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Status of black carbon monitoring in ambient air in Europe

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Executive summary

Black carbon (BC) is increasingly discussed in science and environmental policy areas as an example of an air pollutant that affects both human health and contributes to climate change (e.g. WHO, 2012; UNEP/WMO, 2011; Bond et al., 2013; IPCC, 2013). In order to be able to make comparable measurements of BC in ambient air and to relate BC monitoring to health impacts and climate change it is important to understand how BC is defined.

This report provides a summary of BC definitions as discussed in the air quality monitoring community. Secondly, it provides a summary of the current status of BC-related monitoring in Europe. Information presented in the report includes an overview of available measurement techniques and associated technical issues, monitoring networks and current data reporting practices.

BC is a light-absorbing, carbon-containing constituent of particulate matter (PM) formed by the incomplete combustion of fossil fuels, biomass and biofuels. BC is directly emitted into the air. Major sources include vehicles (particularly diesel-driven road vehicles), non-road mobile machinery (e.g. forest machines), ships, residential heating (e.g. small coal or wood burning stoves) and open biomass burning (e.g. forest fires or burning of agricultural waste).

In terms of the potential to harm human health, PM is one of the most important air pollutants as it penetrates into sensitive regions of the respiratory system, and can cause or aggravate cardiovascular and lung diseases. BC is mainly present in the so-called ultrafine fraction of particulate matter ($PM_{0.1}$ ([1])). Due to their small size, $PM_{0.1}$ particles can be transported through the respiratory tract and across the lung membranes. Once absorbed directly into the bloodstream they can relocate to other organs. BC is a major component of diesel soot, which has been declared as a substance that can cause cancer by the World Health Organization (WHO, 2012).

As regards its climate-related impacts, BC scatters and absorbs solar radiation (light) entering the Earth's atmosphere. It is the component of airborne PM which most absorbs light and is viewed as a major contributor to climate change (e.g. Bond et al., 2013). BC acts over a much shorter period than classic greenhouse gases (GHG) such as carbon dioxide (CO_2) because it has a shorter life time in the air. According to current research BC contributes to the warming of the atmosphere (US EPA, 2012; Ramanathan and Carmichael, 2008; Bond et al., 2013).

The report highlights BC measurement work carried out in air quality monitoring networks, particularly in urban networks. The monitoring community uses measurements from a method to analyse light-absorbing properties of BC-containing particles in order to gain a light absorption coefficient. This coefficient can be translated into a unit that measures particle mass so that the results can be used to assess possible health impacts.

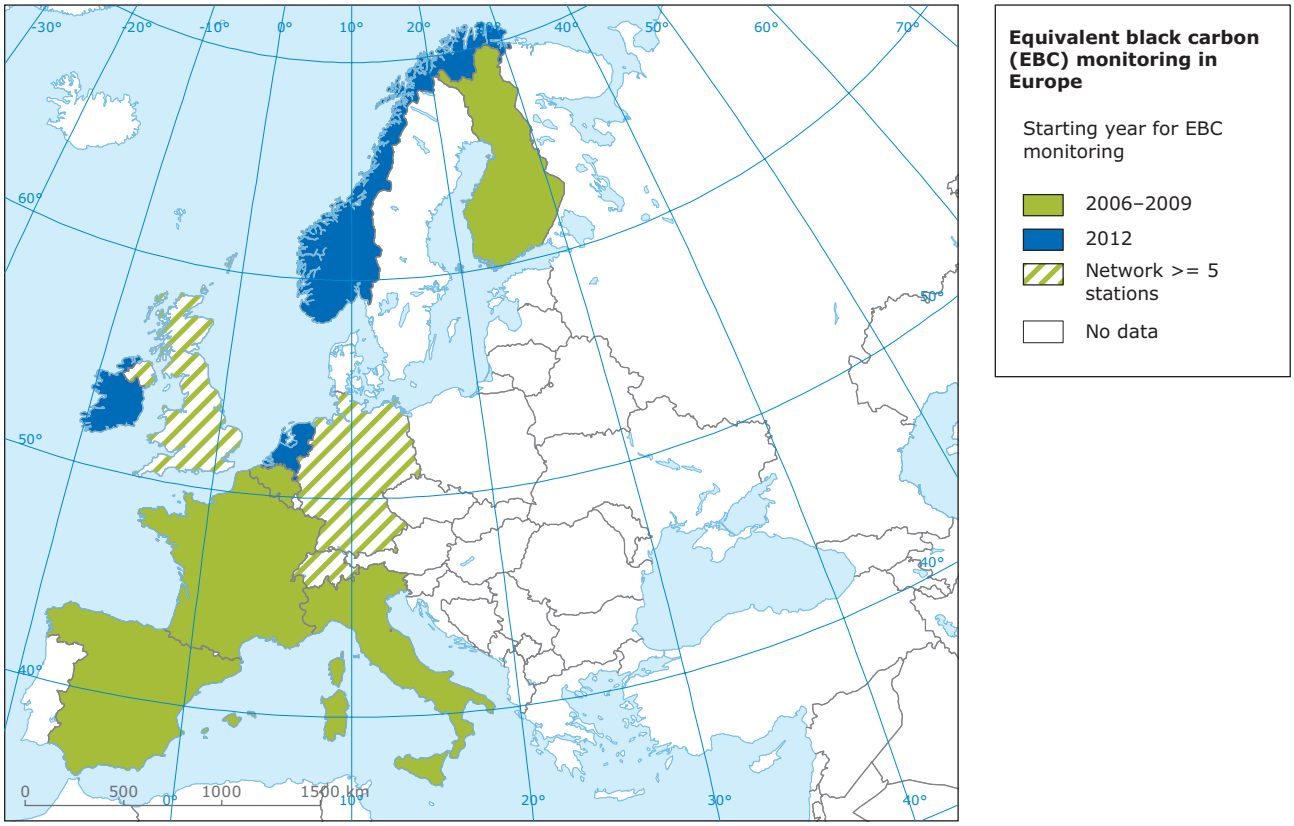
The European Union's Air Quality (AQ) Directive (EC, 2008) requires Member States to sample, analyse and report fine particulate matter ($PM_{2.5}$ ([2])) concentrations. For stations in rural areas, the Member States also have to report how much BC-related components the measured $PM_{2.5}$ contains. The report notes that this reporting has yet to be fully implemented (EC, 2011). Monitoring of BC in ambient air at urban background and traffic sites is not required by EU legislation. Overall the information on BC measurements is largely missing in the Europe-wide AirBase database ([3]) (EEA, 2013a). For 2011 AirBase includes such measurement data for stations located in Finland (two), Germany (eight), Ireland (two), and one each in Malta, the Netherlands and Poland.

