as a 3-year average mainly to reduce the sensitivity for extreme meteorological conditions. For example, the ozone EU-target value for health protection is defined as a 3-year average; both the short-term standards for $PM_{2.5}$ and O_3 in Canada and the USA are defined as 3-year averages. The comparison is, however, limited to one single year (2013). It is not expected that this will influence main conclusions, as concentrations in 2013 do not strongly deviates from those in 2012 or 2014.

The European regulation requires that the metals and BaP should be monitored at PM_{10}. Other countries do not prescribe a specific particle size. Here all size fractions have been included in the benchmark.

Reference measurement methods are prescribed by the EU and by most of the selected countries. In the air quality database no tests have been implemented to check whether the used measurement methods comply with the reference methods set by the various standards.

A complicating factor in evaluating compliance is that the definition of the locations where the standards have to be met, differs. The EU-standards, for example, have to be met at any location to which the general public has regular access. Monitoring stations have to be established on location where the highest concentrations are to be expected. This includes typical hotspot locations like traffic or industrial hotspots. Other national standards have to be assessed in locations where representative air quality levels likely to be experienced by the general population, are expected. These are typically urban or residential background locations; hotspot situations are not included in the assessment. With equal threshold levels, standards applicable also at roadside locations are more stringent than thresholds applicable at urban background locations.
The national web sites informing on the air quality standards are not always clear on this point. However, the national web sites generally provided information on the siting criteria for monitoring stations used in compliance checking. In case no information on the application area was available, we inferred the application area based on the siting criteria, see Annex A for further details.

3 Selection of the air quality data set

The data reported to the EEA referring to year 2013 (EEA, 2015) is used to compare European ambient concentrations with the selected international standards. Various standards (Table 1) are based on statistical indicators that are not routinely available in the EEA database. The primary (hourly or daily) data have been downloaded (EEA, 2015) and, without any further quality checking, these data are used to calculate all necessary indicators[1].

For a proper comparison between the standards as implemented in the countries, the use of consistent set of aggregation rules and rules for the selection of station/time-series is essential for the benchmark. Below is an overview of the criteria applied in selecting the time series.

The standards have been defined for different averaging periods, for example, SO_2 standards have been set for hourly, MDA1[2], daily and annual data. To preserve a consistent set, only time series for the shortest averaging period (that is, hourly data for NO_2, SO_2, O_3, and CO, daily data for PM_{10}, $PM_{2.5}$ and lead) are selected. In practice, this implies that data from passive sampler (e.g. diffusion tubes) are excluded. For benzene, BaP and the other metals standards have been set for annual averages only; in these cases, the averaging period of the primary data is not relevant.

In their regulations, the countries may have indicated explicitly minimum criteria on data coverage. Applying the various national rules will result in mutually inconsistent data sets. To harmonise the data set, similar requirements on data coverage are adopted:

- 4-hourly, 8-hourly and daily averaged values are valid when at least 75% of the hourly data is available;
- MDA1, MDA4, MDA8 values are valid when at least 75% of the running 1h, 4h or 8h values are available;

[1] While working with the data set some obvious mistakes were found and whenever possible, corrected. This mainly relates to cleaning of the primary reported data for duplicates. It appeared that hourly data (SO_2, NO_2, O_3, CO) from Poland was not fully included in the data set. The available Polish hourly time series did not fulfil the data coverage criteria and had to be excluded from the analysis.
[2] MDA1 is the maximum daily hourly concentration. Similarly, MDA4 (MDA8) is the maximum daily running 4-hourly (8-hourly) concentration.

- Time series with a data coverage of less than 75% are rejected. For benzene a 50% and for BaP and the metals a 14% data coverage is required.

The short-term standards are defined in terms of an allowed number of exceedances of a specified threshold or in terms of a percentile value. It has been shown (de Leeuw, 2012) that the number of exceedances is, in contrast to the corresponding percentile value, very sensitive for missing values. Non-compliance stations will be identified by comparing the percentile values with the threshold. The relation between percentiles and number of exceedances is given in Annex B.

All station types (background and hot-spot) have been included in the final set. Although in some of the selected countries the standards are not applicable at hot-spot locations, we have - in line with EU regulations and to ease the comparison- included all stations. In this way we might overestimate the stringency.

By harmonising the data in the way described in this and the previous section, the results will not reflect the compliance situation in a legal sense. However, it does provide a clear assessment of the Europe's air quality compared to international standards.

4 Evaluation of Europe's ambient air

Evaluation whether the observed concentrations in Europe are in compliance with the air quality standards as listed in Table 1 might be done by comparing the threshold level with the observed indicator. Comparing the numbers of non-compliance stations might provide information on which of the standards is the most stringent one.
However, such a comparison does not fully answer the question which of the standards provides the best protection of human health. The most stringent standard can be defined as the standard that gives the largest gain in health when a full compliance would be realised. The health impact attributable to one pollutant is, in first approximation, linear in the concentration and the size of the exposed population. The product of a change in exposure and the exposed population is therefore a proxy of the gain in health under full compliance conditions.

To estimate the exposure at a single station, the *Exposure Reduction by full Implementation (ERI)* can be defined as:

$$ERI = \left(\sum_{i=1}^{N_{period}} \delta_i \; (C_i - T)\right) \cdot \left(\frac{1}{dc}\right), \qquad [1]$$

where

T is threshold value (as given in Table 1),
C_i is concentration at time i,
$\delta_i = 1$ if $C_i > T$, and
$\delta_i = 0$ if $C_i \leq T$.

In order to correct for missing values, the factor $\left(\frac{1}{dc}\right)$ is introduced; *dc* is the data coverage defined as $dc = N_{valid}/N_{period}$ where N_{valid} is the number of valid hourly/daily measurements and N_{period} is the total number of hours/days per year.

Equation [1] is summed over <u>all</u> exceedances in a year. When the standard allows for a limited number of exceedances of the threshold level, a correction has to be introduced. When N_{AQS} is the number of *allowable exceedances* and N_{exc} is the number of *observed exceedances* ($N_{exc} = \sum \delta_i$), N_{AQS} times the average exposure during an exceedance situation can be subtracted by introducing the factor $\left(1 - \frac{N_{AQS}}{N_{exc}}\right)$:

$$ERI = \left(\sum_{i=1}^{N_{period}} \delta_i \ (C_i - T)\right) \cdot \left(1 - \frac{N_{AQS} \cdot dc}{N_{exc}}\right) \cdot \left(\frac{1}{dc}\right) \qquad \text{when } N_{exc} > N_{AQS} \qquad [2]$$

$$= \ 0 \qquad \text{when } N_{exc} \le N_{AQS}$$

N_{AQS} is the allowable number set assuming a 100% data coverage; in Eq [2] a correction for missing data is introduced.

