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Air Quality Zone Delimitation in Norway

Evaluation and delimitation proposal

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Scientific report

Preface

This report shows the results of a project carried out by NILU - Norwegian Institute for Air Research and commissioned by the Norwegian Environment Agency, formerly known as the Climate and Pollution Agency (Klif). An evaluation of the air quality in Norway over the last five years has been performed to set up the basis for a new AQ-zone delimitation for reporting to European Commission concerning compliance of air quality directives.

The work in this report has been led by Susana López-Aparicio and carried out in collaboration with Dag Tønnesen. Internal quality control at NILU has been carried out by Cristina Guerreiro and Claudia Hak. The early version of the report benefited from the comments and suggestions from Leonor Tarrasón, Wenche Aas and Sverre Solberg. The main contact person at the Norwegian Environment Agency is Sigmund Guttu.

Kjeller, August 2013

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Summary

An evaluation of the air quality in Norway over the last five years has been performed to set up the basis for a new Air Quality zone (AQ-zone) delimitation for reporting to European Commission concerning compliance of air quality directives. Air pollution levels (i.e. PM_{10}, NO_2, SO_2, CO, O_3, benzene, heavy metals, B(a)P) have been assessed regarding exceedances of limit values, target values, Norwegian national targets, and upper/lower assessment thresholds (UAT/LAT) defined for the protection of human health, vegetation and/or natural ecosystems. The results from this evaluation complemented with information regarding background concentration levels in Norway have been used to propose a new AQ-zone delimitation.

The present evaluation of the air quality information compiled in Norway during the last five years indicates that the spatial distribution of pollution exceedances is very different for the different pollutants. PM_{10} and NO_2 are of main concern in urban environment where exceedances are frequent and widespread. SO_2 is a main concern for the protection of human health and vegetation in industrial areas or areas affected by industrial emissions. Ozone levels are not critical for the protection of human health or vegetation in Norway. Levels of air pollutants such as benzene, arsenic, cadmium, nickel and benzo(a)pyrene need to be followed up. Exceedances of benzene limit values are observed in Oslo, nickel concentrations exceeded target levels in Kristiansand, and benzo(a)pyrene concentrations, although below target values, are at higher levels in urban environments (traffic and background stations), most probably associated with wood-burning.

The current AQ-zone delimitation used since year 2000 is formed by 7 zones (3 agglomerations and 4 regions) and it is defined to be the same for all reported pollutants. The proposed AQ-zone delimitation differs between pollutants or groups of pollutants. The proposed AQ-zone delimitation includes:

- AQ-zone delimitation for PM_{10}, NO_2, NO_x, benzene and B(a)P
- AQ-zone delimitation for SO_2 and heavy metals
- AQ-zone delimitation for ozone
- AQ-zone delimitation for CO

Finally, further needs have been identified. Taking into account the growth of the urban population and the expansion of urban settlements an assessment of the boundaries of the agglomeration zones can be foreseen. The aim of this boundary assessment would be to evaluate a potential enlargement of agglomeration zone in order to guarantee that high populated areas around the cities are covered. In addition, the new proposal for AQ-zone delimitation will involve a further evaluation of the needs for AQ-monitoring.

Air Quality Zone Delimitation in Norway - Evaluation and delimitation proposal

1 Introduction

European air quality legislation establishes that Member States are to divide their territory into air quality zones (AQ-zones), which include both regions and agglomerations. The current Air Quality Directive 2008/50/EC defines zones as "part of the territory of a Member State, as delimited by that Member State for the purposes of air quality assessment and management", and agglomeration as "a zone that is a conurbation with a population in excess of 250 000 inhabitants or, where the population is 250 000 inhabitants or less, with a given population density per km^2 to be established by the Member States". In these zones and agglomerations, referred to as AQ-zones in this report, member states assess air quality based on measurements, modelling or other techniques, and the results (e.g. exceedances of limit values, target values, upper/lower assessment thresholds) are reported to the European Commission (EC) according to the air quality directive. The main aim of the AQ-zone delimitation is to assess ambient air quality in the Member States on the basis of common methods and criteria.

Norway is currently divided for air quality reporting to the EC into seven zones, three of them are urban areas or agglomerations (i.e. Greater Oslo, Bergen and Trondheim) and four major regions (i.e. *Øst- and Sørlandet*, *Vestlandet*, *Midt-Norge* and *Nordland*, *Troms* and *Finnmark*) as shown in Figure 1. The AQ-zone delimitation for Norway in these seven zones was introduced in 2000 based on information available from the 1990s. The information concerning air pollution levels in Norway has improved since 1990s, and moreover the air pollution situation has changed (Gjerstad et al., 2012). In view of that, the AQ-zone delimitation requires review for further reporting to the EC with regard to the pollutants covered by the directive.

Today, we have access to more information from continuous measurements carried out in several Norwegian urban environments than earlier, along with information obtained from modelling and geostatistical techniques. The current air quality situation is dominated by high pollution levels, mainly PM_{10} and NO_2, in towns and cities. This change provides basis for a different AQ-zone delimitation than the currently used. Furthermore, AQ-zones are currently defined to be the same for the various regulated air pollutants (e.g. PM_{10}, NO_2, O_3, SO_2, benzene, heavy metals, B(a)P), but this could be reconsidered for future reporting to the EC. For instance, air pollutants such as PM_{10} and NO_2 are of main concern in urban areas and SO_2 in industrial areas. Ozone on the other hand seems to be at very low concentration in urban areas, whereas it may be of main concern at rural locations. Therefore, there are good arguments to consider different AQ-zone delimitations for different compounds.

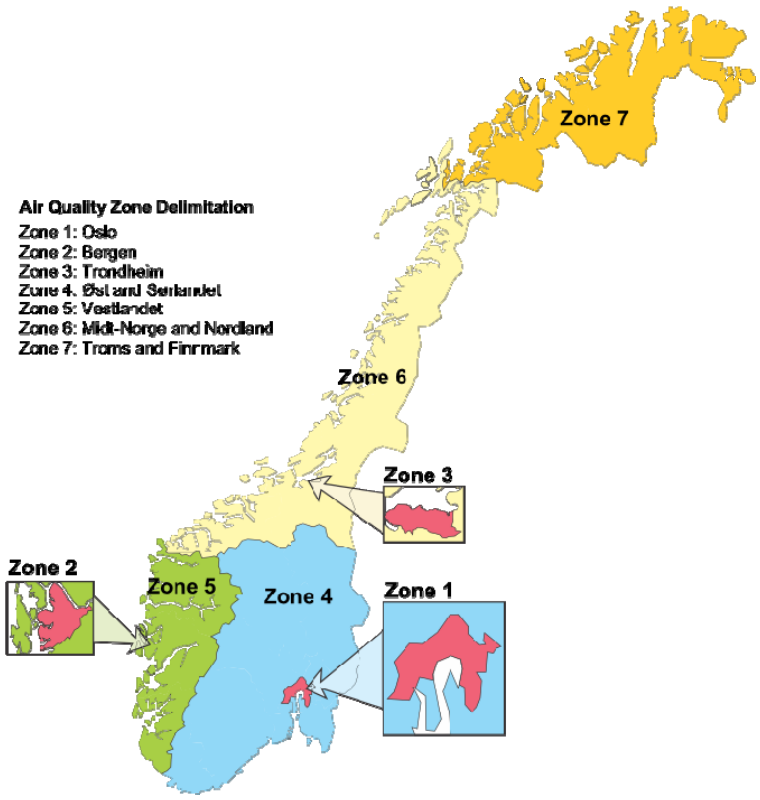

Figure 1: Air Quality zone delimitation for reporting to EC concerning compliance of air quality directive.

2 Objectives

The aim of this project is to evaluate the current air quality zone delimitation based on new knowledge, in addition to proposing a new AQ-zone delimitation for future reporting according to AQ-directives. In order to reach this aim, the following objectives were planned:

- Evaluation of air quality in Norway in the last five years concerning levels of regulated compounds (i.e. PM_{10}, SO_2, O_3, NO_2, CO, benzene, As, Cd, Ni, B(a)P; as defined in EC 2005; EC 2008) for the protection of human health and ecosystems;
- Present an overview of the exceedances of limit values, target values, national targets and upper/lower assessment thresholds for the regulated compounds;
- To propose a new AQ-zone delimitation for Norway based on the air quality evaluation and, in some cases, on the comparison of air quality in different locations.

3 Methodology

The evaluation of air quality in Norway has been performed mainly based on measurement data from stations widely distributed in Norway (Table 1 and Table 2). The main criteria used for the AQ-evaluation has been: a) the exceedances of limit values established by European AQ-directives (EC 2005; EC 2008), b) Norwegian national targets (Miljøverndepartementet 1998), and c) upper/lower assessment thresholds (UAT/LAT) for the protection of ecosystems

(Table 3) and human health (Table 4). A proposal for new AQ-zone delimitation is presented based on this evaluation, and supplemented with information regarding background concentration over Norway obtained from geostatistical methods (Schneider et al., 2011). In some cases, such as for ozone, geographically juxtaposed AQ-zones will be compared in order to evaluate their potential fusion in one single AQ-zone.

Table 1: Measurement stations taken into account in the evaluation of AQ in Norway in the last five years. Zone (2000) refers to the AQ-zone according to the delimitation introduced in 2000. Grey shaded area indicates the compound that is monitored in each station.

LOCATION	Station Name	Type	PM_{10}	NO_2	NO_x	SO_2	O_3	CO	Zone (2000)
BERGEN	Danmarkplass	Traffic	■	■	■			■	2
	Rådhuset	Urban Background							2
BIRKENES	Birkenes	Regional Background					■		4
BÆRUM	E16 Sandvika Nord	Traffic	■	■	■				1
DRAMMEN	Bangeløkka	Traffic	■	■	■			■	4
	Drammenselva	Urban Background		■			■		4
	Grev Wedelsplass	Urban Background		■			■		4
	Nedre Storgata	Urban Background	■						4
FREDRIKSTAD	St. Croix	Traffic	■	■	■				4
GEIRANGER	Geiranger	Shipping	■	■	■				3
GRENLAND	Haukenes	Regional Background		■	■		■		4
	Lensmannsdalen	Traffic	■	■	■				4
	Sverresgate	Traffic		■	■				4
	Øyekast	Urban Background	■	■	■				4
	Ås, Heistad	Industry		■	■	■			4
HALDEN	Oskleva	Industry		■	■				4
	Vaterland bru	Industry	■						4
HAMAR	Hamar	Traffic	■	■	■				4
HAMMERFEST	Fuglenes	Urban Background	■	■	■				7
KARASJOK	Karasjok	Regional Background					■		7
KARPDALEN	Karpdalen	Industry				■			7
KÅRVATN	Kårvatn	Regional Background					■		6
KOLLSNES	Blomvåg	Industry	■	■	■				5
	Herdleværet	Industry					■		5
KONGSBERG	Kongsberg	Traffic	■	■	■				4
KRISTIANSAND	Gartnerløkka	Traffic	■	■	■			■	4
	Stener Heyerdahl	Urban Background	■	■	■				4
	Vestre Strandgt	Traffic	■	■	■			■	4
LILLEHAMMER	Bankplassen	Traffic	■	■	■			■	4
	L. Barnehagen	Urban Background	■	■	■				4
MO I RANA	Gruben	Urban Background	■						6
	Moheia	Industrial							6
MOSS	Bytårnet skole	Urban Background	■						4
	Kransen	Traffic							4
OSLO	Åkebergveien	Urban Background	■	■	■				1
	Alnabru	Traffic	■	■	■				1
	Bærum	Regional Background					■		1
	Bygdøy Alle	Traffic	■	■	■				1
	Grønland	Urban Background		■		■	■		1
	Hjortnes	Traffic	■	■	■				1
	Kirkeveien	Traffic	■	■				■	1
	Manglerud	Traffic	■	■	■				1
	Rv 4, Aker sykehus	Traffic	■	■	■				1
	Skøyen	Urban Background	■						1
	Smestad	Traffic	■	■	■				1
	Sofienbergparken	Urban Background	■						1
PRESTEBAKKE	Prestebakke	Regional Background					■		4
SANDVE	Sandve	Regional Background					■		5
SARPSBORG	Vollgata	Industry				■			1
STAVANGER	Kannik	Traffic	■	■	■			■	5
	Våland	Urban Background							5
SVANVIK	Svanvik	Industrial				■			7
TJELDBERGODDEN	Tjeldbergodden	Industry		■	■		■		6
TROMSØ	Hansjordnesbukta	Traffic	■	■	■				7
	Tverrforbindelsen	Traffic	■						7
TRONDHEIM	Bakke kirke	Traffic	■	■	■				3
	Elgeseter	Traffic	■	■	■			■	3
	Heimdalsmyra	Traffic	■	■	■				3
	Torvet	Urban Background	■						3
TUSTERVATN	Tustervatn	Regional Background					■		6
ÅLESUND	Grimmerhaugen	Urban Background	■						6
	Posthuskrysset	Traffic	■	■	■				6

Table 2: Measurement stations taken into account in the evaluation of benzene, arsenic (As), cadmium (Cd), nickel (Ni), and benzo(a)pyrene (B(a)P). Zone (2000) represents the AQ-zone according to the delimitation introduced in 2000. Grey shaded area indicates the compound that is analysed in each station.