([1]) $PM_{0.1}$ is particulate matter with an aerodynamic diameter of 0.1 micrometres or smaller.
([2]) $PM_{2.5}$ is particulate matter with an aerodynamic diameter of 2.5 micrometres or smaller.
([3]) AirBase is a European-wide air quality database which contains validated air quality monitoring information for more than 30 participating countries throughout Europe. AirBase is hosted by the European Environment Agency (EEA).

In view of the different methodologies used to monitor BC levels, this report also provides a summary of the current networks and applied practices for measurements, irrespective of whether they have been reported to the AirBase database or not. The current review shows that BC monitoring is part of several urban national air quality monitoring networks, mostly as a continuation of the 'black smoke' or 'soot' monitoring that had been put in place based on Member State regulations. For example Germany, Switzerland and the United Kingdom have long-standing and continued urban BC monitoring networks (Map ES.1).

The report notes that measurements at regional background monitoring sites of the European Monitoring and Evaluation Programme (EMEP) focus on climate change aspects, alongside possible impacts on health and ecosystems (Tørseth et al., 2012). Monitoring sites are also run in cooperation with the World Meteorological Organization's (WMO) Global Atmosphere Watch (GAW) programme. Another aim of the EMEP ([4]) monitoring sites is to harmonise approaches on measurement and efforts related to global climate change issues via the World Data Centre on Aerosols (GAW-WDCA, 2013). In addition, the monitoring database (EBAS) is addressed within the report as an example of a well-established monitoring network. BC-related mass concentration data from twenty-one stations in thirteen European countries over the period 2010–2012 were reported to the database. Twenty-two European stations reported absorption coefficient data for the same period (EBAS, 2013).

Map ES.1 Starting year for urban EBC monitoring in European countries



Note: A diagonally lined background indicates the presence of EBC networks, with at least five stations (arbitrary threshold set for the definition of 'network') monitoring EBC in a coordinated manner and with comparable instrumentation within the same country.

In the networks shown here, optical BC measurements are converted into EBC by correcting the online measurements with filter-based EC concentrations determined by thermo-optical analysis.

Source: EEA after Viana et al., 2012.

([4]) The European Monitoring and Evaluation Programme (EMEP) is a cooperative programme for the monitoring and evaluation of the long-range transmissions of air pollutants in Europe under the UNECE LRTAP Convention.

1 Backgound

A cornerstone of the European Union's (EU) air quality (AQ) legislation is the Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (AQ Directive; EC, 2008). The directive introduced a range of binding and non-binding objectives for particulate matter (PM) (see Table 1.1 and Box 1.1). The directive inter alia sets PM_{10} limit values for short-term (24-hour) and long-term (annual) exposure as well as for $PM_{2.5}$ long-term (annual) exposure. In addition the directive sets a standard for a $PM_{2.5}$ population average exposure indicator, both as an obligation for 2015 and a non-binding reduction target for 2020. Current air quality standards for PM in the EU and those recommended by WHO use the PM mass concentration as a metric, i.e. those standards do not consider the chemical composition of PM (see Box 1.1).

The AQ Directive requires that EU Member States monitor PM air pollution in a way that is representative for population exposure, addressing the urban environment and areas close to (road) traffic. Additionally, the directive sets a minimum requirement for rural background monitoring of PM. This includes also a chemical speciation of $PM_{2.5}$ mass, i.e. analysing inter alia the elemental carbon (EC) and organic carbon (OC) content of the particles.

1.1 What is black carbon?

BC — or carbonaceous compounds in general — are a constituent of PM dispersed in the air, and they are a major component of soot. BC's effects on human health are mainly derived from its association with PM (IGSD, 2010). It is important, though, to stress that carbonaceous components in the air in general are a highly variable mixture of different carbon-containing compounds with different material properties. BC is a useful qualitative description when referring to light-absorbing carbonaceous substances in atmospheric aerosol (Petzhold et al., 2013). A significant advantage of monitoring BC by absorption photometry is that it delivers results in real time with a high time resolution (e.g. hours), in contrast to measuring EC by a time-consuming analytical method where soot is sampled on a filter and then analysed (see for example Figure 1.1).

Table 1.1 Air quality limit and target values for PM_{10} and $PM_{2.5}$ as given in the Air Quality Directive

Size fraction	Averaging period	Value	Comments
PM_{10}, limit value	One day	50 µg/m³	Not to be exceeded on more than 35 days per year. To be met by 1 January 2005
PM_{10}, limit value	Calendar year	40 µg/m³	To be met by 1 January 2005
$PM_{2.5}$, target value	Calendar year	25 µg/m³	To be met by 1 January 2010
$PM_{2.5}$, limit value	Calendar year	25 µg/m³	To be met by 1 January 2015
$PM_{2.5}$, limit value ([a])	Calendar year	20 µg/m³	To be met by 1 January 2020
$PM_{2.5}$, exposure concentration obligation ([b])		20 µg/m³	2015
$PM_{2.5}$ exposure reduction target ([b])	0–20 % reduction in exposure (depending on the average exposure indicator in the reference year) to be met by 2020		

Note: ([a]) Indicative limit value (Stage 2) to be reviewed by the Commission in 2013 in the light of further information on health and environmental effects, technical feasibility and experience of the target value in Member States.

([b]) Based on a three-year average.

Source: EU, 2008c.

Box 1.1 Aerosols, particles, particulate matter, PM_{10} and $PM_{2.5}$

In atmospheric science, the word **aerosol** is normally used. An aerosol is a suspension of fine solid particles or liquid droplets in the air.

This report also employs the word **particle** when addressing **PM** in the air. The EU's air quality legislation covers two PM size fractions:

- **PM_{10}** is particulate matter with an aerodynamic diameter of 10 µm or less;
- **$PM_{2.5}$** is particulate matter with an aerodynamic diameter of 2.5 µm or less (also termed 'fine PM').

The PM mass concentration is defined as the mass of PM divided by volume of air, and is usually measured in micrograms PM per cubic metre (µg/m^3).