Equation [2] can also be applied in case the standard is expressed as a percentile value. In this case N_{AQS} is estimated from the percentile:

$$N_{AQS} \ = \ (1 - P) \ \cdot \ N_{period} \qquad [3]$$

where P is the percentile (e.g. P = 0.98).

For annual mean concentrations, ERI simplifies to:

$$ERI = \ \delta_i \ (C_i - T) \qquad [4]$$

The dimension of *ERI* is given, similar to, for example, AOT40 and SOMO35, as [*concentration x time*].When comparing standards with different averaging periods, the *ERI* should be converted to a common time unit. Taking a year as reference, the *ERI*-value is divided by 365 (in case of standards defined on a daily base, including those based MDA*x*-values), by 8760 for an hourly standard and a running 8-hour standard.

Once *ERI* is calculated at a single station, a grand total is calculated by summation over all non-compliance stations. The most stringent standard might be defined as the one having the largest *ERI* value. Alternatively, a weighting according to the population can be introduced: a small reduction in an urban area might result in a larger health benefit than a large reduction in a rural area. Such a population weighting requires information on the representativeness area of a station. In first approximation an estimate of the population is obtained from an overlay of station coordinates with a high-resolution population map. Population (in inhabitants) is based on JRC data for the majority of countries (JRC, 2009). For countries and regions that are not included in dataset, ORNL population data is used (ORNL, 2008). The population refers to the population living within a 1 km-radius around the station.

5 Results and discussion

5.1 Particulate matter, $PM_{2.5}$ and PM_{10}

All selected countries have set standards for either PM_{10} or $PM_{2.5}$: Australia and New Zealand set daily standards for PM_{10} only, Canada for $PM_{2.5}$ only. The other countries have, in general, set short-term (daily) and long-term (annual) standards both for PM_{10} and $PM_{2.5}$.
Eleven standards have been set for $PM_{2.5}$; Canada and WHO have similar annual standards (10 µg/m^3); the other nine all differ either in level, indicator or in the number of allowed exceedances.
Table 2 gives an overview of the compliance situation with respect to the selected $PM_{2.5}$ standards. Regarding the number of non-compliance situations, an annual standard of 35 µg/m^3 or more is seldom exceeded. Most widely exceeded are the daily and annual standards set by Canada and WHO.
The ranking according to the number of non-compliance stations is slightly different from the ranking according to *ERI*. In general, full implementation of an annual standard results in a larger reduction than full implementation of a daily standard; compare, for example, daily and annual standards of USA and Canada. With approximately the same number of non-compliance stations, the *ERI* for the annual standard is about 3 times the *ERI* for the daily standard.

Although less frequently exceeded, the EU standard would provide by full implementation a larger exposure reduction than the Chinese or Indian daily standards. When accounting for the magnitude of the exceedances the largest benefits are to be expected with an annual standard of 10 µg/m^3 (Canada, WHO).
Assuming that levels measured at the stations are representative within a 1 km radius, the introduction of a population weighting of *ERI* does not change the relative ranking of the standards. It could be argued that stations at hotspot (traffic, industrial) locations have a smaller representativeness area than the 1 km radius. When taking this into account by including 10% of the population, the ranking remains the same. Fully neglecting hotspot stations – that is, including only the background stations conform e.g. the USA approach – does not change the relative ranking either. For this, the population weighting was not further included in the analysis.

Table 2.Summary of compliance situation of $PM_{2.5}$ standards.

country	Averaging time	Level (µg/m^3)	allowed number of exceedances(a)	Fraction of non-compliance stations	ERI (µg/m^3)·year
IND	year	40	-	0.1	5
CHN	year	35	-	0.6	16
EU	year	25	-	7.8	317
IND	day	60	P98	17.9	174
CHN	day	75	0	36.9	135
USA	year	12	-	71.6	3825
USA	day	35	P98	72.9	898
CND	day	28	P98	80.4	1487
CND	year	10	-	80.8	5212
WHO	year	10	-	80.8	5212
WHO	day	25	P99	87.8	1947

(a) Allowed number of exceedances; when standard is based on a percentile value, this is indicated by Pxx.

Figure 1 shows box-whisker plots of the observed scaled concentrations for each of the standards. For each standard, the box shows the distribution of the relevant concentration indicator as defined by averaging time and statistical indicator, scaled to the level set by the standard. To illustrate this: the daily Canadian standard is defined as a 98-percentile of daily values not exceeding 28 µg/m^3; in this case the box plot gives the daily 98-percentiles observed at each station divided by 28 µg/m^3 The daily Chinese standard does not allow any exceedance of a level of 75 µg/m^3; here the box plot shows the observed maximum daily concentrations divided by 75 µg/m^3. By this scaling, compliance situations are given by a scaled concentration below 1; values greater than 1 refer to an exceedance station.
From the similar distribution it can be seen that the daily and annual standards in Canada and USA are nearly equivalent. For China, India and WHO the daily standards are stricter than the annual standards.

Table 3 and Figure 2 present similar information on the PM_{10} standards. With respect to the number of exceedances the least and most strict standard is given by the Chinese annual standard and the daily standard in New Zealand. Based on the *ERI*, the WHO annual standard is the strictest. A full implementation of the WHO annual standard will result in the largest exposure reduction. A full compliance with the EU annual LV will result in a smaller exposure reduction than a full compliance with the daily LV, as was already known from previous studies (de Leeuw and Ruyssenaars, 2011).

When comparing the compliance situation for $PM_{2.5}$ (Fig. 1) and PM_{10} (Fig. 2) is it clear that in general the $PM_{2.5}$ standards are more widely exceeded than the PM_{10} standards. Whereas the EU $PM_{2.5}$ standards are relatively 'soft' compared to the others, the EU daily PM_{10} standard is stricter than those of China, India and the USA.

Comparing the two pollutants on the *ERI* is not possible. Equal reductions in exposure do not correspond to an equal reduction in the burden of disease. Additional information on concentration-response functions will be needed here.