LOCATION	Station Name	Benzene	As	Cd	Ni	B(a)P	Zone (2000)
ÅLESUND	Posthuskrysset						6
ANDØYA	Andøya						7
BERGEN	Danmarksplass						2
BERGEN	Rådhuset						2
BIRKENES	Birkenes						4
BIRKENES	Nye Birkenes						4
DRAMMEN	Bangeløkka						4
DRAMMEN	Drammenselva						4
DRAMMEN	Nedre Storgate						4
GRENLAND	Lensmannsdalen						4
KARPDALEN	Karpdalen						7
KRISTIANSAND	Gartnerløkka						4
KRISTIANSAND	Hennig Olsen						4
KRISTIANSAND	Stener Heyerdahl						4
KRISTIANSAND	Vestre Strandgate						4
LILLEHAMMER	Bankplassen						4
OSLO	Hjortnes						1
OSLO	Kirkeveien						1
OSLO	Manglerud						1
OSLO	Smestad						1
OSLO	Sofienbergparken						1
SAUDA	Søndenålia						5
SVANVIK	Svanvik						7
TRONDHEIM	Elgeseter						3
TRONDHEIM	Torvet						3

3.1 Data source

Air quality in Norway has been evaluated based on available data from continuous measurements in different monitoring stations. The data coverage has been in most of the cases slightly over five years, from 2008 (1st January) to 2013 (1st April). Table 1 shows an overview of the monitoring stations considered in this study for PM_{10}, NO_2, SO_2, CO and O_3, as well as their locations, type of station (i.e. traffic, urban background, industrial or regional background) and the zone which the stations belongs to (i.e. Zone 1-7). Likewise, Table 2 shows the stations where samples are analysed for heavy metals (HM; As, Cd, Ni), benzene and PAH (i.e. B(a)P) and thus the sources of the data evaluated in this report. These compounds are expressed as yearly average concentration and the data coverage is approximately from 2007 to 2012 for benzene, from 2009 to 2011 for HM, and from 2009 to 2012 in some of the locations where B(a)P is analysed.

Although all the stations shown in Table 1 and Table 2 have been evaluated with respect to limit values, only some of the stations are reported, due to the large amount of data. The selection of stations has been based on criteria such as location regarding population density, high number of exceedances of limit and/or national target values, or stations located in the same AQ-zones which were used for comparisons (e.g. Hamar and Lillehammer both in Zone 4).

3.2 Limit and target values

Table 3 and Table 4 show the limit/target values (EC 2005, 2008), Norwegian national targets (Miljøverndepartementet 1998), as well as the upper and lower assessment thresholds (EC 2005, 2008) for the protection of ecosystems and human health, respectively. The evaluation of air quality in Norway in the last years has been carried out based on the number of exceedances of limit or target values.

According to AQ Directive 2008/50/EC:

- Limit value means "level fixed on the basis of scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained within a given period and not to be exceeded once attained".
- Target values means "level fixed with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained where possible over a given period";
- Upper assessment threshold means "level below which a combination of fixed measurements and modelling techniques and/or indicative measurements may be used to assess ambient air quality;
- Lower assessment threshold means "level below which modelling or objective-estimation techniques alone may be used to assess ambient air quality.

The evaluation of the exceedances of upper/lower assessment threshold values is carried out following the recommendation of the AQ directives (EC 2005, 2008); thus assessment thresholds will be considered as exceeded if they have been exceeded during at least three years out of a period of five years.

Table 3: Limit values, target values (TV) and long-term objective (LTO) for the protection of vegetation (NO_x, SO_2 and O_3) and natural ecosystems (NO_x). UAT and LAT: Upper and Lower Assessment thresholds.

		Averaging Period	
Component	**Limit value**	**3/6 months**	**1 year**
NO_X	EU directive		30
	UAT		24
	LAT		19.5
SO_2	EU directive	20 (oct - mar)	20
	UAT	12	
	LAT	8	
Ozone	EU directive (TV)	AOT40 18000 (may - july)	
	EU directive (LTO)	AOT40 6000	

Table 4: Limit values (NO_2, PM_{10}, SO_2, CO, Benzene), target values (O_3, As, Cd, Ni and B(a)P), long term objective (LTO; O_3) and Norwegian national targets for the protection of human health (EC 2005, EC 2008, Miljøverndepartementet 1998; Forurensningsforskriften, 2013). UAT and LAT: Upper and Lower Assessment thresholds. Values as μgm^{-3} except for CO (mgm^{-3}) and As, Cd, Ni and B(a)P (ngm^{-3}). Numbers in brackets (y^{-1}): number of exceedances allowed per calendar year, or averaged over three years in the case of ozone.

		Average Period			
Component	**Limit value**	**1 hour**	**8 hours**	**24 hours**	**1 year**
NO_2	AQ directive	200 (18 y^{-1})			40
	UAT	140 (18 y^{-1})			32
	LAT	100 (18 y^{-1})			26
	National Target	150 (8 y^{-1})			
PM_{10}	AQ directive			50 (35 y^{-1})	40
	UAT			35 (35 y-1)	28
	LAT			25 (35 y-1)	20
	National Target			50 (7 y^{-1})	
SO_2	AQ directive	350 (24 y^{-1})		125 (3 y^{-1})	
	UAT			75 (3 y-1)	
	LAT			50 (3 y-1)	
Ozone	AQ directive		120 (25 y^{-1})		
	AQ directive (LTO)		120		
CO	AQ directive		10		
	UAT		7		
	LAT		5		
Benzene	AQ directive				5
	UAT				3.5
	LAT				2
As	AQ directive				6
	UAT				3.6
	LAT				2.4
Cd	AQ directive				5
	UAT				3
	LAT				2
Ni	AQ directive				20
	UAT				14
	LAT				10
BaP	AQ directive				1
	UAT				0.6
	LAT				0.4

4 Evaluation Results

This chapter shows the results from the evaluation of air quality in Norway during the period between 2008 and beginning of 2013 (1st April 2003). The evaluation is

mainly based on air pollution levels at different averaging periods (e.g. hour, day, year) and the comparison between these levels and limit / target values defined by the European air quality directives or Norwegian national targets. The reported pollutants are PM_{10}, NO_2, SO_2, O_3, benzene, some heavy metals (i.e. As, Ni, Cd) and B(a)P. Other compounds such as CO and Pb, even though they are included in the air quality directive (EC, 2008), are not included in this report. Pb is not measured in Norway and levels of CO are low, below 4.5 mg m^{-3} (maximum daily 8 hours mean) in urban environments such as Bergen, Drammen, Oslo, Stavanger and Trondheim. CO concentration has been below lower assessment thresholds since 2008.

The last section of this chapter shows the Norwegian background levels of ozone, PM_{10} and NO_2 obtained from geostatistical techniques. This information is used in combination with measurement data to define a new AQ-zone delimitation for air quality reporting.

4.1 Air Quality in Norway – Exceedances

4.1.1 Particulate Matter (PM_{10})

Particulate matter ($PM_{2.5}$ and PM_{10}), as well as nitrogen dioxide (NO_2), are the most important air pollutants in urban atmospheres in Norway. They originate from combustion processes such as those associated to traffic and wood burning and, in the case of PM_{10}, abrasion/resuspension processes are additional sources. Pollution regulation limits for PM_{10} are defined for daily and annual averaging periods (Table 4). In Norway, exceedances of the daily PM_{10} limit values are very much associated with road services activities such as sanding and resuspension subsequent to de-icing.

Figure 2 and Figure 3 show the distribution of exceedances of the daily AQ-criteria and upper assessment threshold (35 µg m^{-3}; yellow field), and daily limit values (50 µg m^{-3}; orange field) defined for PM_{10}. The exceedances of daily PM_{10} occur mainly in spring and autumn, coinciding with the period of de-icing and sanding. Similar figures have been produced for other locations with similar results (Annex A). The AQ directive establishes that the daily PM_{10} limit value must not be exceeded more than 35 times in a calendar year. In Trondheim and Mo i Rana, as in other urban environments in Norway (Annex A), the number of exceedances of the daily limit values is above 35 times in 2012 (Figure 2 and Figure 3).

The number of exceedances of the daily PM_{10} limit values in the last five years has been evaluated in different Norwegian urban environments and the outcome indicates that daily mean levels of PM_{10} can be of concern. For instance in Trondheim, the number of exceedances of daily PM_{10} limit values is systematically above 35 times per year in the last five years (Figure 4). In Stavanger, the number of exceedances is systematically above national target (i.e. 7 times per year calendar) and in the first months of 2013, the number of exceedances of daily PM_{10} values is already about 35 times (Figure 4). In most of the selected locations, the number of exceedances of daily limit value for PM_{10} is above national target (i.e. 7 times per year).

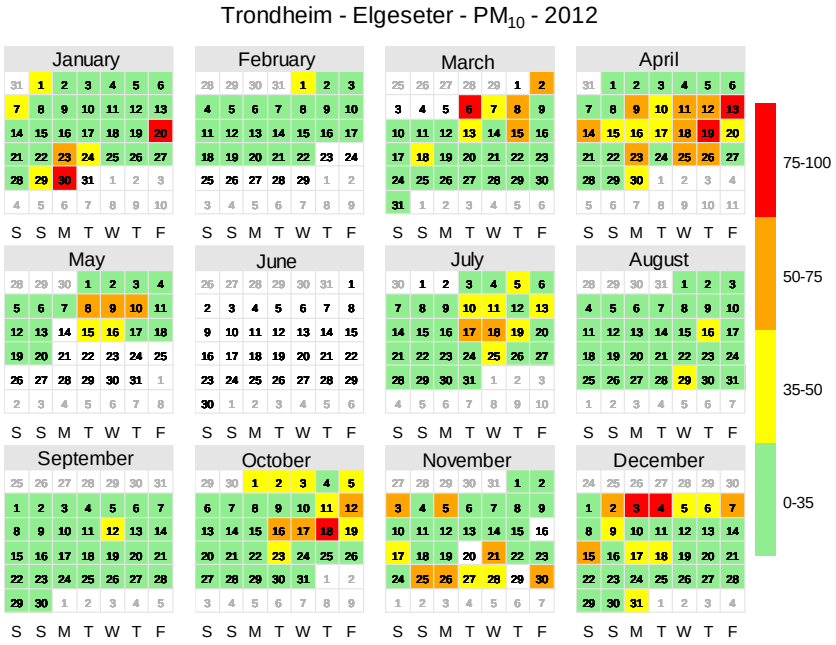

Figure 2: Calendar with daily mean PM_{10} concentration at Elgeseter (Trondheim) in 2012. Unit: µg m^{-3}.

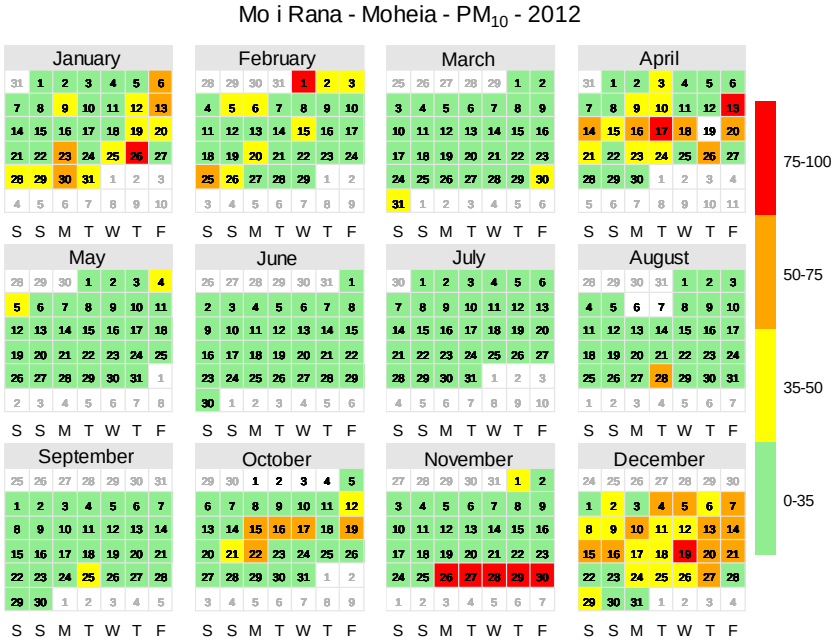

Figure 3: Calendar with daily mean PM_{10} concentration at Moheia (Mo i Rana) in 2012. Units: µg m^{-3}.

Numbers of exceedances above 35 times per calendar year of the UAT and LAT are widespread in the Norwegian measurement network. Both assessment thresholds are yearly exceeded more than 35 times since 2008 (Figure 4), and in some cases, such as Bygdøy Allé (Oslo), Kannik (Stavanger) and Danmarkplass (Bergen), more than 35 exceedances have already occurred in the first month of 2013 (i.e. from January to March). The evaluation of the exceedances of PM_{10} daily levels at urban environment indicates that PM_{10} is of main concern in urban environment. A limit value for PM_{10} is also defined for annual averaging period at 40 µg m^{-3}. However, exceedances of the year limit value have not been observed.