However, a conversion of the absorption coefficients into a concentration unit is crucial for assessing possible health effects of monitored BC. Particles are commonly measured in terms of the mass of PM per volume of air, and the measurement unit commonly used is micrograms per cubic metre (µg/m^3). Box 1.2 gives an overview of different definitions, based on the analytical methods used to study soot.

1.2 Possible health effects of black carbon

Black carbon is increasingly discussed in science and environmental policy areas as an example of an air pollutant that affects both human health and contributes to climate change (e.g. WHO, 2012; UNEP/WMO, 2011; Bond et al., 2013; IPCC, 2013).

Figure 1.1 Carbonaceous compounds on a filter used to determine particulate matter mass concentrations with thermal-optical techniques

Note: 'Charge' means that several filters were prepared for sampling under the same conditions (heated etc.), here on the 28 November 2011. The date in red indicates the day when the filter was sampled for 24 hours (00:00 to 23:59).

Source: Axel Eggert, Federal Environment Agency (UBA), Germany.

Box 1.2 Definition of 'black carbon'

Soot, the product of incomplete combustion of fuels, can be analysed by means of different methodologies. When its light-absorbing properties are measured, soot is referred to as BC. When its concentration is measured by thermal-optical techniques, soot is known as elemental carbon (EC).

Despite intensive efforts over the past decades, no widely accepted standard measurement method exists for the determination of BC or light-absorbing carbon. Real-time BC measurements can be performed using optical methods which measure the absorption of light through a filter collecting airborne particles. The most widely used online method is aethalometry ([5]). Off-line thermal-optical analysis ([6]) has been widely used for the determination of OC and EC on filter substrates.

Because of recent controversy within the air quality monitoring and aerosol research communities regarding the ambiguity of terms such as BC, black smoke (BS), EC, light-absorbing aerosols, etc., the following definitions were suggested by the Global Atmospheric Watch (GAW) Scientific Advisory Group (GAW/WMO, 2012; Buseck et al., 2012; Petzold et al., 2013).

Black carbon (BC) is a useful qualitative description when referring to light-absorbing carbonaceous substances in atmospheric aerosol; however, for quantitative applications the term requires clarification on how 'BC' has been derived.

Equivalent black carbon (EBC) should be used instead of BC for measurements derived from optical methods. The aerosol absorption coefficient is converted into EBC by correcting the online measurements with filter-based EC concentrations determined by thermo-optical analysis.

Equivalent refractory carbon should be used instead of BC for measurements derived from incandescence methods (e.g. laser-induced incandescence).

Elemental carbon (EC) should be used for measurements derived from thermo-optical methods.

Other terms used in the air quality communities follow:

Organic carbon (OC) is carbon bound in organic compounds which are directly emitted into the air, but also formed from organic precursor gases emitted from anthropogenic and natural sources (the latter relating primarily to terrestrial vegetation). Particles containing OC may also pose a significant risk to human health (Mauderly and Chow, 2008).

Non-mineral carbon (nmC) is defined as total carbon, excluding carbon of mineral origin, e.g. carbonates.

Measured BC levels are usually closely related to PM concentrations. Fine PM in particular ($PM_{2.5}$ and smaller) has been identified as the most harmful air pollutant in Europe, in terms of its adverse impacts on human health. Short-term and long-term exposure to PM is associated with a broad range of human health impacts, including respiratory and cardiovascular effects as well as premature death (WHO, 2013).

It has been suggested by health experts that particles from combustion sources with a certain chemical composition are more relevant to human health than are particles from other sources (e.g. WHO, 2012). This issue was also raised during the on-going review of the EU air policy (Box 1.3).

A recent review by the World Health Organization (WHO) concludes that BC may not be a major directly

([5]) The principle of the aethalometer is to measure the attenuation (ATN) of a beam of light transmitted through a filter, while the filter is continuously collecting an aerosol (PM) sample.

([6]) The properties of materials (e.g. PM) are studied as they change according to temperature. By using thermal-optical analysis, the (changing) optical property of the material is measured.

Box 1.3 EU's air policy review by 2013

In 2011, the European Commission established the need for a comprehensive review of the Thematic Strategy on Air Pollution (TSAP) (EC, 2005) which had been adopted by the EU's Member States in 2005. The TSAP includes interim objectives for health and the environment to be attained in 2020. However, these objectives fell short of the long-term targets set by the Sixth Environment Action Programme (6EAP). The 6EAP was adopted in 2002 to provide a strategic framework for EU action in the field of the environment up to 2012, prioritising action on climate change, nature and biodiversity, natural resources and waste, and the environment and health (EC, 2002).

In this context, the EC is presently (i.e. by 2013) undertaking a review of the EU air pollution policy: it addresses the strategy (TSAP), the air quality legislation, the National Emission Ceilings (NEC) Directive (Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants) (EC, 2001), and possible measures to further reduce air emissions from key sources and pollutants, including transport, domestic combustion, and agriculture.

toxic component of $PM_{2.5}$ (see Box 1.4). However, it may operate as a universal carrier of a wide variety of chemicals of varying toxicity to the lungs, the body's major defence cells, and possibly the systemic blood circulation (WHO, 2012). Further, in June 2012 the International Agency for Research on Cancer (IARC), an agency of WHO, declared diesel soot as a Class 1 carcinogen (WHO, 2012). WHO states that it would be advantageous to develop an additional AQ standard to address the effects of road vehicle PM emissions that are not well captured by $PM_{2.5}$ mass. Such a standard, named a 'guideline' in WHO nomenclature, should build on the work carried out on BC and/or EC (WHO, 2012) and evidence on other pollutants in vehicle emissions. BC is a proxy for traffic exhaust emissions, while other non-exhaust sources such as tyre and brake wear also contribute to $PM_{2.5}$ pollution.

Box 1.4 Health effects of black carbon — WHO review

In 2012, WHO launched a systematic review of the accumulated evidence on the health effects of BC by addressing the following specific questions (WHO, 2012):

- What metrics have been used to estimate the health effects of exposure to BC?
- What are the effects of BC exposure observed in epidemiological studies (health outcomes, exposure/response function)?
- What are the effects of BC in the human-controlled exposure experiments? Are they different qualitatively (for example, different health outcomes) and/or quantitatively from the effects of $PM_{2.5}$ mass concentration and other measured components of $PM_{2.5}$?
- What are the mechanisms of the effects of BC indicated by toxicological studies?