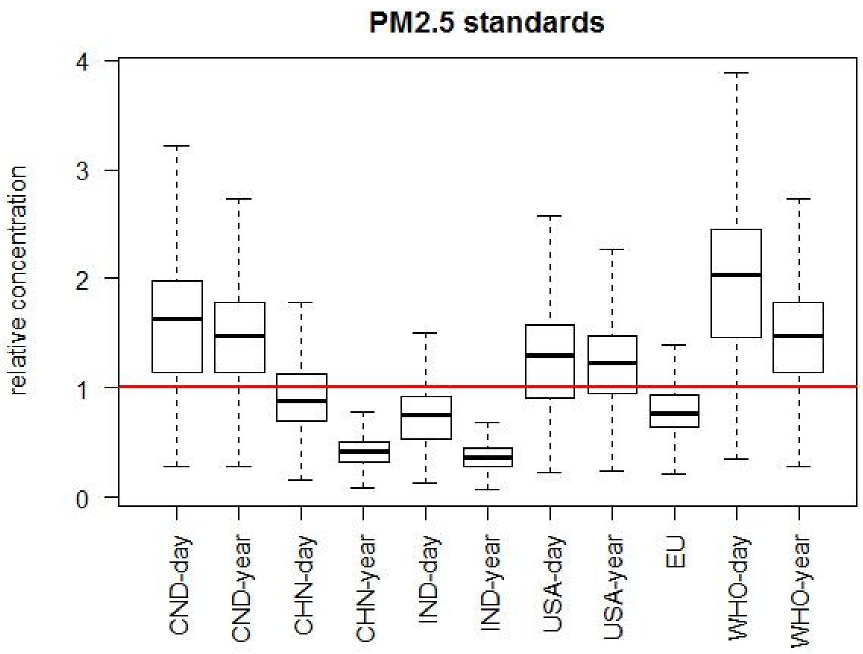

Figure 1. Comparison of the exceedance situation with respect to $PM_{2.5}$ standards. The y-axis shows the concentration relative to the level of the standard. Reference year 2013. Note that outliers have not been shown.

Table 3.Summary of compliance situation of PM_{10} standards.

country	Averaging time	Level ($\mu g/m^3$)	allowed number of exceedances(a)	Fraction of non-compliance stations	ERI ($\mu g/m^3$)·year
CHN	year	70	-	0.2	97
IND	year	60	-	0.4	161
EU	year	40	-	4.5	843
IND	day	100	P98	8.6	352
USA	day	150	1	11.3	182
CHN	day	150	0	11.5	218
EU	day	50	35	19.9	1331
WHO	year	20	-	65.1	11428
AUS	day	50	5	77.1	2806
WHO	day	50	P99	80.6	2913
NZL	day	50	1	91.5	3133

(a) Allowed number of exceedances; when standard is based on a percentile value, this is indicated by Pxx.

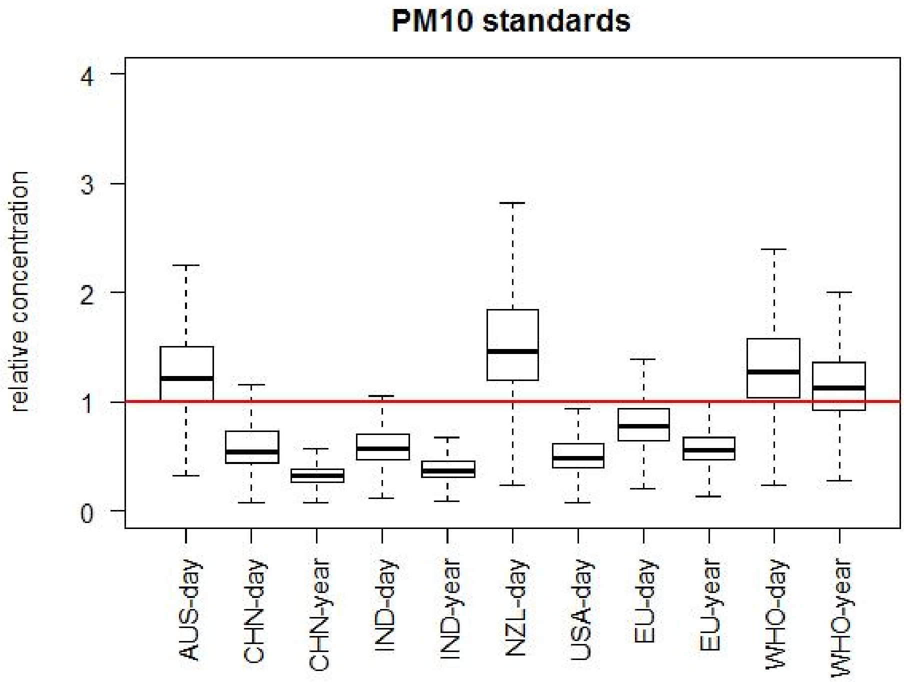

Figure 2. Comparison of the exceedance situation with respect to PM_{10} standards. The y-axis shows the concentration relative to the level of the standard. Reference year 2013. Note that outliers have not been shown.

5.2 Nitrogen dioxide

The NO_2 standards show a large uniformity with respect to the level: for 4 out of 6 hourly standards a level of 200 µg/m^3 is defined; equal levels (80 µg/m^3) are set for the two daily standards (China, India) and for 4 out of the 6 annual standards a level of 40 µg/m^3 is defined. However, as the statistical indicators differ strongly (for example, 0, 1, 9 or 18 allowable exceedance of the hourly concentration of 200 µg/m^3), differences in number and magnitude of exceedances are found (Table 4, Figure 3).

The most widely exceeded standard is the Chinese daily standard, however, in terms of the largest exposure reduction (ERI) the annual standard as adopted by China, India, WHO and EU is the most strict. The EU hourly standard is occasionally exceeded (at less than 1% of the stations); the expected reduction in exposure by full compliance with the hourly is three orders of magnitude smaller than in case of a full compliance of the annual EU standard.

Table 4.Summary of compliance situation of NO_2 standards.

country	Averaging time	Level (µg/m³)	allowed number of exceedances(a)	Fraction of non-compliance stations	ERI (µg/m³)·year
USA	year	100	-	0.0	0
EU	hour	200	18	0.9	3
NZL	hour	200	9	2.1	4
USA	MDA1	190	P98	2.1	33
AUS	year	57	-	2.2	452
AUS	MDA1	230	1	5.2	23
IND	day	80	P98	9.5	247
CHN	hour	200	0	9.9	8
WHO	hour	200	0	9.9	8
CHN	year	40	-	11.7	2786
EU	year	40	-	11.7	2786
IND	year	40	-	11.7	2786
WHO	year	40	-	11.7	2786
CHN	day	80	0	26.0	323

(a) Allowed number of exceedances; when standard is based on a percentile value, this is indicated by Pxx.