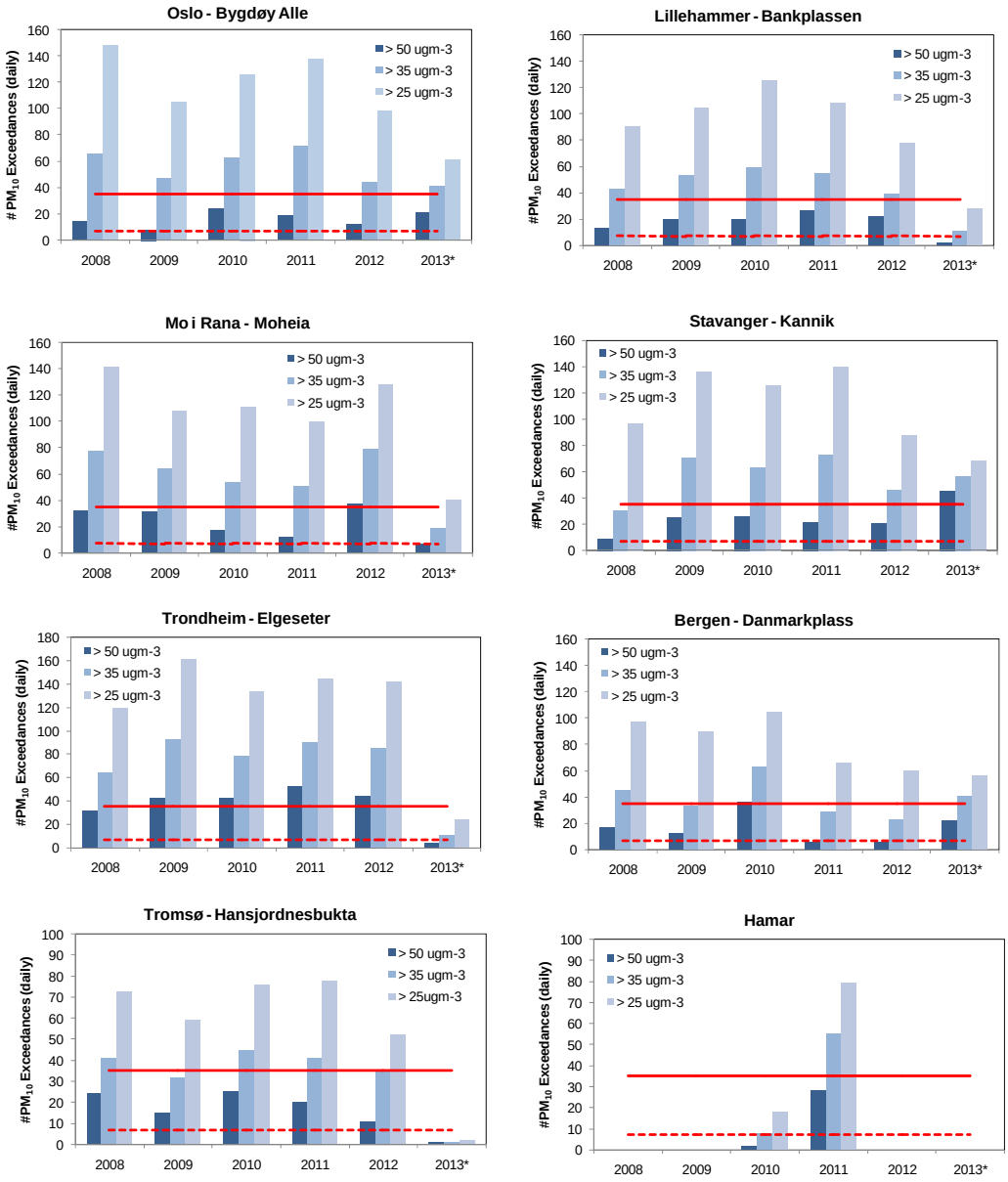

Figure 4: Number of exceedances of daily PM_{10} limit value (50 µg m^{-3}), UAT (35 µg m^{-3}) and LAT (25 µg m^{-3}) in selected locations. Red straight line: number of allowed exceedances by EU AQ directive (35 times). Red dashed line: number of allowed exceedances, national target (7 times).

4.1.2 Nitrogen Dioxide (NO_2) and Oxides of Nitrogen (NO_x)

NO_2 is mainly associated with combustion processes and a main concern in urban areas, where it is related to traffic emissions. In Norway, NO_2 is one of the air pollutant of main concern in the winter season, when stable meteorological conditions and low temperatures do not favour dispersion and consequently high levels are reached. Figure 5 shows as example the hourly concentration of NO_2 measured at Bygdøy Allé (Oslo) in 2012 and the monthly mean values. Maximum NO_2 concentration levels, even above hourly limit values (i.e. 200 µg m^{-3}), were measured in the coldest months, from November to April. The mean monthly NO_2 concentration shows slightly higher levels in winter, although the highest

difference is observed from maximum concentration levels (dots in Figure 5, bottom), showing a seasonal pattern.

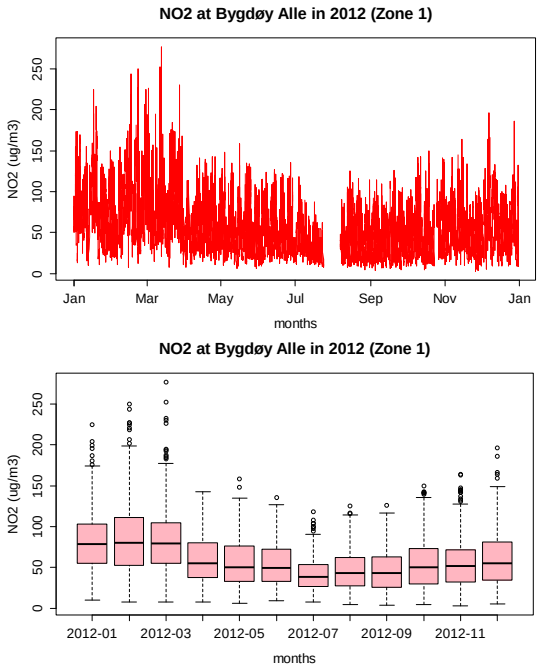

Figure 5: Hourly NO_2 concentration (top) measured in 2012 at Bygdøy Allé (Oslo) and the box-whisker plot obtained from the same data (bottom). The box-whisker plot represents the monthly median values (think lines in the boxes), lower and upper quartiles (low and upper limit of the boxes), maximum and minimum values excluding outsiders (whiskers) and the outsiders (dots).

NO_2 limit values and national targets for the protection of human health are defined for hourly and yearly averages (Table 4), whereas the NO_x critical level for the protection of vegetation and natural ecosystems is only defined for yearly averaging periods (Table 3). Figure 6 shows the number of exceedances of the hourly limit value (i.e. 200 µg m^{-3}), national target (i.e. 150 µg m^{-3}), and upper and lower assessment thresholds (140 and 100 µg m^{-3}) in selected locations. Numbers of exceedances of the limit value above 18 times per calendar year are observed mainly in Oslo (from 2009 to 2011) and Bergen (2009 and 2010), whereas exceedances of the Norwegian national target are widespread in space and time (Figure 6). The national target for hourly mean NO_2 concentration (150 µg m^{-3}) must not be exceeded more than 8 times in a calendar year. Exceedances of the national target above 8 times are even observed in 2013, representing only the first three months of the year, at all measurements stations represented in Figure 6.

The evaluation of NO_2 levels regarding the UAT and LAT shows that the number of exceedances is above 100 and 500 times per year, respectively, in urban environments such as Oslo (AQ-zone 1) and Bergen (AQ-zone 2; Figure 6). In Stavanger, exceedances are observed from 2008 to 2010, in Drammen from 2010 to 2013, and in Lillehammer and Ålesund, the LAT is the only one exceeded systematically above 18 times per year during three consecutive years.

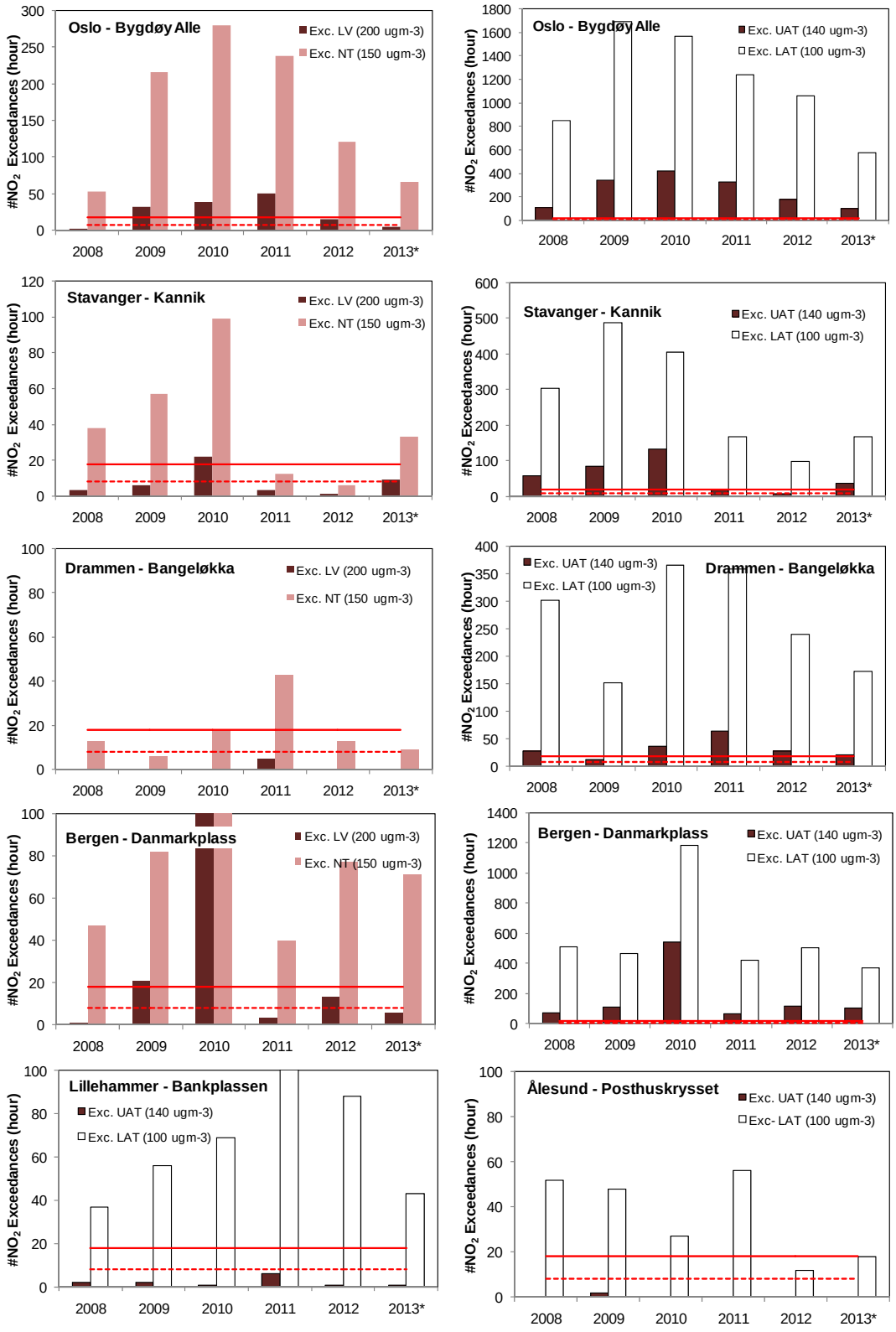

Figure 6: Number of exceedances (Exc.) of NO_2 hourly limit and target values for the protection of human health. 2013: 1st January - 1st April. LV: limit value (AQ Directive 2008/50/EC). NT: Norwegian national target. UAT and LAT: Upper/lower assessment thresholds. Straight red line: allowed number of exceedances per year, AQ directive (18 times y^{-1}). Dashed red line: allowed number of exceedances per year, national target (8 times y^{-1}).*

Figure 7 shows the annual NO_2 mean concentration in some locations in Norway and the comparison with the annual limit values for NO_2 (40 µg m^{-3}), the UAT (32 µg m^{-3}) and the LAT (26 µg m^{-3}) for the protection of human health. The annual mean concentration in several measurement stations in Oslo (AQ-zone 1), Stavanger (AQ-zone 5), Trondheim (AQ-zone 3) and Drammen (AQ-zone 4) are above the annual limit value defined for NO_2 every year since 2008. Traffic measurement stations in Fredrikstad, Kristiansand, Lillehammer and Ålesund show high annual NO_2 mean concentrations above UAT.

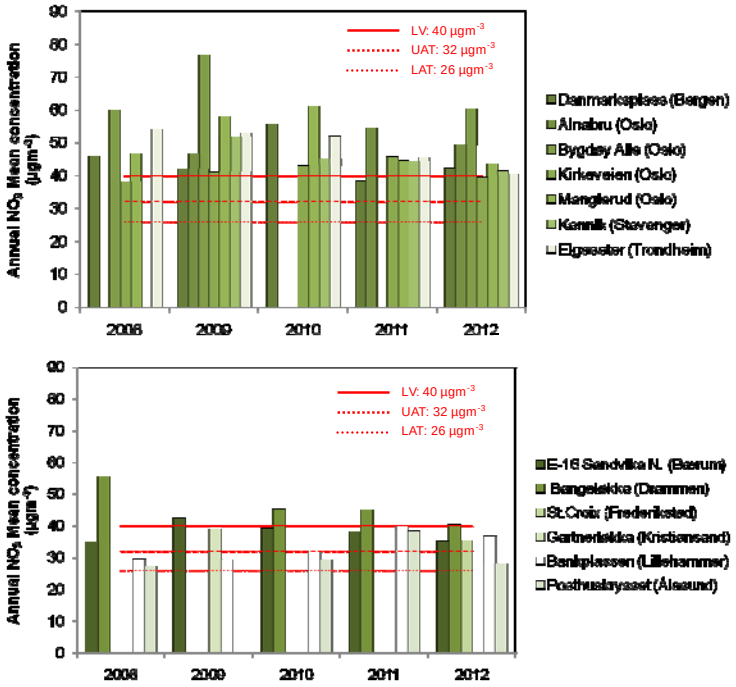

Figure 7: Annual NO_2 mean concentration at selected locations compared with limit and assessment thresholds (AQ Directive 2008/50/EC). LV: Annual limit value for the protection of human health; UAT: Upper assessment threshold; LAT: Lower assessment threshold.