WHO's conclusions are as follows:

1. Short-term epidemiological studies provide sufficient evidence of an association of daily variations in BC concentrations with short-term changes in health (all-cause and cardiovascular mortality, and cardiopulmonary hospital admissions).
2. Cohort studies provide sufficient evidence of associations of all-cause and cardiopulmonary mortality with long-term average BC exposure.
3. Studies of short-term health effects suggest that BC is a better indicator of harmful particulate substances from combustion sources (especially traffic) than undifferentiated PM mass. However, the evidence for the relative strength of association from long-term studies is inconclusive.

Within the framework of the current EU air policy review, an 18-month project entitled the 'Review of evidence on health aspects of air pollution' (REVIHAAP) was finalised in April 2013 (WHO, 2013; Box 1.5). The health impacts review was jointly financed by WHO and the European Commission and is a response to 24 key policy questions, posted by the EC to support policymakers.

The main overall statement within the framework of this review is as follows:

- The scientific conclusions of the 2005 WHO Guidelines on the evidence for a causal link between $PM_{2.5}$ and adverse health outcomes in humans have been confirmed and strengthened and, thus, clearly remain valid.

Concerning the chemical composition of PM, the conclusion is as follows:

- Some components may be more harmful than others. BC, secondary organic aerosols (SOAs) and secondary inorganic aerosols (SIAs) ([7]) are named as metrics for possible health effects of mixtures of pollutants from a variety of sources. Secondary aerosol is PM formed in the atmosphere from precursor substances.

1.3 Black carbon contributes to the warming of our atmosphere

BC contributes to poor air quality, but it also scatters and absorbs incoming solar radiation. BC has recently emerged as a major contributor to so-called 'short-lived climate forcing' (SLCF), i.e. to climate change. BC acts over a much shorter period than classic greenhouse gases such as carbon dioxide (CO_2), because its lifetime in the atmosphere is shorter than that of most GHGs ([8]). Some scientists suggest that BC is likely to be the second most important contributor to global warming, after CO_2 (Ramanathan and Carmichael, 2008; UNEP/WMO, 2011; Bond et al., 2013). BC can indirectly affect regional cloud formation and precipitation patterns and have warming, but also (indirect) cooling effects. Scientists have a high degree of confidence that the net effect of BC is warming our atmosphere (e.g. the scientific assessment by Bond et al., 2013). BC warms the Earth by absorbing heat in the atmosphere and by reducing albedo, the ability to reflect sunlight, when deposited on snow and ice (Masiello, 2004). When BC is deposited on snow and ice, it absorbs sunlight (e.g. Stohl et al., 2013). This process warms both the air above and the snow and ice below, and thus accelerates melting. Through changes in the radiative energy balance of the

Box 1.5 WHO recommendations in relation to the EU's air policy review in 2013

The actions recommended as part of WHO REVIHAAP project (WHO, 2013) in relation to the EU's Air Policy Review are as follows:

1. It would be advantageous to develop an additional air quality guideline to capture the effects of road vehicle PM emissions not well captured by $PM_{2.5}$, building on the work on BC and/or EC (WHO, 2012) and evidence on other pollutants in vehicle emissions.
2. Besides the public health and/or air quality concerns, BC is also an important short-lived climate forcer (SLCF) (see also Section 1.3), which contributes to the warming of the Earth's atmosphere. Reducing BC emissions and concentrations is beneficial for population health and, for sources with high BC/OC ratios, helps to mitigate short-term climate change.
3. A reduction in exposure to $PM_{2.5}$ containing BC and other combustion-related PM material for which BC is an indirect indicator should lead to a reduction in the health effects associated with PM.
4. $PM_{2.5}$ should continue to be used as the primary metric in quantifying human exposure to PM and the health effects of such exposure, and for predicting the benefits of exposure reduction measures.
5. The use of BC as an additional indicator may be useful in evaluating local action aimed at reducing the population's exposure to combustion PM (for example, from motorised traffic).

([7]) Sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) are major contributors to $PM_{2.5}$ in Europe's air. They can be transferred into ammonium sulphate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3), both aerosols without any organic compounds included.

([8]) An exception is methane (CH_4), a gas which belongs also to the short-lived climate forcer group.

climate system, BC can cause temperature changes that produce a variety of impacts on humans, plants and ecosystems.

Scientists are conducting integrated and multidisciplinary research to improve our understanding and determine more clearly the role of BC in air pollution, concerning its effects on human health, in relation to climate change processes, and how we might reduce its emissions and impacts. There is already a wealth of information on climate change effects of BC available, for example, as reviewed in the extensive study by Bond et al. (2013).

1.4 Where does black carbon come from?

Black carbon is formed by the incomplete combustion of fossil fuels, biomass and biofuels. Unlike some pollutants which are formed in the atmosphere from precursors, BC is directly emitted into the air. Major sources include:

- mobile sources, particularly diesel-driven road vehicles, non-road mobile machinery, (e.g. machines used in forestry and agriculture, locomotives and rail cars) and ships;
- residential heating in small- and medium-scale combustion facilities, particularly burning of biomass such as the fossil fuel coal and wood;
- open biomass burning, including forest fires and burning of agricultural waste.

BC is directly emitted into the air from these sources, not formed in the atmosphere from precursor substances.

The amounts of BC released can be estimated by emission inventories. The official *EMEP* ([9])*/EEA air pollutant emission inventory guidebook — 2013* provides guidance to countries on how to compile such inventories. Following a review of the respective methodologies addressing BC, updated emission factors and an updated version of the whole guidebook was published earlier this year (EEA, 2013b). An emission factor is a measure of the average amount of a specific pollutant discharged into the atmosphere, in case of BC, by combustion processes. For example, in order to express BC emissions in kilotonnes (kt) per energy unit, e.g. petajoule (PJ) of fuel burnt, the percentage of BC in a certain amount of $PM_{2.5}$ emitted to the air is estimated per source and fuel. This is also the approach used in the updated guidebook (EEA, 2013). There is some uncertainty in this means of estimating BC emissions, but the advantage is that the BC fraction is consistent with the $PM_{2.5}$ fraction. Another approach to derive 'BC' emission factors directly is the measurement of EC in exhaust, i.e. at the source.