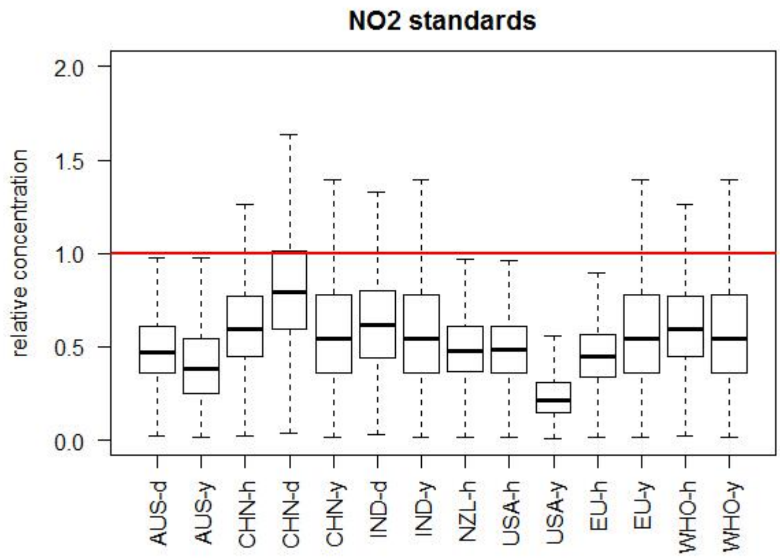

Figure 3. Comparison of the exceedance situation with respect to NO_2 standards. The y-axis shows the concentration relative to the level of the standard. Reference year 2013. Note that outliers have not been shown.

5.3 Ozone

Notwithstanding that the EU standard is widely and frequently exceeded, it appears to be one of the weakest standards, see Table 4. However, in terms of exposure reduction by full implementation the EU standard ranks as number 4 after the WHO standard, Indian 8-hour and Canadian 8-hour.

Table 4.Summary of compliance situation of O_3 standards.

country	Averaging time	Level (µg/m³)	allowed number of exceedances(a)	Fraction of non-compliance stations	ERI (µg/m³)·year
IND	hour	180	P98	0.0	0
AUS	MDA1	200	1	10.6	21
CHN	hour	200	0	11.7	3
EU	MDA8	120	25	28.0	459
CHN	MDA8	160	0	29.5	67
AUS	MDA4	160	1	44.2	130
USA	MDA8	140	3	47.1	244
NZL	hour	150	0	72.3	71
CND	MDA8	126	3	73.0	793
IND	8hour	100	P98	74.4	1012
WHO	MDA8	100	0	97.4	4813

(a) Allowed number of exceedances; when standard is based on a percentile value, this is indicated by Pxx.

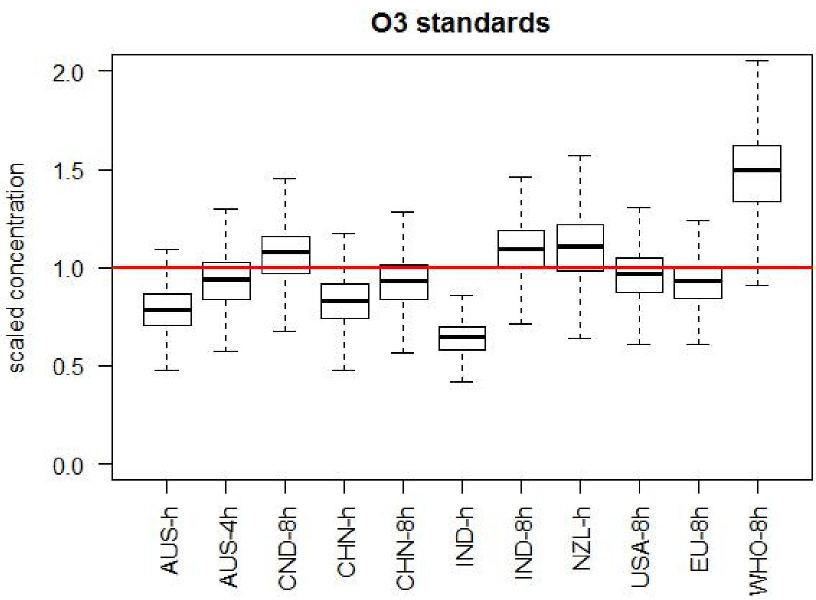

Figure 4. Comparison of the exceedance situation with respect to ozone standards. The y-axis shows the concentration relative to the level of the standard. Reference year 2013. Note that outliers have not been shown.

5.4 Other pollutants

Sulphur dioxide

With exception of the WHO standard that is exceeded at about one third of the stations, exceedances of the other standards are observed at less than 5 % of the stations. In general , these exceedances are related to high levels observed at several (sub)urban industrial stations. Note that these extremes are not shown in Figure 5.

The *ERI*-value estimated for the USA and WHO standard are in the same order or magnitude. The USA standard is mainly exceeded at industrial stations; at various stations extremely high 99-percentile values of 300 to 770 µg/m^3 have been observed.

Table 5.Summary of compliance situation of SO_2 standards.

country	Averaging time	Level (µg/m^3)	allowed number of exceedances(a)	Fraction of non-compliance stations	ERI (µg/m^3)·year
AUS	day	210	1	0	0
IND	year	50	-	0	0
AUS	year	53	-	0	0
CHN	year	60	-	0	0
EU	hour	350	24	0.2	1
EU	day	125	3	0.3	0
IND	day	80	P98	0.6	3
CHN	day	150	0	0.7	1
NZL	hour	350	9	0.9	2
NZL	hour	570	0	2.0	1
AUS	MDA1	530	1	2.2	22
CHN	hour	500	0	2.5	2
USA	MDA1	200	P99	4.7	217
WHO	day	20	0	34.6	298

(a) Allowed number of exceedances; when standard is based on a percentile value, this is indicated by Pxx.

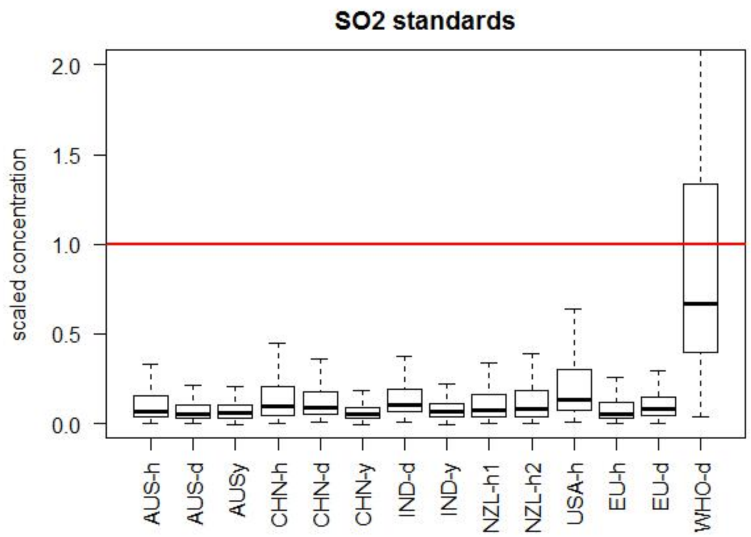

Figure 5. Comparison of the exceedance situation with respect to SO_2 standards. The y-axis shows the concentration relative to the level of the standard. Reference year 2013. Note that outliers have not been shown.