The NO_x limit value for the protection of vegetation and natural ecosystems is defined for yearly averaging period at 30 µg m^{-3}. Figure 8 shows the annual NO_x concentration levels in several locations and the comparison with the limit value, UAT and LAT. All stations shown in Figure 8 are traffic stations and thus the concentrations are very high compared with the limits. NOx-data from rural stations is not available and therefore the evaluation based on urban stations is not sufficient to address effects on vegetation. However, NO_2 is measured as daily average at some regional background stations in Norway; for instance measurements carried out in 2012 shows mean values of about 1.41, 2.51, 0.72 and 0.59 µg m^{-3} at Birkenes, Hurdal, Kårvatn and Tustervatn, respectively. From these values we could expect low NO_x concentration and most possible levels below limit values for the protection of vegetation (30 µg m^{-3}).

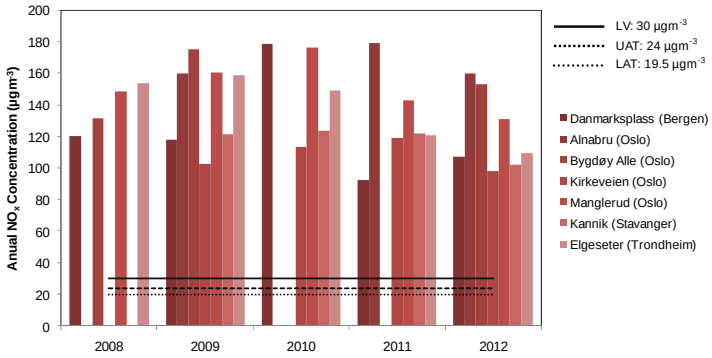

Figure 8: Annual NO_x concentration levels. LV: Annual limit value for the protection of vegetation and natural ecosystems; UAT: Upper assessment threshold; LAT: Lower assessment threshold.

4.1.3 Sulphur Dioxide (SO_2)

Sulphur dioxide (SO_2) is a highly reactive gas mainly associated with industrial emissions. The largest emission source of SO_2 is fossil fuel combustion at power plants, followed by emissions from other industrial facilities. In Norway, monitoring of SO_2 is carried out at industrial areas in Grenland district, and in Sarpsborg and Sør Varanger municipalities. This last one associated with the Nickel-smelter activities being carried out in Nikel and Zapoljarnij (Russia), close to the Norwegian – Russian border, and which emissions reach Norwegian territory under eastern/southern wind conditions (Berglen et al., 2011).

Limit values for the protection of human health are defined for hourly and daily mean concentrations (EC 2008), not to be exceeded more than 24 times and 3 times per calendar year, respectively, while the Norwegian national target is only defined for daily mean concentration (Table 4).

Karpdalen shows the highest number of exceedances of the hourly limit value for SO_2 (Figure 9), and in 2010 and 2011, the number of exceedances was above the allowed 24 times per calendar year established by air quality legislation. The measurements carried out in Sarpsborg since 2011 show a high number of exceedances, above the allowed 24 per calendar year in 2011.

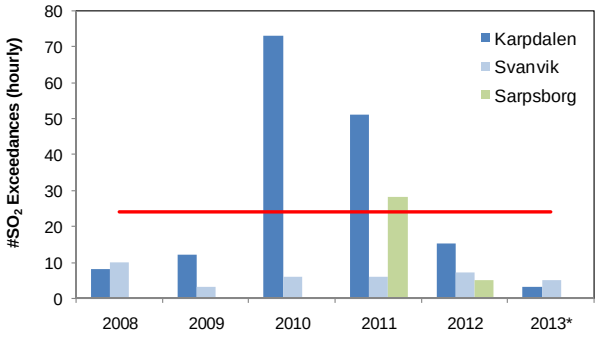

Figure 9: Number of exceedances of the hourly limit value to SO_2 in Sarpsborg and Sør Varanger (Karpdalen and Svanvik) municipalities.

The daily limit value for SO_2 is defined at 125 µg m^{-3}, not to be exceeded more than 3 times in a calendar year. In Sør Varanger, numbers of exceedances above

the allowed 3 times are yearly observed from 2009 to 2012 at Karpdalen (Figure 10). In Svanvik on the other hand, the number of exceedances of the limit value is below 3 times per year from 2008 to 2013, although exceedances of the national target (90 µg m^{-3}) are observed in 2010 and 2012. In Sarpsborg municipality, the number of exceedances of the daily limit values is below 3 times per year, but the national target is exceeded 7 times in 2011.

Exceedances of the upper and lower assessment thresholds cannot be established in Sarpsborg as there is only data available from two years (2011 and 2012). In Sør Varanger, exceedances of both UAT and LAT (> 3 times per year) are observed yearly since 2009 at both stations, Karpdalen and Svanvik. In addition, the available data from 2013 (January to March) at Karpdalen shows that the national target, and the UAT and the LAT are already exceeded more than 3 times this year (Figure 10).

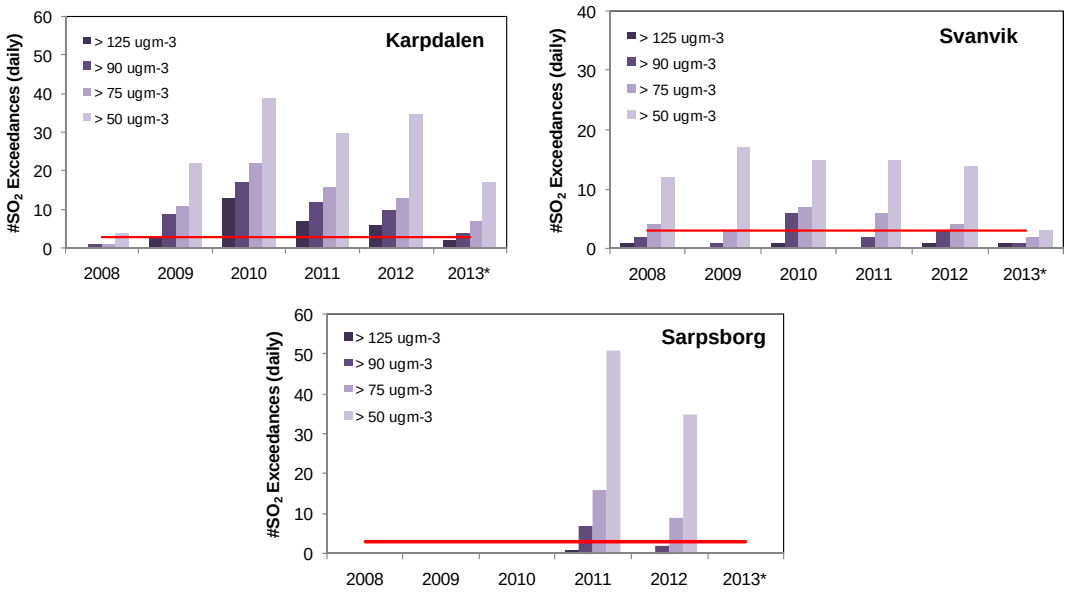

Figure 10: Number of exceedances of the daily limit value (125 µg m^{-3}), not to be exceeded more than 3 times per year (straight red line), national target (90 µg m^{-3}), UAT (75 µg m^{-3}) and LAT (50 µg m^{-3}) observed at Sør Varanger (Karpdalen and Svanvik) and Sarpsborg municipalities.

The SO_2 levels evaluated in this report have been monitored in areas affected by industrial emissions. However, SO_2 is also monitored in urban environments such as in Oslo (Table 1). The levels observed in Oslo (Grønland monitoring station) are very low, hereby maximum hourly and daily average from 2009 to 2013 have been observed at 26 and 8 µg m^{-3}, respectively. From this observations we can make a note that in Norway SO_2 is a pollutant of concern in industrial areas or areas affected by emissions from industrial activities. This aspect will be taken into account in the delimitation of AQ-zones for specific compounds such as SO_2.

SO_2 has been identified as one of the most important phytotoxic pollutants, for which uptake by vegetation can produce severe damage, from reversible to irreversible. Therefore, limit SO_2 values for the protection of vegetation are defined (Table 3). Figure 11 shows annual and winter (i.e. October to March) mean concentrations of SO_2 in the selected industrial locations. In Sarpsborg for

instance, both annual and winter limit values are exceeded in 2011 and 2012. However, it should be noticed that the measurement site in Sarpsborg does not fulfil the requirements of sampling points targeted at the protection of vegetation and natural ecosystems (EC 2008). In Sør Varanger, annual limit value is exceeded in Karpdalen in 2010, whereas winter mean values are exceeded yearly in Karpdalen since 2009. Karpdalen experiences in addition exceedances of the upper assessment threshold (2009-2012), whereas Svanvik only experiences exceedances of the lower assessment threshold value (2010-2012).

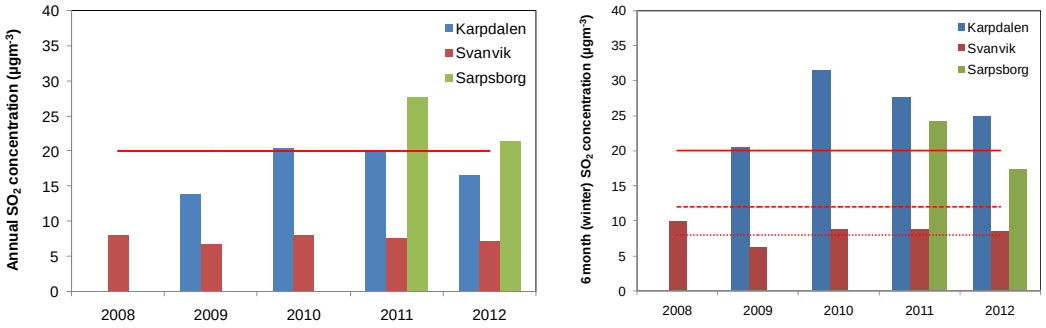

Figure 11: Annual (left) and winter (right; October to March) mean SO_2 concentration in Sør Varanger (Karpdalen and Svanvik) and Sarpsborg municipalities. Straight red line: annual limit value for the protection of vegetation. Dashed red line: upper assessment threshold. Dotted red line: lower assessment threshold.

4.1.4 Ozone

Ozone is a transboundary pollutant formed in the atmosphere from reaction of primary pollutants, such as NO_x and volatile organic compounds (VOCs). Ozone is addressed by the directive of the European Parliament (EC 2008), where air quality targets and long term objectives are defined for the protection of human health and vegetation (Table 3 and Table 4).

Ozone is measured at different urban and regional background stations in Norway (Table 1). The target value for the protection of human health is defined at 120 µg m^{-3}, for maximum daily eight-hour mean period, not to be exceeded on more than 25 days per calendar year averaged over three years, and the long term objective (LTO) defined at the same level (i.e. 120 µg m^{-3}) with not exceedances allowed. The AQ criterion defined by the Norwegian Environment Agency (formerly Klif) for ozone is established at 100 µg m^{-3} for hourly values, and 80 µg m^{-3} for eight-hour mean period. Figure 12 shows the number of exceedances of the target value (i.e. 120 µg m^{-3}) at different background stations in Norway. High number of exceedances is observed in Drammen in 2008 and 2009 but the concentration level dropped considerably when the observation method changed in 2010. As the target value for ozone must not be exceeded on more than 25 days per year, averaged over a period of three years, these areas comply with the AQ directive (Figure 12). Although we must take into account that the LTO is defined at the same level (120 µg m^{-3}) and exceedances are not allowed. The AQ criterion established by the Norwegian Environment Agency for maximum daily eight-hour mean concentration of ozone is very strict (80 µg m^{-3}) and a significant number of exceedances is systematically observed at all monitoring stations. For

instance, the average number of exceedances of 80 µg m^{-3} over the latest three years (2010-2012) is 127, 77, 99, 83, 103 and 106 at Birkenes, Drammen, Grenland, Prestebakke, Sandve and Tustervatn.

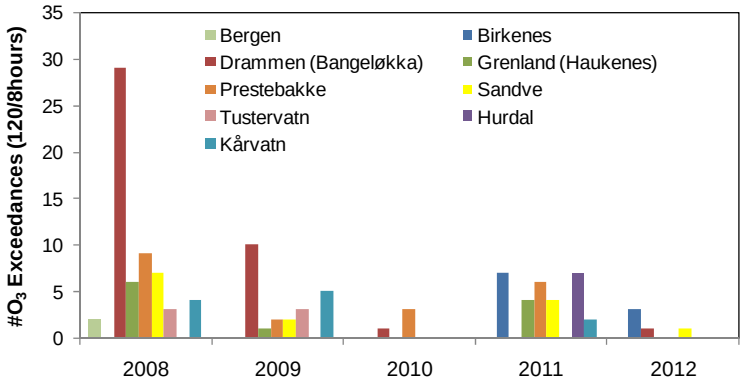

Figure 12: Number of exceedances of the maximum daily eight-hour mean O_3 value not to be exceeded more than 25 days per calendar year averaged over three years. Birkenes 2008-2010 data not included, different monitoring site.