Reliable emission inventories, also for BC, are an indispensable input to air quality models such as chemical transport models (CTMs), used for assessing present and future air quality situations. The International Institute for Applied Systems Analysis (IIASA) uses the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model to estimate BC emissions (GAINS, 2013). The GAINS emission factor database is updated frequently. IIASA colleagues have contributed to several important studies cited in this report (e.g. those of UNEP/WMO, 2011; and Bond et al., 2013).

1.5 Monitoring of black carbon as a proxy for traffic combustion exhaust

It is well known that road traffic is usually the main pollutant source in European urban environments (Colvile et al., 2001; Ruellan et al., 2001; Harrison et al., 2008). Black carbon levels vary proportionally with those of traffic-related gaseous pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2) and nitric oxide (NO). Due to this high correlation one might suppose that monitoring the levels of these gaseous pollutants would be enough to extrapolate exposure to traffic-derived equivalent balck carbon (EBC) levels (see Box 1.2). However, the EBC/CO, EBC/NO_2 and EBC/NO ratios vary widely among European cities, as a function of distance to traffic emissions, vehicle fleet composition and the influence of other emission sources such as biomass burning. Thus, some experts from the scientific AQ community suggest that for traffic-related particulate pollution, new approaches should be introduced in future urban monitoring strategies (Reche et al., 2011; for details see also Annex 1). They recommend that the focus of networks required by the EU's AQ Directive should be broad enough to facilitate the assessment of population-based exposure appropriate for health effect studies and source apportionment of air pollutants (AirMonTech, 2013a).

([9]) European Monitoring and Evaluation Programme (EMEP): Cooperative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe under the UNECE LRTAP Convention.

1.6 Actions to reduce particulate matter and black carbon emissions

Many countries have existing national laws and regulations to mitigate PM emissions, including the indirect control of BC emissions. Some examples are as follows:

- requiring regular vehicle emissions tests, retirement, or retrofitting (e.g. adding particulate traps, including penalties for failing to meet air quality emissions standards, and heightened penalties for on-the-road 'super-emitting' vehicles);
- banning or regulating slash-and-burn clearing of forests and burning of agricultural waste;
- requiring shore-based power/electrification of ships at port, regulating idling at terminals, and mandating fuel standards for ships seeking to dock at port;
- banning or regulating the sale of certain fuels and/or requiring the use of cleaner fuels for certain uses;
- regulating and/or limiting biomass burning in urban and non-urban areas;
- requiring permits to operate industrial, power generating, and oil refining facilities, and periodic permit renewal and/or modification of equipment;
- requiring filtering technology and high-temperature combustion (e.g. super-critical coal) for existing power generation plants, and regulating annual emissions from power generation plants.

Scientific evidence and new analyses demonstrate that control of BC particles through rapid implementation of proven emission reduction measures would have immediate and multiple benefits for human well-being (UNEP/WMO, 2011). For the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007; IPCC, 2013), focus on the immediate reduction of BC is a high priority.

The International Network for Environmental Compliance and Enforcement (INECE) issued a Climate Compliance Alert on BC in 2008 which cited reduction of BC as a cost-effective way to reduce a major cause of global warming (INECE, 2008).

In May 2012, the Parties to the Convention on Long-Range Transboundary Air Pollution (UNECE, 2012) approved new emission reduction commitments for main air pollutants by 2020 (amended Gothenburg Protocol of 1999). The Parties have broken new ground in international air pollution policy by specifically including the SLCF BC as a component of PM. Once the protocol enters into force, the amendment requires the reporting of national inventories of BC emissions, where these are available. However, it requests each party to 'give priority … to emission reduction measures which also significantly reduce BC in order to provide benefits for health, environment and to help mitigation of near-term climate change'. Thus, there is no real obligation to develop a BC emission inventory.

The Arctic Council ([10]) Task Force (2011) has recommended that Arctic Council nations individually and collectively work to implement some early actions to reduce BC, such as these (see Box 1.6).

The BC issue has also been considered in the current review of EU air policy, primarily by focusing on primary PM emission abatement measures, particularly:

- end-of-pipe technologies, i.e. diesel particle filters for road and off-road vehicles or machinery;
- technologies allowing the reduction of emissions from medium- and small-scale combustion facilities, including domestic stoves (e.g. pellet stoves and boilers; product standards);
- better implementation of the ban of open field burning of agricultural waste; such a ban has already been introduced in many EU Member States.

([10]) The Ottawa Declaration of 1996 formally established the Arctic Council as a high level intergovernmental forum to provide a means for promoting cooperation, coordination and interaction among the Arctic States, with the involvement of the Arctic Indigenous communities and other Arctic inhabitants on common Arctic issues, in particular issues of sustainable development and environmental protection in the Arctic.

Box 1.6 Arctic Council Task Force on short-lived climate forcers: progress report and recommendations for ministers

- Arctic Council nations continue their efforts to estimate and develop BC emission inventories and voluntarily and periodically share these inventories.
- Arctic Council nations consider specific mitigation options for the transportation, residential, open burning, and shipping sectors, and that they periodically share information on progress in reducing their BC emissions.
- Measures to reduce BC from transportation, especially diesel powered, could include more retrofitting of older vehicles and equipment; retirement of old engines, vehicles, and equipment; and enhancing or expanding current controls to the extent that PM standards are not in place.
- Similar retrofit retirement or replacement measures could be applied to reduce BC emissions from stationary engines and equipment.
- Measures to reduce BC from residential heating could include standards, change-out programmes, technologies for more efficient combustion, and retrofits addressing wood stoves, boilers, and fireplaces.
- To reduce BC from agricultural burning, prescribed forest burning, and wildfires, measures could include demonstration projects for management alternatives to burning, prevention of accidental fires, and greater resources devoted to fire monitoring and prevention. When controlled burning is necessary, such as when fire plays a critical and natural ecological role, management techniques may help reduce emissions or limit their impacts.
- Measures to reduce BC from marine shipping in and near the Arctic could include Council-wide adoption of voluntary technical and non-technical measures, adoption of the proposed amendment of the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI to establish an Energy Efficiency Design Index, and collaboration with International Maritime Organization (IMO) on certain other actions.
- For gas flaring, it is too soon to identify specific BC mitigation options, but increased research and better emission inventories are recommended to improve understanding of the significance of this source.

Measures to mitigate BC will probably also reduce OC emissions, and this leads to some uncertainties concerning the possible climate change impacts (Szidat et al., 2009; UNEP/WMO, 2011). OC reflects sunlight and contributes to a reduction of sunlight at the ground, i.e. it has a cooling effect. This uncertainty is particularly great for mitigation options that focus on biomass burning, and less so for those that focus on fossil fuel burning, here diesel in particular. Burning of fossil fuels emits significantly less OC than the burning of biomass.