Carbon monoxide

The CO standards are exceeded at less than 1% of the stations except for the two Chinese standards which are exceed at 2.5% (daily standard) and 3.2% (hourly standard) of the stations. The largest health benefits are to be expected by a full compliance of the Indian hourly standard and the Chinese daily standard. However, some caution is needed here as the results are dominated by the extreme high concentrations reported for one single station with a maximum daily 8-hour mean of 13 mg/m^3.

Organic pollutants: benzene and benzo[a]pyrene

India and the EU have set the same standards for **benzene** annual mean levels. As benzene is carcinogenic, no safe level of exposure can be recommended. Based on the unit cancer risk as reported by WHO, a reference level of 1.7 µg/m^3 has been estimated assuming an acceptable lifetime cancer risk of 1 x 10^{-5}. In 2013 the standard of 5 µg/m^3 has been exceeded at two hot-spot locations; the total ERI is 2.6 (µg/m^3).year. Evaluation of the WHO reference level shows exceedances at 22% of the stations with an ERI of 114 (µg/m^3).year. Meeting the WHO reference level would reduce the health impact of benzene by nearly a factor 50 compared to meeting the Indian/EU standard. In circa 75% of the air quality management zones the concentrations are below the lower assessment threshold (LAT) of 2 µg/m^3; in these zones monitoring is not mandatory. With a reference level below the LAT it might be that not all locations with a concentration between 1.7 and 2 µg/m^3 have been included.

The situation with respect to **BaP** is similar to the benzene case: India and EU have equal standards of 1 ng/m^3; the WHO reference level of 0.12 ng/m^3 is inferred from the unit risk and is substantially lower than the Indian/EU standards and also below the LAT of 0.4 ng/m^3. At 87% of the operational stations a concentrations above the WHO reference values is observed. Exceedances of the Indian/EU standard are observed at 32% of the stations. A full compliance with the WHO reference level would give at least 50% larger health benefits than meeting the Indian and EU standards.

Metals

Standards set for **arsenic** are the same for India and the EU (6 ng/m^3). As these metals are carcinogenic, the WHO has not recommended an AQG; the unit risk-based reference levels are somewhat higher (6.6 ng/m^3) than the EU/Indian standards. Exceedances of both the EU/Indian standards for arsenic as well as the WHO reference levels have been observed in 2013 at 13 (out of 612) stations.

For **cadmium**, exceedances beyond the 5 ng/m^3 EU target value which equals the WHO AQG, have been observed in 2013 at 6 (out of 656) stations.

For **nickel** equal standards are set in EU and India (20 ng/m^3) while the WHO reference level is estimated as 25 ng/m^3. Concentrations exceeded in 2013 the 20 ng/m^3 standard at four (out of 629) stations; at three of them concentrations are also above the WHO reference level.

Australia, India and the EU have set an annual standard for **lead** that equals the AQG of the WHO. In 2013 one exceedance of this annual threshold have been reported. The Indian daily and USA 3-monthly standards are more frequently exceeded: at 10 and 15 stations, respectively. The USA standard will provide the best health protection.

Ammonia

Although ammonia emissions strongly contribute to the formation of secondary aerosol and to eutrophication, India is the only country that has set an ambient air standard for ammonia for the protection of human health. In the European air quality data base, limited information is available on ammonia concentrations.

The available information indicates that in the period 2000-2014 (a longer period was selected here because of the scarcity of measurement data) the observed NH_3 annual mean did not exceed the Indian standard of 100 µg/m^3. In total, the daily standard has been exceeded on five days; as the standard is defined as a 98-percentile, European monitoring data would be in compliance with the Indian daily standard.

6 Discussion & conclusions

Ambient air quality standards set at the national level (6 countries: Australia, Canada, China, India, New Zealand and USA) and by two international bodies (EU and WHO) have been compared. In total 13 different pollutants have been included in the reviewed standards; at the individual level the number of pollutants for which standards have been set differs: ranging from 2 in Canada to 12 (India, WHO, EU).

At the global scale air pollution is the single environmental health risk; exposure to ambient air pollution, in particular particulate matter and ozone, contributes substantially to the burden of disease (GBD 2015 Risk Factors Collaborators, 2016). Particulate matter and ozone are included in each of the individual sets.

Standards have been set for the other classical components (SO_2, NO_2, CO) by all except by Canada. Standards for benzene, benzo(a)pyrene and the metals As, Cd, Ni and Pb have been defined by India, EU and WHO. For Pb, also Australia and USA have set standards. A standard for ammonia is only set by India.

Although the standards are all aiming at the protection of human health, a large variability among them is seen with different averaging time, reference level and the statistical indicator (number of allowable exceedances, percentile value). For SO_2, 14 different standards have been defined. For each of the pollutants PM_{10} and O_3 11 unique standards are defined. Ten of the eleven standards set for $PM_{2.5}$ are unique. The largest overlap is seen for NO_2: out of 14 there are ten unique standards.

In general, standards for PM, NO_2, and SO_2 have been set for both short-term (hourly, daily) and long-term (annual) exposure. When the European air quality is evaluated against them it is noted that the short- and long-term standards for PM are generally not equivalent. With the exception of the $PM_{2.5}$ standards in Canada and USA, the daily standards are more frequently breached than the annual standards. However, the largest health benefits are expected for a full compliance with the annual standards. This does not hold for the Chinese and Indian standards; under current conditions these standards are hardly exceeded in Europe.

Except for the Chinese daily standard, none of the NO_2 standards has been exceeded at more than 12% of the stations; European's air quality is in full compliance with USA's annual standards (100 $\mu g/m^3$). When standards have been defined for different time scales, these standards are generally not equivalent. However, in contrast to PM, we can see no decreasing trend in the number of non-compliance stations with increasing averaging times. The largest health benefits are expected when the annual standard of 40 $\mu g/m^3$ (China, India, EU, WHO) is met.

The Indian hourly ozone standard is not exceeded at any European monitoring stations while the Indian running 8-hourly standard is, with exceedances at 74% of the stations, one of the strictest standards. The WHO standard is, with respect to the number of exceeding stations and with respect to *Exposure Reduction by full Implementation* (ERI), the strictest standard with exceedances at nearly all stations (97%).

All SO_2 standards, with exception of the WHO standard are exceeded at less than 5% of the stations. Compared to the others, the WHO standard is very strict with 35% of exceeding stations.