Ozone has a huge impact on vegetation as it causes significant damage. Ozone enters the plants and oxidizes plant tissue, involving biochemical and physiological processes. Some of the most known damages are premature leaf loss, reduced photosynthesis and necrosis. Thus, target values and long term objectives are defined for the protection of vegetation based on the dose concept of accumulated ozone exposure (AOT40). It is expressed as dose units (µg m^{-3} * h) and calculated as the sum of the difference between hourly concentrations greater than 80 µg m^{-3} and 80 µg m^{-3} over a period using only the one hour values between 8:00 and 20:00 each day. Figure 13 shows the AOT40 corresponding to an averaging period between May and July at different background stations in Norway. The target value for ozone is not exceeded as it is defined at 18 000 (µg m^{-3} * h) averaged over five years period. The long term objective (6 000 µg m^{-3} * h) is exceeded in few locations (i.e. Grenland and Drammen).

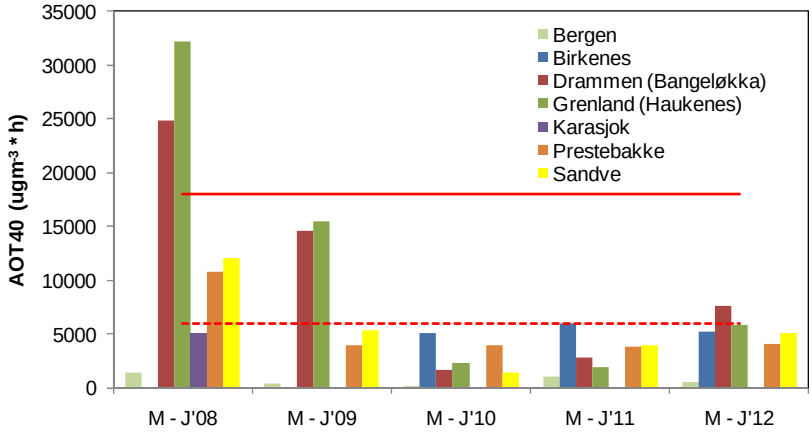

*Figure 13: AOT40 (µg m^{-3} * h) from 2008 to 2012, with averaging period May to July, at different regional background stations in Norway. Red straight line: target value, 18 000 µg m^{-3} * h averaged over five years. Red dashed line: long term objective, 6 000 µg m^{-3} * h.*

In the troposphere ozone is formed by chemical reactions between nitrogen oxides and VOCs driven by solar UV radiations. In Norway most of the ozone is "imported", i.e. transported into the country and only a minor part is produced from own national sources. The variation across the country thus mainly reflects variations in air mass source regions across the country. A comparison of ozone concentration levels since 2008 in different AQ-zones has been performed; hereby zone 4 and zone 5, of similar latitude, zone 6 and zone 7, the two northernmost, (Figure 1) have been compared. This comparison is shown in Figure 14 and Figure 15, and it will contribute to the proposal for new AQ-zone delimitation as we will evaluate the possibility of reducing the number of zones for reporting compliance with ozone target values/long term objectives.

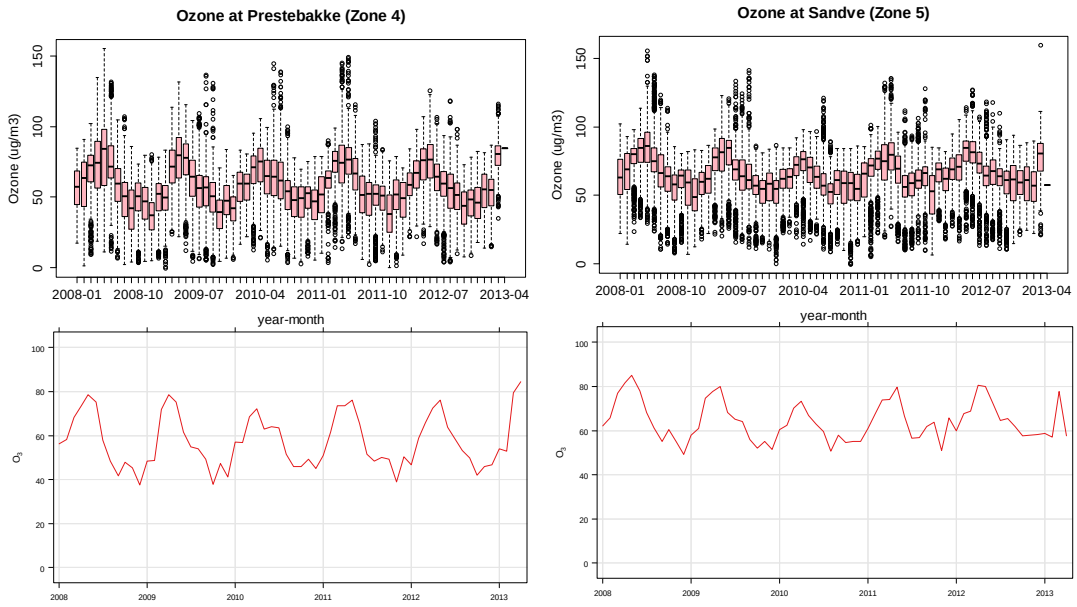

Figure 14: Comparison of O_3 concentration measured in stations in Zone 4 and 5. Box-whisker plots (upper) and monthly average (bottom) concentrations from 1st of January 2008 to 1st of April 2013.

The comparison of ozone concentration measured since 2008 shows similar levels for the zones (Figure 14 and Figure 15). The monthly average concentration in the two latitudinally similar zones (i.e. zone 4 and zone 5) varies between 40 and approximately 80 µg m^{-3}, reaching maximum hourly levels of about 150 µg m^{-3} (2008 and 2011; Figure 14). The two northernmost AQ-zones (i.e. zones 6 and zone 7) show monthly average concentration above 80 µg m^{-3}, values slightly higher than those measured in the two southern zones. From this comparison we can conclude that ozone levels are very similar in the AQ-zone 4 and 5, and in the AQ-zones 6 and 7.

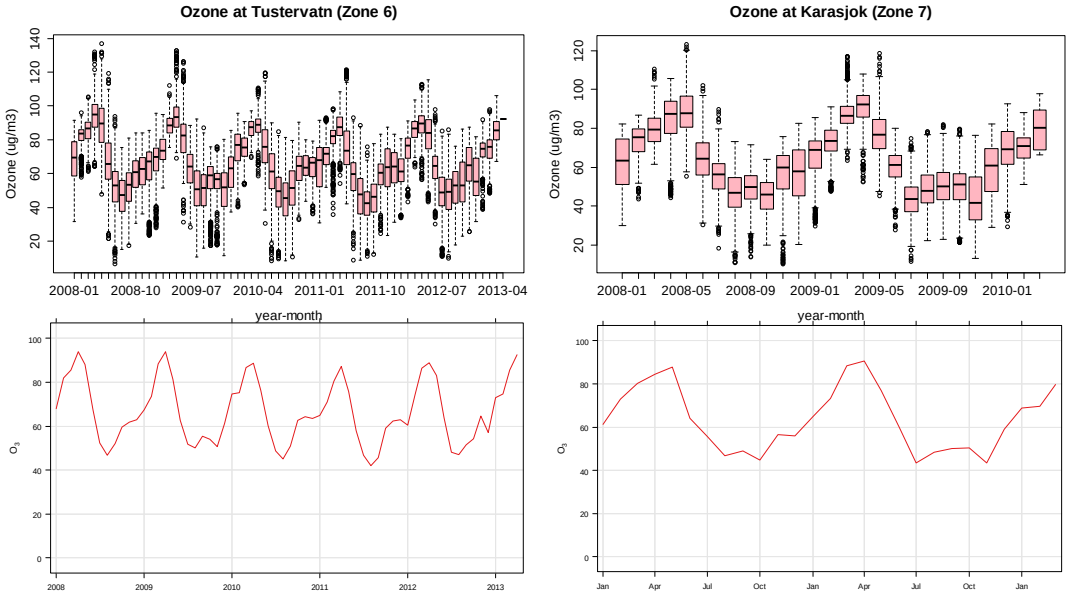

Figure 15: Comparison of O_3 concentration measured in stations in Zone 6 and 7. Box-whisker plots (upper) and monthly average (bottom) concentrations. Data coverage; Tustervatn: 1st of January 2008 - 1st of April 2013; Karasjok: 1st January 2008 – 4th March 2010 .

4.1.5 Benzene

Benzene (C_6H_6) is an organic compound, which is a known carcinogen. It is associated with cigarette smoke, vehicle exhaust, and emissions from coal-, oil-, and wood-burning, among other sources. The limit value for benzene is defined at 5 µg m^{-3} (EC 2008), while the Norwegian national target is defined at 2 µg m^{-3}. Figure 16 shows the available measurement data in Norway since 2007 and the comparison with limit value, national target and upper/lower assessment thresholds. The limit value defined by the air quality directive is not exceeded in any of the years. However, the upper assessment threshold is exceeded in Oslo (Kirkeveien) as benzene concentration above 3.5 µg m^{-3} is measured in three out of five years, 2009, 2010 and 2011. The lower assessment threshold is exceeded (i.e. three out of five years) in every location except Ålesund and Kristiansand.

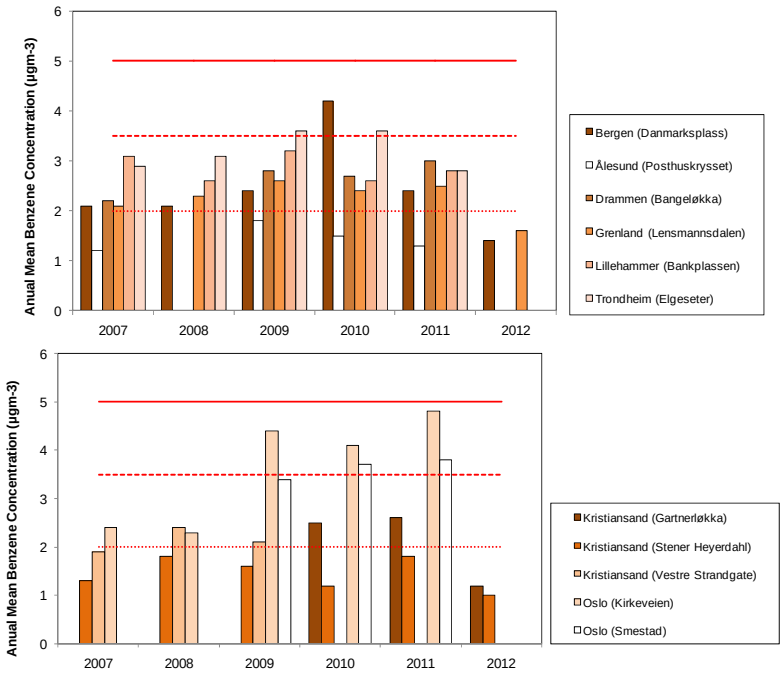

Figure 16: Benzene concentration at different measurement stations in Norway. Red straight line: limit value. Red dashed line: upper assessment threshold. Red dotted line: lower assessment threshold and Norwegian national target.

4.1.6 Heavy metals

Heavy metals such as arsenic, nickel and cadmium are common air pollutants associated with industrial emissions and found as metallic elements or metal oxides contained in particles. Levels are relatively low but they are persistent and accumulate in the environment and consequently in the food chain. They are known human carcinogens, and can damage kidney, bone and skin, among other organs.

The yearly average concentrations of arsenic, cadmium and nickel are shown in Table 5, Table 6 and Table 7 respectively. Arsenic concentration analysed in the PM_{10} fraction is below the target value defined by AQ directive (i.e. 6 ng m^{-3}; EC 2005) and below the lower assessment thresholds (2.4 ng m^{-3}; EC 2005) in most of the locations. High arsenic concentration is analysed in the monitoring stations placed in *Sør Varanger* (Table 5). The arsenic level is above the UAT (i.e. 3.6 ng m^{-3}; EC 2005) in Karpdalen, above the UAT in Svanvik in the 2011 summer season and above the LAT in Svanvik in both winter season sampling periods (i.e. 2010/2011 and 2011/2012). Although these values do not represent yearly average concentrations they indicate that arsenic may be a concern in *Sør Varanger*. In contrast, arsenic concentration is below 1 ng m^{-3} in most of the locations, except in Kristiansand where levels above 1 ng m^{-3} have been analysed in both 2009 and 2011 (Table 5). Similarly, cadmium concentration levels analysed in PM_{10} are higher in Kristiansand and Sauda than in the other measurement locations, although levels are below the target value (5 ng m^{-3}) and the lower assessment threshold (2 ng m^{-3}) defined by the AQ directive (EC 2005).

High concentration of nickel has been analysed in PM_{10} collected in Kristiansand, with levels above the target value (i.e. 20 ng m^{-3}) in 2009 and 2012, and close to it in 2011. The assessment of exceedances of the upper/lower assessment threshold cannot be performed as data is available from only three years, instead of the needed five years period. High concentration of nickel is also observed in the samples from *Sør Varanger* (Svanvik; Table 7), although the averaging period does not correspond to one year, where concentration levels are observed above the LAT (i.e. 10 ng m^{-3}) in the sampling carried out in 2010/2011 winter period, and in the sampling carried out in summer 2010 and 2011.