In summary, reducing BC emissions can be beneficial for human health, particularly in urban environments. For sources with high BC/OC ratios, such efforts also help to mitigate short-term climate change. Pursuing the reduction of short-lived BC emissions can be seen as a quick gain, while carbon policies take longer to have an effect. Focusing on SLCFs and — in parallel — fundamental measures addressing CO_2 and other GHG emissions are complementary pathways when combating climate change.

1.7 Scope of the remainder of this report

The remaining technical part of this report summarises the current status of BC monitoring in ambient air in Europe. The report is an overview of available measurement techniques applied in monitoring networks. It also addresses associated technical issues and current data reporting practices.

The technical core of this report ([11]) focuses on measurement networks monitoring BC (EBC, EC, absorption coefficients) in ambient air in Europe that do not necessarily report to AirBase. It gives a summary of BC measurement approaches and methodologies used in urban and regional monitoring networks in order to address health and climate change aspects. It is beyond the scope of this study to compare the actual concentration levels monitored at stations in the different countries as well as to analyse the costs and benefits of setting up black carbon monitoring stations or networks.

([11]) This EEA technical report is partly based on a technical paper prepared by EEA's European Topic Centre for Air Pollution and Climate Change Mitigation (ETC/ACM) with the title Particle number (PNC) and black carbon (BC) in European urban air quality networks (Viana et al., 2012).

2 Black carbon measurement stations in Europe: instrumentation

BC is under discussion as a potential new metric to be introduced into air quality monitoring networks. Indeed, one of the conclusions presented by experts of the AirMonTech consortium, a Coordination and Support Action within the Seventh Framework Programme (FP7) for EU research, was that BC 'is a strong candidate for future regulatory measurements, as a proxy for combustion products. AirMonTech recommends that it should be reported both as an optical absorption coefficient and as a scaled concentration designed to be equivalent to elemental carbon (EC)'.

This chapter sketches the recent and current deployment of BC monitoring networks in Europe. It is important to stress that the focus here is on urban measurement stations. The overview is based on the feedback from European countries, bibliographical data and knowledge of partners involved in the EEA's European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM). The types of sites, operated instruments, data delivery and quality checks were reviewed. On-going projects supporting developments in BC monitoring were also taken into account. Detailed descriptions of the country information received can be found in the Appendix of the ETC/ACM technical paper on which this summary is based ([12]) (Viana et al., 2013).

2.1 Instrumentation and black carbon measurement technologies

As explained above, is has been recommended that BC should be monitored because of its possible effects on both health and climatic radiative forcing (AirMonTech, 2013a). This chapter provides an overview of the scientific and technical data to assess this possibility. The short analysis is mainly based on the experience of experts working in various European monitoring networks. The technical viability of developing permanent BC measurements in urban air quality monitoring networks depends on:

- how easy it is to install and maintain the measurement devices in already existing monitoring sites or to deploy them in new non-instrumented locations;
- how easy it is to collect, transmit, store and validate the data;
- the capability to produce long time-series of measurement data;
- the possibility of implementing and following a quality assurance/quality control (QA/QC) system and ensuring comparability between measurements taken at different locations.

For the actual measurement of BC, it is recommended to dry the sampled air in front of the instrument in order to minimise the influence of water on light absorption measurements and on particle size distribution (see also Box 2.1). The sampling system may include a $PM_{2.5}$ (or $PM_{1.0}$) inlet to reduce contamination by larger particles (particularly important for particle number concentration monitors).

According to network operators and researchers, BC monitors, particularly the Multi-Angle Absorption Photometer (MAAP), and the aethalometer are small (the size of common gas monitors), robust and easy to use. Main maintenance operations consist of flow rates check/calibration, zero tests (using filtered air), filter taper replacement (that might be necessary every 2 weeks in case of heavy pollution episodes), and optical chamber cleaning. Calibration in the usual sense, however, is more difficult, as no reference material is currently available.

([12]) 'Review of the presence of BC monitoring instrumentation in current air quality networks in Europe', pp. 68–101 of the ETC/ACM Technical Paper.

The MAAP and the aethalometer are both based on the measurement of the optical properties of PM collected on a filter tape, over a short period (typically 5 minutes). All filter-based photometers suffer from non-linearity due to the loading of the filter, which reduces the sensitivity of the measurements. The aethalometer relies on measurements of transmission of light through the filter that needs to be post-processed to obtain ambient aerosol absorption coefficients (B_{abs}, in m^{-1} unit) and then equivalent black carbon (EBC) concentrations (Weingartner et al., 2003; Lack et al., 2008). The MAAP combines the light reflection at multiple angles and light transmission measurements. The MAAP measurements also need to be post-processed to obtain estimates of the absorption coefficient (B_{abs}; see Box 2.2) and EBC (Hyvärinen et al., 2012). Considerable efforts have been recently dedicated to the development of methodologies for aethalometer sampling artefact corrections (e.g. Collaud Cohen et al., 2010). Multi-wavelength light absorption measurements are not currently available using the MAAP. Such measurements, performed by the aethalometer models AE33, AE31, AE42-7, allow for the discrimination of light absorption by other species than BC, such as mineral dust (Fialho et al., 2005; Kirchstetter et al., 2004; Andreae and Gelencsèr, 2006), and for the apportionment of light-absorbing aerosol sources (Arnott et al., 2005; Sandradewi et al., 2008; Favez et al., 2010).

2.2 Processing of black carbon monitoring data

Data transmission and validation processes are relatively straightforward for most instruments, once the appropriate data format (known as print format) is defined. Apart from the necessary corrections of sampling artefacts allowing for a consistent retrieval of absorption coefficients, a significant issue for optical BC measurements is the determination of the conversion factor of actually absorbed material (B_{ab}) to equivalent black carbon (EBC) mass concentrations (see Box 1.2).

The agreement between absorption coefficient measurements and the concentrations of EC measured independently depends on the wavelength used for optical measurements and the origin/ageing of light-absorbing particles. BC absorbs efficiently at all wavelengths, but the red and near-infrared wavelengths are preferred, since in this range, the interference from brown carbon ([13]) or mineral dust is minimal (see also the debate summarised in Box 2.2).