CO standards have been defined in 7 cases; exceedances are observed at less than 3.3% of the stations. For the other pollutants, standards have been defined mainly by India, the EU and WHO. For the non-carcinogenic pollutants the Indian/EU standards are equal or lower than the WHO AQG. For the carcinogenic pollutants benzene and BaP the estimated reference levels assuming an acceptable environmental risk of 10^{-5}, are substantially lower than the Indian/EU standard. For benzene and BaP the reference levels are exceeded at 22% and 87% of the stations while the Indian/EU standards are exceeded at < 1% and 32% of the stations, respectively. Meeting the reference levels would reduce the risk of lung cancer. The reference level for arsenic is 10% higher than the Indian/EU standards.

Table 6 shows a ranking of the three regions setting standards which provides the largest expected health benefits in case of a full compliance for $PM_{2.5}$, PM_{10}, NO_2 and O_3. The results are shown for the strictest standard in each region; in case of $PM_{2.5}$ and NO_2 this is the annual standard. For PM_{10} the WHO annual standard is the strictest; the daily standards set by Australia and New Zealand complete the list. In the case of NO_2, the standards in the four regions in Table 6 are equivalent (see Table 4). For O_3 the standards based on MDA8 or running 8h-means are the strictest. The table shows that for all four pollutants, the WHO standards give the best health protection; only for NO_2 the EU standard is among the top 3 most protective standards.

In preparing Table 6, compliance at all station types is assumed. However, in Australia, Canada, and China compliance is not requested at hot-spot locations. When for these regions the exceedance is allowed at hot-spot locations, minor changes are seen in the ranking of Table 6. The Chinese NO_2-standard is no longer equivalent with the other three and gives less health protection by full compliance. No changes in ranking are seen for the other pollutants.

Table 6. Overview of the three regions (in alphabetic order) setting standards providing the largest health benefits in case of full implementation (that is, providing the largest ERI-values); averaging period given in parentheses: a= annual, d=daily, m = MDA8, r=running 8h-mean.

$PM_{2.5}$	PM_{10}	NO_2	O_3
CND (a)	AUS (d)	CHN (a)	CND (m)
USA (a)	NZL (d)	EU (a)	IND (r)
WHO (a)	WHO (a)	IND (a)	WHO (m)
		WHO (a)	

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Annex A. National Ambient air quality standards

A.1 Australia

The National Environment Protection Council (NEPC) has set national standards for six air pollutants: carbon monoxide, ozone, sulphur dioxide, nitrogen dioxide, lead and particles. The standards are legally binding on each level of Government, and had to be met by the year 2008.
Compliance with the standards is assessed at specially assigned "performance monitoring stations". These stations must be located in a manner such that they contribute to obtaining a representative measure of the air quality likely to be experienced by the general population in the region or sub-region. Meeting the standards at hotspot locations is therefore not required.

Pollutant	Averaging period	Maximum (ambient) concentration (a)	maximum allowable exceedences (b)
Carbon monoxide	8 hours	9.0 ppm (10 mg/m^3)	1 day a year
Nitrogen dioxide	1 hour	0.12 ppm (230 mg/m^3)	1 day a year
	1 year	0.03 ppm (57 µg/m^3)	none
Photochemical oxidants (as ozone)	1 hour	0.10 ppm (200 µg/m^3)	1 day a year
	4 hours	0.08 ppm (160 µg/m^3)	1 day a year
Sulphur dioxide	1 hour	0.20 ppm (530 µg/m^3)	1 day a year
	1 day	0.08 ppm (210µg/m^3)	1 day a year
	1 year	0.02 ppm (53 µg/m^3)	none
Lead	1 year	0.50 µg/m^3	none
Particles as PM_{10}	1 day	50 µg/m^3	5 days a year

(a) In parentheses threshold levels converted to mg or µg/m^3 by using factors given in Annex B
(b) For CO, NO_2, O_3, and SO_2 standards are not violated when, on one single day, during more than one averaging period, concentrations exceed the reference concentration. Compliance with the standards is assured when the maximum daily 1-hour, 4-hour or 8-hour average (indicated by MDA1, MDA4 and MDA8, respectively) does not exceed the reference level.

For $PM_{2.5}$ no standard has been given but the following advisory reporting thresholds and goal are set. These reporting thresholds have not been included in the benchmark.

Pollutant	Averaging period	Maximum (ambient) concentration	Goal
Particles as PM2.5	1 day 1 year	25 µg/m^3 8 µg/m^3	Goal is to gather sufficient data nationally to facilitate a review of the standard as part of the review of this Measure scheduled to commence in 2005.

Source:
http://www.environment.gov.au/protection/air-quality/air-quality-standards
https://www.environment.gov.au/system/files/pages/dfe7ed5d-1eaf-4ff2-bfe7-dbb7ebaf21a9/files/aaq-nepm-varied.pdf

A.2 Canada

Canadian Ambient Air Quality Standards are health-based air quality objectives for pollutant concentrations in outdoor air. Canada established air quality standards for fine particulate matter and ground-level ozone, two pollutants of concern to human health and the major components of smog.
The work to support the development of additional ambient air quality standards for sulphur dioxide and nitrogen dioxide has been initiated by the federal, provincial, and territorial governments.

Monitoring of compliance is performed at so-called CAAQS Reporting Stations[3]. These community-oriented stations should be located in areas that reflect the "neighbourhood" or "urban" scale. Neighbourhood or urban scale monitors should be located in residential, commercial and industrial or other areas where people live, work and play rather than at expected maximum impact points for specific emission sources. Community-oriented monitoring sites should not be unduly influenced by nearby emission sources. For example, monitoring stations should not be located in close proximity to the fence line of an industrial facility or next to a major roadway. Based on these siting criteria it is concluded that compliance with the standards is not required at hotspot locations.

Standards have been set for 2015 and 2020; the 2015-standards have been included in the benchmark.

Pollutants	Averaging period	Standards (a) 2015	2020	metric
$PM_{2.5}$	year	10 µg/m³	8.8 µg/m³	The 3-year average of the annual average concentrations.
$PM_{2.5}$	day	28 µg/m³	27 µg/m³	The 3-year average of the annual 98th percentile of the daily 24-hour average concentrations
Ozone	8 hour	63 ppb (126 µg/m³)	62 ppb (124 µg/m³)	The 3-year average of the annual 4th highest daily maximum 8-hour average concentrations.

(a) Numbers in parentheses give threshold values in µg/m³ recalculated using the factors given in Annex B.

Source: http://www.ec.gc.ca/default.asp?lang=En&n=56D4043B-1&news=A4B2C28A-2DFB-4BF4-8777-ADF29B4360BD

[3] CCME (2012) Guidance document on achievement determination Canadian ambient air quality standards for fine particulate matter and ozone.