*Table 5: Yearly average arsenic concentration (ng m^{-3}) analysed in the PM_{10} fraction. *: values in Svanvik and Karpdalen (Berglen et al., 2011; 2012) represent average arsenic concentration in summer 2010 (36 sampling days), summer 2011 (54 sampling days), winter 2010/2011 (59 sampling days) and winter 2011/2012 (23 and 18 sampling days) (Data Source for Andøya, Birkenes and Zeppelin: Aas et al., 2013). Shaded areas represent values above LAT (2.4 ng m^{-3}) and/or UAT (3.6 ng m^{-3}).*

LOCATION	Station	Year	Value
ANDØYA	Andøya	2010	0.069
ANDØYA	Andøya	2011	0.062
ANDØYA	Andøya	2012	0.063
BIRKENES	Birkenes	2009	0.212
BIRKENES	Nye Birkenes	2010	0.177
BIRKENES	Nye Birkenes	2011	0.33
BIRKENES	Nye Birkenes	2012	0.151
KARPDALEN	Karpdalen	2011/2012*	3.91
KRISTIANSAND	Hennig Olsen	2009	1.06
KRISTIANSAND	Hennig Olsen	2011	1.44
KRISTIANSAND	Hennig Olsen	2012	2.26
SAUDA	Søndenålia	2009	0.492
SAUDA	Søndenålia	2010	0.673
SVANVIK	Svanvik	2010*	1.90
SVANVIK	Svanvik	2010-2011*	2.75
SVANVIK	Svanvik	2011*	4.57
SVANVIK	Svanvik	2011/2012*	2.07
ZEPPELIN	Zeppelinfjellet	2009	0.06
ZEPPELIN	Zeppelinfjellet	2010	0.048
ZEPPELIN	Zeppelinfjellet	2011	0.071
ZEPPELIN	Zeppelinfjellet	2012	0.036

Table 6: Yearly average cadmium concentration (ng m^{-3}) analysed in the PM_{10} fraction. (Data Source for Andøya, Birkenes and Zeppelin: Aas et al., 2013)

LOCATION	Station	Year	Value
ANDØYA	Andøya	2010	0.017
ANDØYA	Andøya	2011	0.01
ANDØYA	Andøya	2012	0.011
BIRKENES	Birkenes	2009	0.037
BIRKENES	Nye Birkenes	2010	0.04
BIRKENES	Nye Birkenes	2011	0.05
BIRKENES	Nye Birkenes	2012	0.028
KRISTIANSAND	Hennig Olsen	2009	0.32
KRISTIANSAND	Hennig Olsen	2011	0.06
KRISTIANSAND	Hennig Olsen	2012	0.04
SAUDA	Søndenålia	2009	0.144
SAUDA	Søndenålia	2010	0.317
ZEPPELIN	Zeppelinfjellet	2009	0.017
ZEPPELIN	Zeppelinfjellet	2010	0.014
ZEPPELIN	Zeppelinfjellet	2011	0.015
ZEPPELIN	Zeppelinfjellet	2012	0.008

*Table 7: Yearly average nickel concentration (ng m^{-3}) analysed in the PM_{10} fraction. *: values in Svanvik and Karpdalen (Berglen et al., 2011; 2012) represent average nickel concentration in summer 2010 (36 sampling days), summer 2011 (54 sampling days), winter 2010/2011 (59 sampling days) and winter 2011/2012 (23 and 18 sampling days). Shaded areas represent values above LAT (10 ng m^{-3}), UAT (3.6 ng m^{-3}) and/or target value (20 ng m^{-3}). (Data Source for Andøya, Birkenes and Zeppelin: Aas et al., 2013)*

LOCATION	Station	Year	Value
ANDØYA	Andøya	2010	0.323
ANDØYA	Andøya	2011	0.122
ANDØYA	Andøya	2012	0.173
BIRKENES	Birkenes	2009	0.661
BIRKENES	Nye Birkenes	2010	0.503
BIRKENES	Nye Birkenes	2011	0.613
BIRKENES	Nye Birkenes	2012	0.29
KARPDALEN	Karpdalen	2011/2012*	7.08
KRISTIANSAND	Hennig Olsen	2009	28.66
KRISTIANSAND	Hennig Olsen	2011	18.9
KRISTIANSAND	Hennig Olsen	2012	22.59
SAUDA	Søndenålia	2009	1.053
SAUDA	Søndenålia	2010	1.807
SVANVIK	Svanvik	2010*	14.05
SVANVIK	Svanvik	2010-2011*	13.81
SVANVIK	Svanvik	2011*	20.18
SVANVIK	Svanvik	2011/2012*	4.48
ZEPPELIN	Zeppelinfjellet	2009	0.132
ZEPPELIN	Zeppelinfjellet	2010	0.142
ZEPPELIN	Zeppelinfjellet	2011	0.085
ZEPPELIN	Zeppelinfjellet	2012	0.065

4.1.7 Benzo(a)pyrene

Benzo(a)pyrene (B(a)P; $C_{20}H_{12}$) is a polycyclic aromatic hydrocarbon (PAH), known mutagenic and highly carcinogenic. It is a by-product of incomplete combustion from a wide variety of sources such as wildfires, industries, traffic, tobacco smoke and wood burning, which is the main source of atmospheric B(a)P.

Table 8 shows the yearly B(a)P concentration at different locations in Norway. B(a)P concentrations analysed at urban environments (Bergen, Drammen, Oslo, Trondheim) are higher than at regional background locations (e.g. Birkenes), which is probably associated with wood-burning emissions. The target value defined for B(a)P (i.e. 1 ng m^{-3}) is not exceeded at any of the locations, and higher B(a)P levels than the lower assessment threshold (i.e. 0.4 ng m^{-3}) are obtained in Bergen (2010), Drammen (2010), at traffic (2010) and urban background (2008) stations in Oslo, and in Trondheim (2010 and 2012). In spite of these relatively high levels, exceedances of the lower assessment threshold cannot be evaluated as we do not have a five year period to assess the potential exceedances (three years out of five).

Table 8: Yearly average benzo(a)pyrene concentration (ng m^{-3}) analysed in the PM_{10} fraction.

LOCATION	Station	Year	Value
ANDØYA	Andøya	2010	0.005
ANDØYA	Andøya	2011	0.005
ANDØYA	Andøya	2012	0.005
BERGEN	Danmarksplass	2012	0.13
BERGEN	Rådhuset	2009	0.3
BERGEN	Rådhuset	2010	0.67
BERGEN	Rådhuset	2011	0.18
BERGEN	Rådhuset	2012	0.13
BIRKENES	Nye Birkenes	2010	0.032
BIRKENES	Nye Birkenes	2011	0.026
BIRKENES	Nye Birkenes	2012	0.017
DRAMMEN	Drammenselva	2012	0.39
DRAMMEN	Nedre Storgate	2010	0.67
DRAMMEN	Nedre Storgate	2011	0.39
DRAMMEN	Nedre Storgate	2012	0.39
OSLO	Hjortnes	2009	0.36
OSLO	Hjortnes	2010	0.54
OSLO	Hjortnes	2011	0.31
OSLO	Hjortnes	2012	0.19
OSLO	Sofienbergparken	2008	0.57
OSLO	Sofienbergparken	2009	0.34
OSLO	Sofienbergparken	2010	0.28
OSLO	Sofienbergparken	2011	0.37
OSLO	Sofienbergparken	2012	0.19
TRONDHEIM	Torvet	2009	0.12
TRONDHEIM	Torvet	2010	0.67
TRONDHEIM	Torvet	2011	0.258
TRONDHEIM	Torvet	2012	0.44
ZEPPELIN	Zeppelinfjellet	2010	0.003
ZEPPELIN	Zeppelinfjellet	2011	0.004
ZEPPELIN	Zeppelinfjellet	2012	0.002

4.2 Summary Overview of Exceedances in Norway

4.2.1 Protection of human health

- **PM_{10}** is of main concern in the urban environment where exceedances of the daily limit values are frequent, mainly in spring and autumn, related to de-icing and road activities such as sanding. Exceedances of the upper and lower assessment thresholds are widespread.
- **NO_2** is also a main concern in the urban environment and the national target is significantly exceeded (> 8 times per year). In urban environments such as Bergen and Oslo, the number of exceedances of the UAT and LAT (hourly value) is commonly above 100 and 500 times per year, respectively. The annual mean concentration in several urban agglomerations (Oslo, Stavanger, Trondheim and Drammen) is above annual limit value for the protection of human health every year since 2008.
- **SO_2** is a main concern in industrial areas or areas affected by emissions from industry (e.g. Sør Varanger). Sør Varanger does not comply with daily limit values for SO_2 as more than 3 exceedances per year (allowed limit) are observed from 2009 to 2012.
- Exceedances of the **O_3** target value are below the allowed 25 days per year averaged over a period of three years, but exceedances of the LTO are observed at several stations. Furthermore, exceedances of the AQ criterion defined by the Norwegian Environmental Agency (i.e. 100 $\mu g\, m^{-3}$ for hourly values, and 80 $\mu g\, m^{-3}$ for eight-hour mean period) are observed at all monitoring stations.
- **Benzene** upper assessment threshold is exceeded in Oslo, at the traffic station located in Kirkeveien.
- **Arsenic** and **cadmium** concentration levels do not exceed target values. The target value defined for **nickel** is exceeded at Kristiansand and high values are observed at Svanvik (2011 winter period). Arsenic and nickel concentration levels above lower/upper assessment thresholds are observed in the sampling carried out in Sør Varanger, although the data coverage (value < year average and only 3 years) does not allow to evaluate exceedances.
- The target value defined for **benzo(a)pyrene** is not exceeded. However, high values are obtained at urban locations.

4.2.2 Protection of vegetation and natural ecosystems

- Critical **NO_x** levels for the protection of vegetation and natural ecosystems are observed. However, such levels are observed at traffic monitoring stations only, which are not designed to assess vegetation exposure.
- **SO_2** levels observed at some industrial areas or affected by industrial emissions (i.e. Sør Varanger) are critical for the protection of vegetation.
- There are no exceedances of the **O_3** target value for the protection of vegetation, but the long term objective is exceeded few times.

4.3 Insights from the updated background concentration over Norway

Figure 17 shows the annual mean background concentration over Norway in 2007 (NO_2) and 2008 (PM_{10} and O_3). The area with highest mean PM_{10} and NO_2 concentrations is Greater Oslo which is the most densely populated area in Norway (Figure 17), with the biggest road traffic network and thus highest traffic emissions. Hotspots are also found along the coastline corresponding to main urban agglomerations; Kristiansand, Stavanger, Bergen and Trondheim. The updated background concentration over Norway is consistent with the measurement data presented in the previous chapter, showing that PM_{10} and NO_2, predominate in urban environment or agglomerations, whereas inland background levels and concentrations in the mountain areas are very low, between 0 and 5 µg m^{-3}. This consistency is to be expected as the background maps presented here are based on measured observations and air quality modelling results.

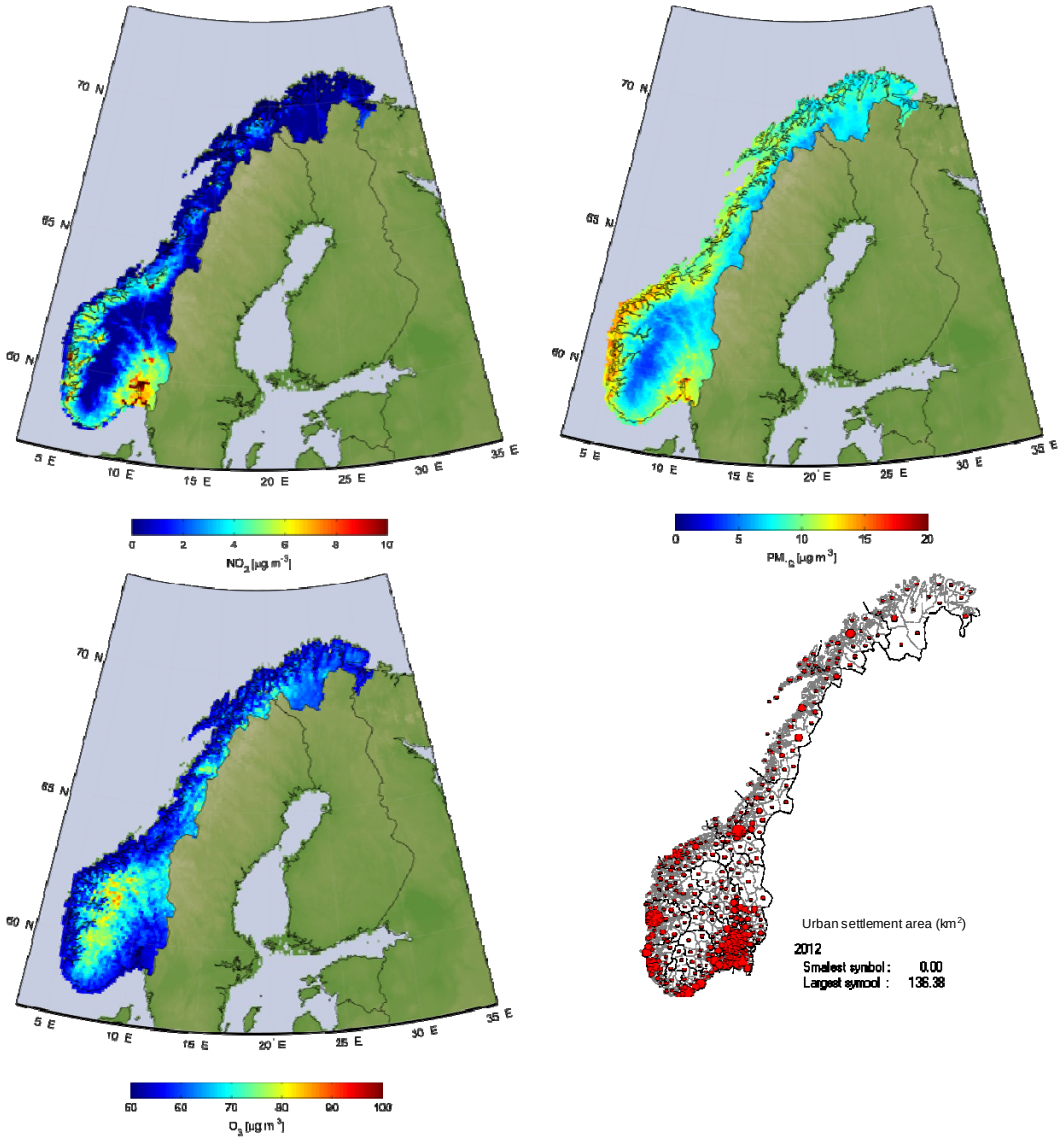

Figure 17: Maps of annual mean NO_2, PM_{10} and O_3 concentrations for 2008 (2007 for NO_2) over Norway. spatial resolution: 10 x 10 km (Schneider et al., 2011). Urban settlement area (km^2) in Norway in 2012 (bottom right; Source of the data: Statistikkbanken, SSB 2013).