From the point of view of urban network operators, the conversion of absorption to EBC is preferred, in order to obtain a mass-based metric and to ensure comparability across stations and networks. As for the MAE (Box 2.2) to be used for this conversion,

Box 2.1 European Committee for Standardisation (CEN)

According to the AQ Directive (EC, 2008), the chemical composition of $PM_{2.5}$ shall be analysed at regional background stations, including among certain inorganic compounds, EC and OC.

Concerning the standardisation of these measurements, the European Committee for Standardisation 'Air Quality' (CEN/TC 264) established a working group (WG 35), which was recently given the mandate to validate methodologies suggested by experts (CEN/TR, 2011) and to recommend a standard method to analyse EC and OC in $PM_{2.5}$ mass. The group of experts will start its work at the end of 2013.

A field test will be carried out at rural and urban backgrounds as well as traffic sites, to determine the most suitable thermal-optical protocol among the three preselected optical devices. BC measurements will be tested alongside the thermo-optical methods; however, these investigations will not be considered as equivalency tests.

It is also worth mentioning that an ad hoc working group (WG 32) of the European Committee for Standardisation (CEN/TC 264) 'Air Quality' is currently working on technical specifications dedicated to deriving standardised methodologies for the monitoring of ultrafine particle size distribution and number concentration (for details, see Viana et al., 2012).

([13]) Light-absorbing organic material is also called 'brown carbon'. Brown carbon is often a by-product of biomass burning, but its exact formation mechanism is poorly understood. Rather than just being emitted directly from a source such as a fire, brown carbon can form through complex reactions in airborne atmospheric particles.

it appears that the variability of MAE values in urban areas is relatively low, with values being rather stable compared with rural areas where this variability is higher. Thus, in urban areas, applying locally determined MAE values for conversion of absorption measurements to EBC would imply lower degrees of uncertainty, while maximising comparability between results. In all cases, reporting of BC data should always also report the MAE value applied.

For a reliable estimation of EBC concentrations, it is thus recommended to perform B_{abs} measurements at near-infrared regions. If this is not possible, it must be checked if the influence of light-absorbing organic or mineral dust aerosols can assumed to be negligible. If this is the case, the BC concentration could then be calculated as the ratio between B_{abs} and an appropriate MAE value obtained empirically or from the literature (or, for the MAAP instrument, using the one proposed by default within device software: 6.6 m^2/g at 670 nm).

Further data treatments of multi-wavelength light absorption measurements can be used to apportion combustion and non-combustion carbonaceous material (CM; see Box 2.3).

The development of receptor models based on multi-wavelength light absorption is still in its early stage, and is subject to continuous improvements. In particular, different methodologies are currently proposed to resolve the equation shown in Box 2.3, using, for instance, universal, on the one hand, or site-specific, on the other hand, C_1 and C_2 constants. It should also be kept in mind that these methodologies are very sensitive to initial conditions, leading to high uncertainties. This is the reason why

Box 2.2 Optical black carbon measurements: conversion into equivalent black carbon (EBC) mass concentrations

The relevant conversion factor is the so-called mass absorption efficiency (MAE); the unit is square metres per gram, m^2/g), a function of the wavelength (λ) used for the measurement and of the mixing state of BC with other species such as water, organic coating or inorganic salts (Bond and Bergström, 2006). Indeed, light absorption by aerosols can be parameterised as proportional to $\lambda^{-\alpha}$, with α being referred to as the Ångstrom absorption exponent, and internal mixing of BC with light-scattering aerosol species may lead to an increase of MAE compared to pure BC. The latter is commonly expected to exhibit an Ångstrom absorption exponent close to 1 (e.g. 1.0 ± 0.1), and an MAE of about 7.5 m^2/g at 550 nm, according to Bond and Bergstrom (2006).

A growing number of studies have indicated good correlations between EC and B_{abs} measured at near-infrared regions, with a regression slope of about 5 m^2/g, in good agreement with α and MAE values proposed by Bond and Bergstrom (2006). However, it must be noted that MAE values of up to 15 m^2/g have been obtained in regional background areas in southern European regions. Further, the relationship between absorption and thermal-optical measurements will necessarily be influenced by the uncertainties of each of these methods, which are frequently relatively high.

Several papers in the literature focus on the correction algorithms to be applied to optical measurements of soot concentrations (Petzold et al., 2005; Collaud Coen et al., 2010; Müller et al., 2011; Hyvärinen et al., 2012), and a number of respective studies to the measurement of BC (Schmid et al., 2001; Cavalli et al., 2011; Maenhaut et al., 2012; Bond et al., 2013). The authors refer to the differences in thermo-optical results as a function of the methods and temperature protocols used. The use of different temperature protocols (EUSAAR, IMPROVE, NIOSH ([14]) etc.) will necessarily result in different conversion factors, unless a standard protocol is defined (work currently in progress by CEN WG 35 — see above).

A topic of current debate in the scientific community is whether conversions of absorption measurements to equivalent BC mass should be performed and, if so, whether this should be done with a constant MAE factor (e.g. the default 6.6 m^2/g from the MAAP instrument) or with locally determined factors (Reche et al., 2011; Wang et al., 2013).

([14]) The European Supersites for Atmospheric Aerosol Research (EUSAAR), Interagency Monitoring of Protected Visual Environments (IMPROVE) and National Institute of Occupational Safety and Health (NIOSH) protocols are the most widely used thermal-optical protocols in the atmospheric science community (see, for instance, EUSAAR, 2011).

Box 2.3 Source apportionment of combustion and non-combustion carbonaceous material

Apportioning combustion and non-combustion CM is possible by using the following equation, for instance:

$$CM_{total} = CM_{ff} + CM_{wb} + CM_{other} = C_1 \times b_{abs,ff,950nm} + C_2 \times b_{abs.wb.470nm} + C_3$$

where $b_{abs, ff, 950nm}$ represents the absorption coefficient of CM_{ff} at 950nm, $b_{abs, wb, 470nm}$ represents the absorption coefficient of CM_{wb} at 470 nm, C_1 and C_2 relate the light absorption to the particulate mass of both sources, and C_3 corresponds to the amount of non-combustion OA (assumed here to have a negligible light absorption capacity). It should be noted that here CM_{ff} comprises traffic emissions as well as carbonaceous aerosols originating from fuel oil and natural gas combustion, but excludes coal-burning organic aerosol. Indeed, the latter was shown to significantly absorb light at near UV wavelengths (e.g. Yang et al., 2009) and may thus interfere with $b_{abs, wb, 470nm}$. Another limitation of this approach might be the presence of mineral dust particles.

users usually perform sensitivity tests with wide ranges for these initial conditions (see for instance, Favez et al., 2010; and Sciare et al., 2011), and they suggest that results of these sensitivity tests should be considered when assessing the total uncertainties of the model outputs.