A.3 China

Ambient air quality has been regulated in China since 1982. After an update of the standards in 1996, China released a set of more stringent standards in 2012. The new standards have gone into effect by 1 January 2016.
Different thresholds have been defined for two different air environmental functions: Class 1 zones include natural reserves, scenic spots and other areas that need special protection, Class 2 zones include residential areas, commercial areas, cultural areas, industrial areas and rural areas. As Class 1 limit values are not legally binding for the whole national territory, only Class 2 limit values have been included in the benchmark.

Starting in the 1980s, China established a national ambient air quality-monitoring network consisting of urban, regional and background sites[4]. Urban sites are representative for an area of 25 km^2 and are used to assess attainment of the air quality standards. According to technical guidelines of the Chinese government, these locations must not be in the immediate vicinity of traffic intersections or major industrial polluters, and should be sufficiently distant from any other emission sources. Regional and background stations are representative for an area of 400-2500 km^2; main purpose is to evaluate inter-regional transport, to evaluate the effect of air pollution on ecosystems, and research.

Standards have been set for “basic air pollutants” and for “other air pollutants”, see Table A3.1 and A3.2. Requirements for the basic pollutants (Table A3.1) have to be implemented in the whole of China. Implementation of the requirements of the other pollutants (Table A3.2) is not at the national level; it is determined by the administrative department of the State Council on environmental protection and by the governments at the provincial level depending on the actual situations. Pollutants listed in Table A3.2 are not included in the benchmark.

[4] China National Environmental Monitoring Center (2013) Ambient air quality monitoring technique and methods in China. *www.chinaaseanenv.org/upload/Attach/dmc/27537284.ppt*

Table A3.1. Thresholds for basic air pollutants

Pollutant	Averaging time	Limit		Unit
		Class 1	Class 2	
SO_2	annual	20	60	μg/m^3
	24 hours	50	150	
	hourly	150	500	
NO_2	annual	40	40	μg/m^3
	24 hours	80	80	
	hourly	200	200	
CO	24 hours	4	4	mg/m^3
	hourly	10	10	
O_3	daily, 8-hour maximum	100	160	μg/m^3
	hourly	160	200	
PM10	annual	40	70	μg/m^3
	24 hours	50	150	
$PM_{2.5}$	annual	15	35	μg/m^3
	24 hours	35	75	

Table A3.2. Thresholds (in μg/m^3) for other air pollutants.

Pollutant	Averaging time	Limit	
		Class 1	Class 2
Total Suspended Particles (TSP)	annual	80	200
	24 hours	120	30
NO_x	annual	50	50
	24 hours	100	100
	hourly	250	250
Lead (Pb)	annual	0.5	0.5
	seasonal	1	1
Benzo[a]pyrene (BaP)	annual	0.001	0.001
	24 hours	0.0025	0.0025

Source: http://www.china-eia.com/en/policiesregulations/technicalstandards/9152.htm

A.4 India

The objectives of the National Ambient Air Quality Standards (NAAQS) are:

- To indicate the levels of air quality necessary with an adequate margin of safety to protect the public health, vegetation and property;
- To assist in establishing priorities for abatement and control of pollutant level;
- To provide uniform yardstick for assessing air quality at national level;
- To indicate the need and extent of monitoring programme.

Attainment of the standards is assessed by ambient air quality monitoring under the nation-wide National Air Quality Monitoring Programme (NAMP). Station locations have been categorized based on land use, viz. residential, industrial and traffic intersection. From this, it is inferred that the standards have to be met also at hot-spot locations.
The Air Quality Standards notified on November 2009 are given below. In the benchmark the standards defined for industrial, residential, rural and other areas have been used.

Pollutants	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and other Areas	**Ecologically Sensitive Area (notified by Central Government)**
Sulphur dioxide (SO_2), µg/m^3	Annual*	50	20
	24 Hours**	80	80
Nitrogen dioxide (NO_2), µg/m^3	Annual*	40	30
	24 Hours**	80	80
PM_{10} µg/m^3	Annual*	60	60
	24 Hours**	100	100
$PM_{2.5}$ µg/m^3	Annual*	40	40
	24 Hours **	60	60
Ozone (O_3), µg/m^3	8 hours**	100	100
	1 hours **	180	180
Lead (Pb), µg/m^3	Annual *	0.50	0.50
	24 Hour**	1.0	1.0
Carbon monoxide (CO), mg/m^3	8 Hours **	2	2
	1 Hour**	4	4
Ammonia (NH_3), µg/m^3	Annual*	100	100
	24 Hour**	400	400
Benzene (C_6H_6), µg/m^3	Annual *	5	5
Benzo(a)Pyrene (BaP)- particulate phase only, ng/m3	Annual*	1	1
Arsenic (As), ng/m^3	Annual*	6	6
Nickel (Ni), ng/m3	Annual*	20	20

** Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform interval.*
*** 24 hourly, 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.*

Source: http://www.cpcb.nic.in/National_Ambient_Air_Quality_Standards.php

A.5 New Zealand

New Zealand has defined standards for 5 pollutants (see below). These standards are applicable “at any place that is an airshed; and that is in the open air; and where people are likely to be exposed to the contaminants”. The standards include a threshold concentration and a number of times per year this threshold can be exceeded. The standards came into force on 1 September 2005.
By an amendment of June 2011 PM_{10}-derogation was made possible for a limited period of time. Derogation is based on the concentrations observed in the five years (as available) prior to 1 September 2011. If there were one to ten exceedances of the threshold per year, then the target applies from 1 September 2016 onwards. If there were more than ten exceedances per year then a two-stage target applied: 3 or fewer exceedances are allowed in the period 1 September 2016 to 31 August 2020 and one exceedance from 1 September 2020 onwards.
In the benchmark the option of derogation has not been considered.

The standards apply in the open air wherever people may be exposed over the relevant time averaging period. This includes roadside verges, residential areas, central business districts, parks, beaches, etc. The standards do not apply indoors, in indoor workplace environments, in outdoor workplace environments where the public are not exposed, inside tunnels or inside vehicles *(Ministry for the Environment, (2004). The User Guide to Resource Management (National Environmental Standards Relating to Certain Air Pollutants, Dioxins and Other Toxics) Regulations 2004. Ministry for the Environment, Wellington, New Zealand).* From this, it is inferred that the standards have to be met also at hot-spot locations.