Ozone background concentration shows the opposite pattern than PM_{10} and NO_2 (Figure 17), as high mean concentration levels are calculated in the inland mountain areas and low annual mean O_3 concentration in Greater Oslo area and along the coastline, where the most important urban settlements are located.
The different pattern observed between background O_3 and PM_{10}/NO_2 concentrations support the idea of establishing different AQ-zones for different compounds.

5 Air Quality Zone Delimitation Proposal

A proposal for new AQ-zone delimitation for reporting relating to European directives is presented in this chapter.

Earlier in this report, we have seen that different pollutants are of concern in different areas. For instance, different patterns have been observed in the background concentration over Norway between ozone and NO_2/PM_{10}, and air pollutants such as SO_2 are dominant in industrial areas rather than in urban environments. Consequently, and for allowing better management of pollution control, different AQ-zone delimitations are suggested for air pollutants or groups of pollutants. $PM_{2.5}$ levels in Norway have not been evaluated in this study, but as the zone delimitation proposal is mostly based on pollutant sources, the recommendation for PM_{10} apply also to $PM_{2.5}$.

5.1 Zone delimitation for PM_{10}, $PM_{2.5}$, NO_2, NO_x, benzene and B(a)P

Pollutants associated with combustion sources, such as traffic emissions and wood burning, and whose concentration levels are of certain concern in urban environments, have been grouped together. These pollutants are NO_2, NO_x, PM_{10}, $PM_{2.5}$, benzene and B(a)P, and a common AQ-zone delimitation is proposed (Figure 18). Based on the evaluation of air pollution in Norway in the last five years, these pollutants are of concern, as frequent exceedances of limit or target values are observed in urban environments. For instance, exceedances of limit values and assessment thresholds defined for NO_2 and PM_{10} are widespread in urban environments of the Norwegian territory. The main difference between the proposed AQ-zone delimitation for these pollutants (Figure 18) and the current zone delimitation (Figure 1) is an increase of the number of zones from 7 to 9. The main agglomerations, Oslo, Bergen and Trondheim, are kept as independent zones, and Stavanger is included as a new agglomeration zone. *Øst/Sørlandet*, *Vestlandet*, and *Troms/Finnmark* are kept as regions, and the previously named zone 6 (*Midt-Norge* and *Nordland*) has been divided in two different zones, proposed AQ-zone 7 (*Midt-Norge*) and proposed AQ-zone 8 (*Nordland*). The proposed division (i.e. *Midt-Norge* and *Nordland* as different zones) shows better the different climate and meteorological conditions of these two areas, with the consequently differences in pollutant dispersion. Moreover, the distribution of agglomerations in *Midt-Norge* and *Nordland* makes it difficult to extrapolate the information from monitoring stations and guarantee representativeness. For instance, exceedances in Mo i Rana may not be representative of the AQ situation in Ålesund. Considering *Midt-Norge* and *Nordland* as two independent zones may contribute to more accurate description of the AQ situation and allow better management of pollution control.

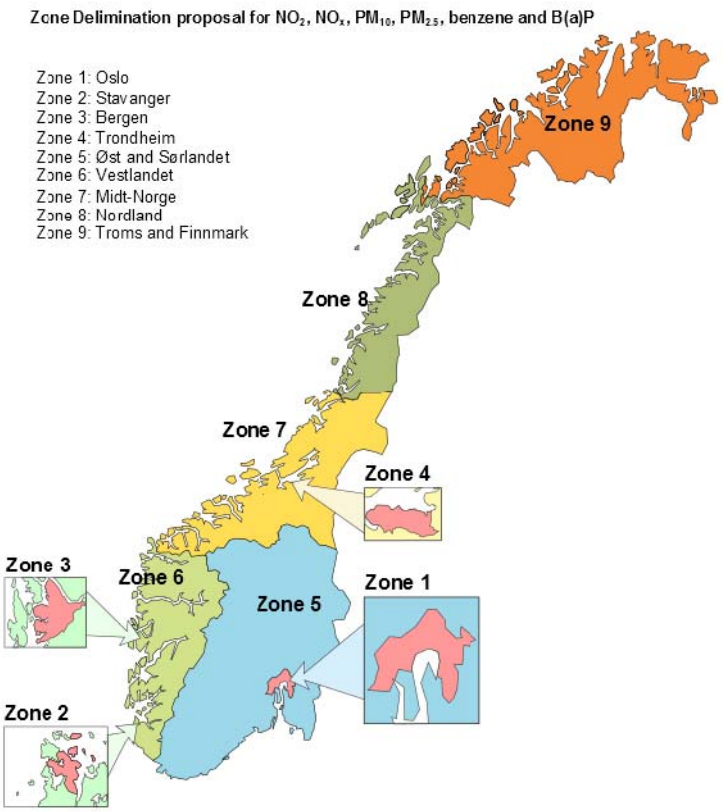

Figure 18: AQ-zone delimitation proposal for air pollutants (NO_2, NO_x, PM_{10}, benzene and B(a)P) associated with combustion sources (i.e. traffic emissions, wood burning).

5.2 Zone delimitation for ozone

For reporting compliance with ozone target values and long term objective, the proposed AQ-zone delimitation is composed by four zones; two agglomerations (i.e. Zone 1: Oslo and Zone 2: Bergen), and two zones; zone 3 comprising *Øst-, Sørlandet* and *Vestlandet*, and a zone 4, comprising *Midt-Norge, Nordland, Troms* and *Finnmark* (Figure 19).

This division is based on 1) evaluation of air quality in Norway, where we observed that exceedances of the O_3 target value are below the allowed 25 days per year averaged over a period of three years. Although exceedances of the AQ criterion defined by the Norwegian Environmental Agency (i.e. 100 µg m^{-3} for hourly values, and 80 µg m^{-3} for eight-hour mean period) are observed at all monitoring stations; 2) the comparison of regional background ozone concentration levels in adjacent zones, zone 4 and 5 (Figure 14), and zone 6 and 7 (Figure 15), shows very similar results, 3) the ozone background levels are high in the inland mountain areas and low in important urban settlements (Figure 17).

It is noteworthy to point out that the minimum number of sampling points (continuous measurements) to assess compliance with target values and long-term objective is 1 and 2 in agglomerations (urban and suburban) with a population below 500 000 (e.g. Bergen; ≈ 270 000) and below 1 000 000 (e.g. Oslo; ≈

600 000[1]), respectively. At least one suburban station will have to be operated in the remaining zones 3 and 4, where the highest exposure of the population is likely to occur. Furthermore, the Directive (EC, 2008) requires a minimum of 1 sampling point per 50 000 km^2 at rural background and recommends 1 station per 25 000 km^2 for complex terrain.

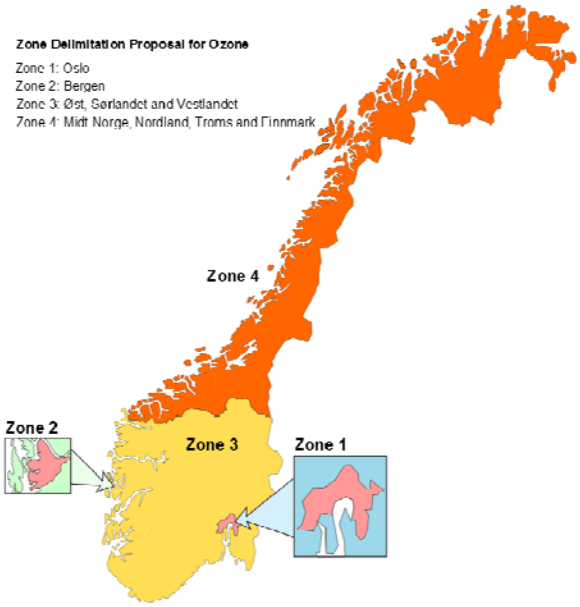

Figure 19: AQ-zone delimitation proposal for ozone.

5.3 Zone delimitation for SO_2 and heavy metals

As it has been shown earlier in this report based on 1) measurements data; and 2) the comparison between pollution levels in industrial areas and urban environment (i.e. SO_2 in Oslo); air pollutants such as SO_2 and heavy metals (arsenic, cadmium and nickel) are important in industrial areas or those areas with significant impact from industrial emissions in neighbouring countries, such as *Sør Varanger*. Therefore, the proposed AQ-zone delimitation for SO_2 and heavy metals considers five zones; 1) *Sarpsborg;* 2) *Skien, Porsgrunn* and *Bamble*, where *Grenland* industry complex is located; 3) Kristiansand, 4) *Sør Varanger*; and 5) Norway excluding the mentioned municipalities (Figure 20).

5.4 Zone delimitation for CO

Concerning CO and based on the observed levels, it is proposed to have only one zone, i.e. Norway, for reporting CO levels (Figure 21) to the European Commission.

Finally, during the work carried out in this report, some gaps and further needs have been identified. Taking into account the growth of the urban population and the expansion of urban settlements an assessment of the boundaries of the agglomeration zones can be foreseen. The aim of this boundary assessment would be to evaluate a potential enlargement of agglomeration zone in order to guarantee

[1] Population given for the city of Oslo, the population in the agglomeration zone will depend on its boundaries.

that high populated areas around the cities are covered. In addition, the new proposal for AQ-zone delimitation in combination with information regarding population distribution involve an evaluation of the needs for AQ-monitoring.

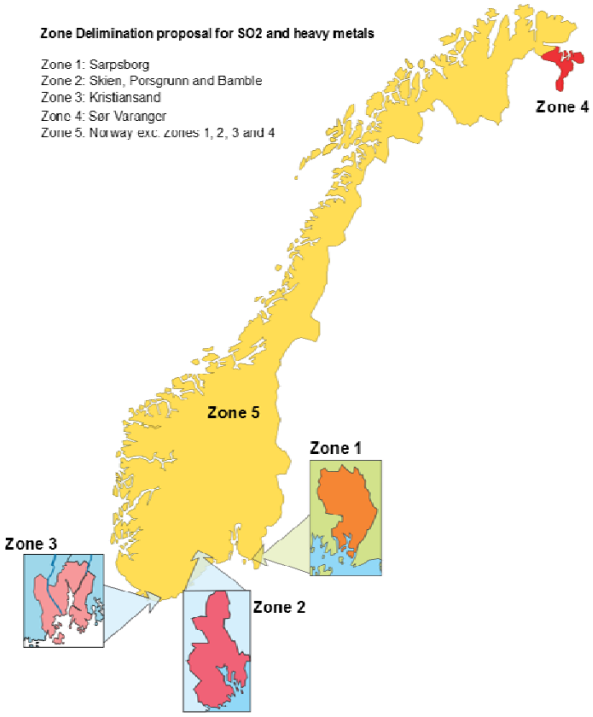

Figure 20: AQ-zone delimitation proposal for air pollutants (SO_2 and heavy metals) mainly associated with industrial emissions.

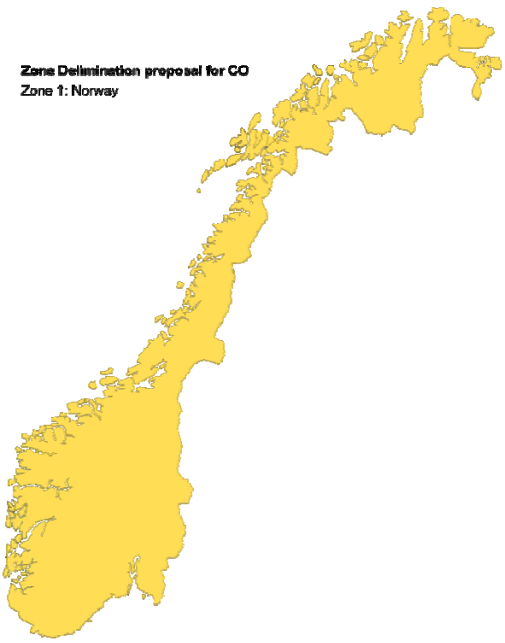

Figure 21: AQ-zone delimitation proposal for CO.

The proposed new AQ delimitation zone indicates that the pollution situation in Norway has changed over the last years. Increased focus on pollution in urban agglomerations and around specific industrial areas justifies the revision of the

existing AQ delimitation zone in favour to the one proposed in this report. This proposed revision will have consequences for future reporting of air quality to the European Commission and for the representativeness of the current monitoring network.

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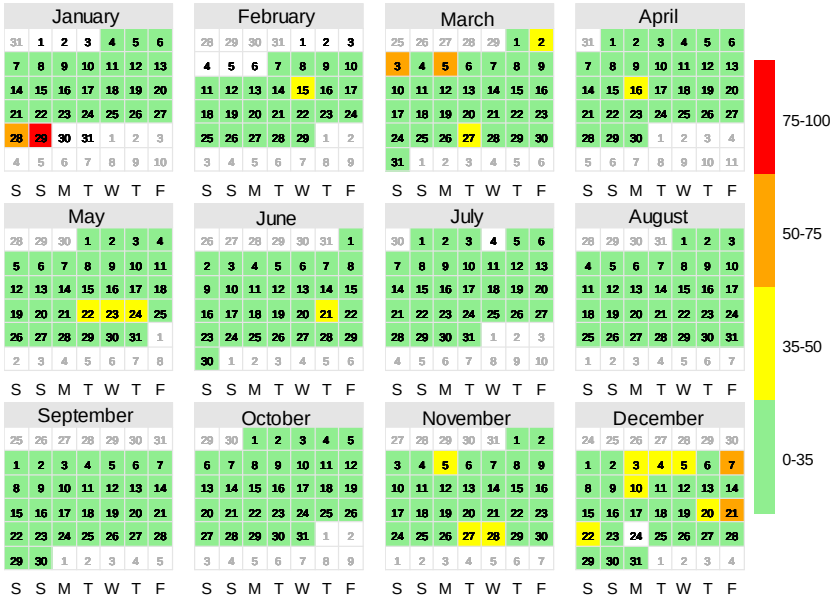
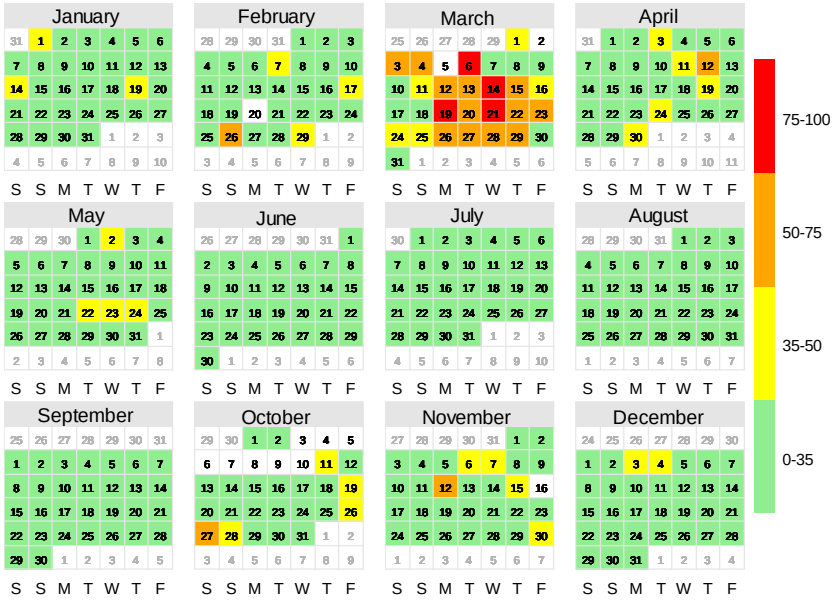
Appendix A

Calendar plots for daily mean PM_{10} concentrations

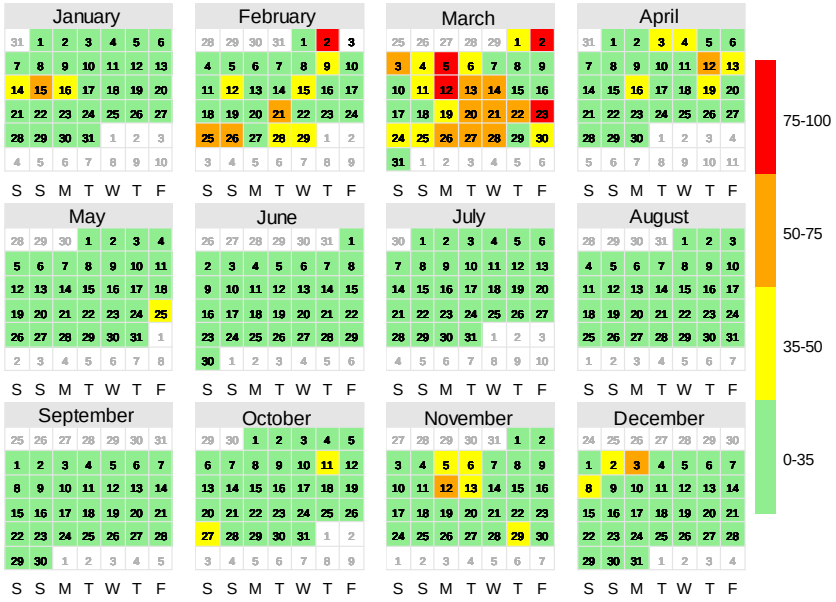
Bergen - Danmarkplass - PM_{10} - 2012



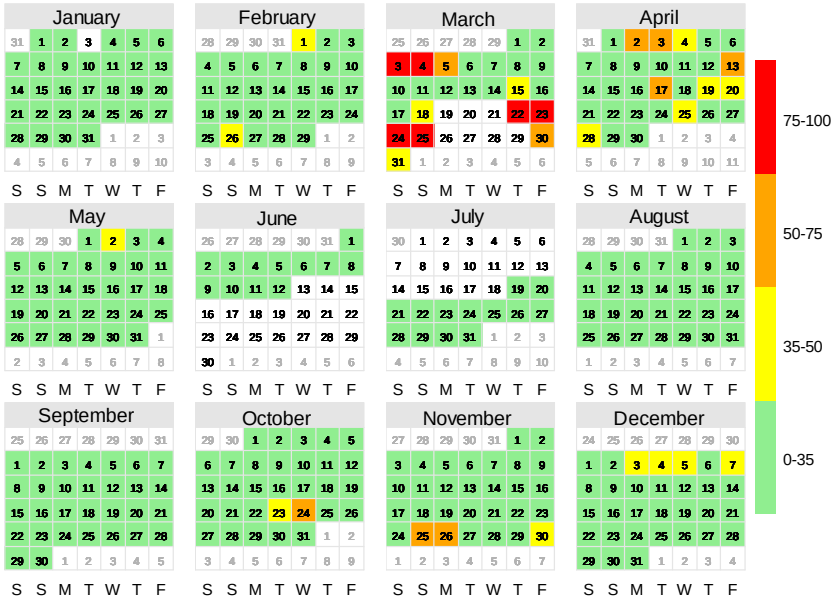
Drammen - Bangeløkka - PM_{10} - 2012



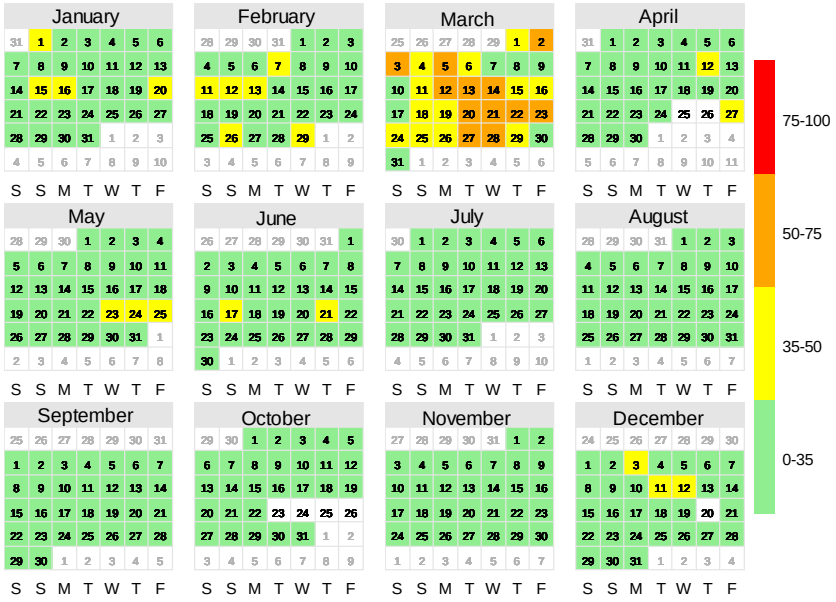
Fredrikstad - St.Croix - PM_{10} - 2012



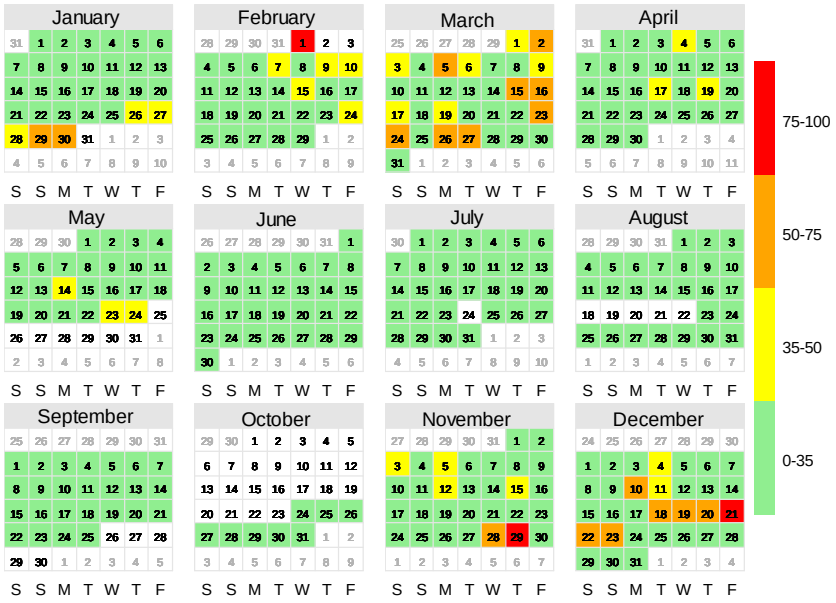
Lillehammer - Bankplassen - PM_{10} - 2012



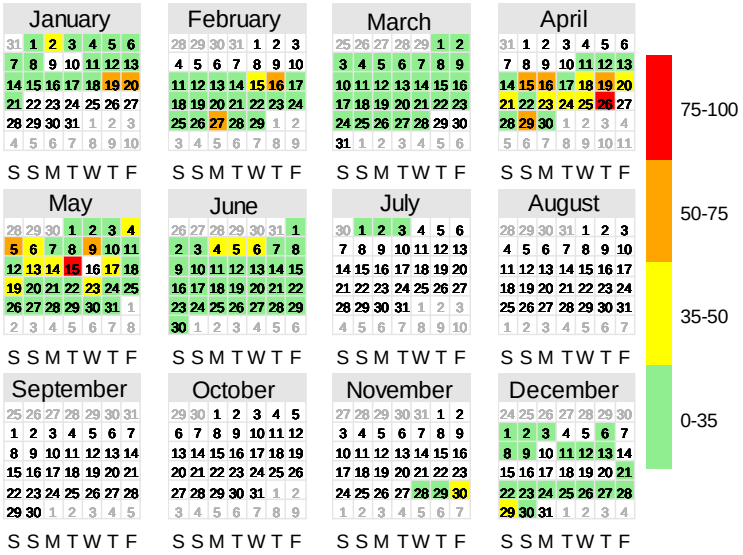
Oslo - Bygdøy Alle - PM_{10} - 2012



Stavanger - Kannik - PM_{10} - 2012



Tromsø - Hansjordnesbukta - PM_{10} - 2012



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Air Quality Zone Delimitation in Norway Evaluation and delimitation proposal	Susana López-Aparicio NILU PROJECT NO. O-113090
AUTHOR(S) Susana López-Aparicio and Dag Tønnesen	CLASSIFICATION * A CONTRACT REF.

QUALITY CONTROLLER: Cristina Guerreiro

REPORT PREPARED FOR
Norwegian Environment Agency
P.O.Box 5672 Sluppen,
7485 Trondheim

ABSTRACT
An evaluation of the air quality in Norway over the last five years has been performed to set up the basis for a new Air Quality zone (AQ-zone) delimitation for reporting to European Commission concerning compliance of air quality directives. Air pollution levels (i.e. PM_{10}, NO_2, SO_2, CO, O_3, benzene, heavy metals, B(a)P) have been assessed regarding exceedances of limit values, target values, Norwegian national targets, and upper/lower assessment thresholds (UAT/LAT) defined for the protection of human health, vegetation and/or natural ecosystems. The results from this evaluation complemented with information regarding background concentration levels in Norway have been used to define a new delimitation: 1) AQ-zone delimitation for PM_{10}, NO_2, NO_x, benzene and B(a)P, 2) AQ-zone delimitation for SO_2 and heavy metals, 3) AQ-zone delimitation for ozone and 4) AQ-zone delimitation for CO.

NORWEGIAN TITLE

Soneinndeling for luftkvalitet i Norge - Vurdering og inndelingsforslag

KEYWORDS		
Air Quality	Environmental Monitoring	Urban Traffic Pollution

ABSTRACT (in Norwegian)
Luftkvaliteten i Norge i de siste fem årene er blitt vurdert for danne grunnlag for en ny soneinndeling for rapportering til EU-kommisjonen om overholdelse av luftkvalitetsdirektiver. Luftforurensningsnivåer (PM_{10}, NO_2, SO_2, CO, O_3, benzen, tungmetaller, B(a)P) ble vurdert med hensyn til overskridelser av grenseverdier, nasjonale mål og øvre/nedre vurderingsterskler (UAT / LAT) definert for beskyttelse av menneskers helse, vegetasjon og / eller naturlige økosystemer. Resultatene av luftkvalitesvurderingen, supplert med informasjon om bakgrunnskonsentrasjon i Norge, er blitt brukt til å definere en ny soneinndeling; 1) soneinndeling for PM_{10}, NO_2, NO_x, benzen og B(a)P, 2) soneinndeling for SO_2 og tungmetaller, 3) soneinndeling for ozon og 4) soneinndeling for CO.

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