Pollutant	**Threshold concentration**	**Time average**	**Allowable exceedances in 12-month period**
Carbon monoxide (CO)	10 mg/m³	8-hours (running mean)	1
Nitrogen dioxide (NO_2)	200 µg/m³	1-hour	9
PM_{10}	50 µg/m³	24-hours	1
Ozone (O_3)	150 µg/m³	1-hour	0
Sulphur dioxide (SO_2)	350 µg/m³	1-hour	9
	570 µg/m³	1-hour	0

Source: http://www.mfe.govt.nz/sites/default/files/2011-user-guide-nes-air-quality.pdf

A.6 United States of America

The Clean Air Act requires the US-EPA to set air quality standards for pollutants considered to be harmful to public health and the environment. The Clean Air Act identifies two types of national ambient air quality standards. ***Primary standards*** provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. ***Secondary standards*** provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. In the benchmark only the primary standards have been considered.
Standards have to be attained at each population-oriented monitor/site; “population-oriented” is here defined as (Code of Federal Regulations, 40 CFR 58.1): *Population-oriented monitoring (or sites) means residential areas, commercial areas, recreational areas, industrial areas where workers from more than one company are located, and other areas where a substantial number of people may spend a significant fraction of their day*. From this, we concluded that the standards have to be met at all station types although the last part of this definition may exclude some of the traffic stations.

Pollutant		Primary/ Secondary	Averaging Time	Level (a)	Form
Carbon Monoxide (CO)		primary	8 hours	9 ppm (10 mg/m^3)	Not to be exceeded more than once per year
			1 hour	35 ppm (40 mg/m^3)	
Lead (Pb)		primary and secondary	Rolling 3 month period	0.15 µg/m^3	Not to be exceeded
Nitrogen Dioxide (NO_2)		primary	1 hour	100 ppb (190 µg/m^3)	98th percentile of 1-hour daily maximum concentrations,
		primary and secondary	1 year	53 ppb (100 µg/m^3)	Annual Mean
Ozone (O_3)		primary and secondary	8 hours	0.70 ppm (140 µg/m^3)	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 µg/m^3	annual mean, averaged over
		secondary	1 year	35.0 µg/m^3	annual mean, averaged over
		primary and secondary	24 hours	35 µg/m^3	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 µg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb (200 µg/m^3)	99th percentile of 1-hour daily maximum concentrations
		secondary	3 hours	0.5 ppm (1300 µg/m^3)	Not to be exceeded more than once per year

(a) Numbers in parentheses give threshold values in µg/m³ recalculated using the factors given in Annex B.

Source: http://www3.epa.gov/ttn/naaqs/criteria.html

A.7 WHO Air Quality Guideline values

WHO has set air quality guidelines for a wide range of pollutants. The WHO guidelines for those pollutants listed in the EU Air quality directive are summarized in the table below. The recommended AQGs should be considered as an acceptable and achievable objective to minimise health effects.
Besides the guideline values, three interim targets (ITs) were set by WHO for PM (Table A7.1), in order to incentivise countries to implement successive and sustained abatement measures to progressively reduce population exposures to PM. Progress towards the guideline values, however, should be the ultimate objective. The annual mean IT-1 levels are estimated by WHO (2006a) to be associated with about 15 % higher long-term mortality than the AQGs. In addition to other health benefits, the annual mean IT-2 levels are estimated to lower the risk of premature mortality by approximately 6 % relative to the IT-1 level, and the same is estimated for IT-3 levels compared to IT-2 levels (WHO, 2006a). The daily mean IT-1, IT-2, and IT-3 levels are expected to translate roughly into a 5 %, 2.5 %, and 1.2 % increase in daily mortality over the AQGs, respectively (WHO, 2006a). The interim targets have not been included in the benchmark.
As for carcinogenic pollutants no save level exists, the WHO did not recommend any guideline for carcinogenic. Based on the unit risk given by WHO and assuming an acceptable environmental risk of 10^{-5}, a *reference level* has been estimated (de Leeuw and Ruyssenaars, 2011). These reference levels have been included in the benchmark.
We have assumed that the AQG have to be met at all locations.

Table A7.1 WHO interim targets, air quality guidelines and estimated reference levels (in µg/m^3 unless indicated).

pollutant	Averaging time	IT-1	IT-2	IT-3	AQG	RL
PM_{10}	24 h*	150	100	75	50	
	annual	70	50	30	20	
$PM_{2.5}$	24 h*	75	50	37.5	25	
	annual	35	25	15	10	
O_3	8 h daily max				100	
NO_2	1 h				200	
	annual				40	
BaP	Annual					0.12 ng/m^3
SO_2	10 minutes				500	
	24 h				20	
CO	1 h				30 mg/m^3	
	8 h				10 mg/m^3	
As	Annual					6.6 ng/m^3
Cd	Annual				5 ng/m^3	
Ni	Annual					25 ng/m^3
Pb	Annual				500 ng/m^3	
C_6H_6	Annual					1.7

Notes: * 99th percentile (3 days/year)

Sources: WHO, 2000; WHO, 2006

A.8 European Union

The limit or target values set by the EU for the protection of human health are summarized in Table A8.1.

Table A8.1. Summary of the Air Quality Directive's limit values and target values for the protection of human health.

	Limit or target value (a)		
Pollutant	**Averaging period**	**Value**	**Maximum number of allowed**
SO_2	Hour	350 µg/m^3	24
	Day	125 µg/m^3	3
NO_2	Hour	200 µg/m^3	18
	Year	40 µg/m^3	0
Benzene	Year	5 µg/m^3	0
CO	Maximum daily 8-hour mean	10 mg/m^3	0
PM_{10}	Day	50 µg/m^3	35
	Year	40 µg/m^3	0
$PM_{2.5}$ (b)	Year	25 µg/m^3	0
Pb	Year	0.5 µg/m^3	0
As	Year	6 ng/m^3	0
Cd	Year	5 ng/m^3	0
Ni	Year	20 ng/m^3	0
BaP	Year	1 ng/m^3	0
O_3	Maximum daily 8-hour mean averaged over 3 years	120 µg/m^3	25

(a) In addition, the air quality directive defines alert thresholds for SO_2, NO_2 and O_3, and an information threshold and long-term objective for O_3. These objectives have not been included in the benchmark.
(b) In addition the air quality directive defines for $PM_{2.5}$ the *exposure concentration obligation* and the *national exposure reduction target.* Both objectives relate to a national averaged concentration in urban areas. These objectives have not been included in the benchmark.

Source: AQ directive (EU 2004, 2008)

Annex B. Conversion factors

Conversion factors between mixing ratios and concentrations (101.3 kPa and 293 K)

Pollutant	Mixing ratio	concentration
carbon monoxide	1 ppm	1.1647 mg/m^3
nitrogen dioxide	1 ppb	1.9130 µg/m^3
ozone	1 ppb	1.9959 µg/m^3
sulphur dioxide	1 ppb	2.6637 µg/m^3

Correspondence between number of exceedances and percentile value

Averaging time	Number of exceedances	percentile
hour	1	99.99
	9	99.90
	18	99.79
	24	99.73
MDA1	1	99.73
MDA4	1	99.73
MDA8	1	99.73
	3	99.18
	25	93.15
daily	1	99.73
	3	99.18
	5	98.63
	35	90.41