2.3 Monitoring of black carbon over time, and comparability of measurements

As a condition for their deployment in monitoring networks for health impact and trend analyses, the implemented measuring equipment should be able to produce long time-series of BC data with high temporal resolution. High temporal resolution is achievable with all instruments mentioned above: BC measurements are usually delivered with a frequency of approximately 1 to 10 minutes. In practice, the constitution of continuous series of validated data could be more sensitive; it is contingent on maintenance, data losses and data invalidation. BC time-series usually display high data captures (> 95 % is not uncommon).

Comparability of measurements taken at different locations is related to:

- the nature of the measurements, i.e. do all the instruments measure the same variable?
- the variability between different instruments which can be evaluated through local, national, or European scale comparison exercises;
- the uncertainty of the measurements.

There is limited literature on the comparison of optical measurement methods for BC in urban air quality monitoring networks; one example is summarised in Box 2.4.

Extensive inter-comparison exercises are regularly carried out in the framework of the ACTRIS (2013) project, and were carried out in the finalised EUSAAR (2011) project. Results from these inter-comparisons can be found in Müller et al. (2011).

Finally, it should be noted that optical BC measurements are commonly compared to EC, which is determined using thermal or thermal-optical protocols. Such comparison usually indicates a satisfactory correlation coefficient but slopes relatively far from 1. This has to be related to the choice of the MAE used to convert absorption measurements to EBC estimates. Various operational networks (e.g. in France, Slovenia, Spain and Switzerland) decided to apply site-specific MAE calculated from the direct comparison between optical absorption measurements (in the unit per metre, m^{-1}) and thermal-optical EC measurements at that site to obtain EBC estimates.

As stated above, no consensus has been reached to date regarding the use of MAE coefficients to convert absorption into EBC mass measurements (or the thermal protocol to be used to determine EC) (Genberg et al., 2013). However, in urban areas and based on experiences within different networks, the use of locally determined or common MAE values is always preferred in order to obtain a mass-based metric.

Box 2.4 Example for a comparison of optical measurement methods for equivalent black carbon

For instance, during three weeks in summer 2002, online BC measurements with the MAAP and an aethalometer (Magee Scientific AE-9) were performed under urban background conditions in downtown Vienna (Austria), a city heavily impacted by diesel emissions (Hitzenberger et al., 2006). The average values of BC obtained with both methods agreed within their standard deviations. On average, the absorption coefficient estimated from the aethalometer attenuation data after wavelength-correction (b_{a_AET}) is in close agreement with the absorption coefficient directly measured by the MAAP at l = 670 nm (b_{a_MAAP}). For 24-hour-averaged data, the ratio b_{a_AET}/ b_{a_MAAP} is 1.00 ± 0.12. For 1-hour-averaged data it is 1.02 ± 0.30. However, considering experience from various countries, the correction of the shadowing effect affecting raw aethalometer measurements remains a challenging issue in the framework of such comparison exercises. Moreover, as some non-BC particles (e.g. iron oxides or humic-like substances) may absorb light in the visible region, intercomparisons between MAAP and aethalometer devices operating at different wavelengths might be influenced by the presence of such non-BC compounds and/or by the cut-off size of the sampling systems.

3 Black carbon monitoring networks

Data on the chemical composition of PM is generally not available in the data sets available in the Europe-wide database AirBase. Reporting to AirBase is based on legal reporting obligations at EU level. The submitted information is also used as a basis to check the attainment of legally binding AQ standards in the EU Member States. Concerning the carbonaceous composition of fine particulate matter ($PM_{2.5}$), the Air Quality Directive only requires that elemental carbon (EC) and organic carbon (OC) be analysed in samples taken at rural background stations and that the results be reported by EU Member States to AirBase (EC, 2008). However, this reporting is yet to be fully implemented (EC, 2012). Monitoring of BC, EC and OC levels measured in ambient air at urban background and traffic sites is not addressed by EU regulation. For 2011, AirBase includes EC measurement data for eight rural background stations, four of them are located in Germany, two in Ireland, and one each in Malta, the Netherlands and Poland. Four stations reporting EC data for 2011 are classified as urban traffic stations, and they are all located in Germany. Monitoring results of two Finish stations are labelled to be BC, and not EC measurements.

However, the measurement of (E)BC has been implemented in several European air quality monitoring networks, in urban networks mostly as a continuation of the older 'black smoke' or soot measurements which had partly been put in place based on national-level regulations (see Map 3.1).

3.1 Overview of existing urban measurement sites and networks

The most comprehensive urban network in Europe is probably the German Ultrafine Aerosol Network (GUAN) with recent extensions in Belgium, which promotes co-located measurements of at least EBC and particle number concentration (particularly needed for monitoring ultrafine particles, $PM_{0.1}$). Moreover, the United Kingdom has long experience in 'black smoke'/EBC concentration monitoring at national level. Examples of more recent developments of EBC monitoring activities by national or local monitoring networks in European countries were also reported within the framework of this study, along with more research-oriented long-term observatories. The presence of measurement instrumentation is summarised with detailed data in Table A2.1 in Annex 2.

The preliminary inventory presented here focuses on the introduction of fixed EBC measurements in European national or local networks (Annex 2), noting the following specificities:

- The inventory does not include punctual monitoring campaigns. However, it encompasses monitoring strategies that combine fixed measurements at some sites and semi-fixed measurements (e.g. every two years) at some others.
- The inventory focuses on EBC monitoring (not on quantification through EC measurements).
- Depending on available information, the monitoring sites and implemented instruments are not described in the same detail.

As mentioned above, two filter absorption photometer instruments are mainly used internationally: the MAAP and the aethalometer. Based on experiences in European countries, useful measurement instrumentations would be the 'multi-wavelength MAAP' and/or aethalometer allowing for consistent online sampling artefact corrections. A respective request has already been made by European AQ experts to manufacturers. The new Aethalometer AE33 now features online compensation of the loading effects.

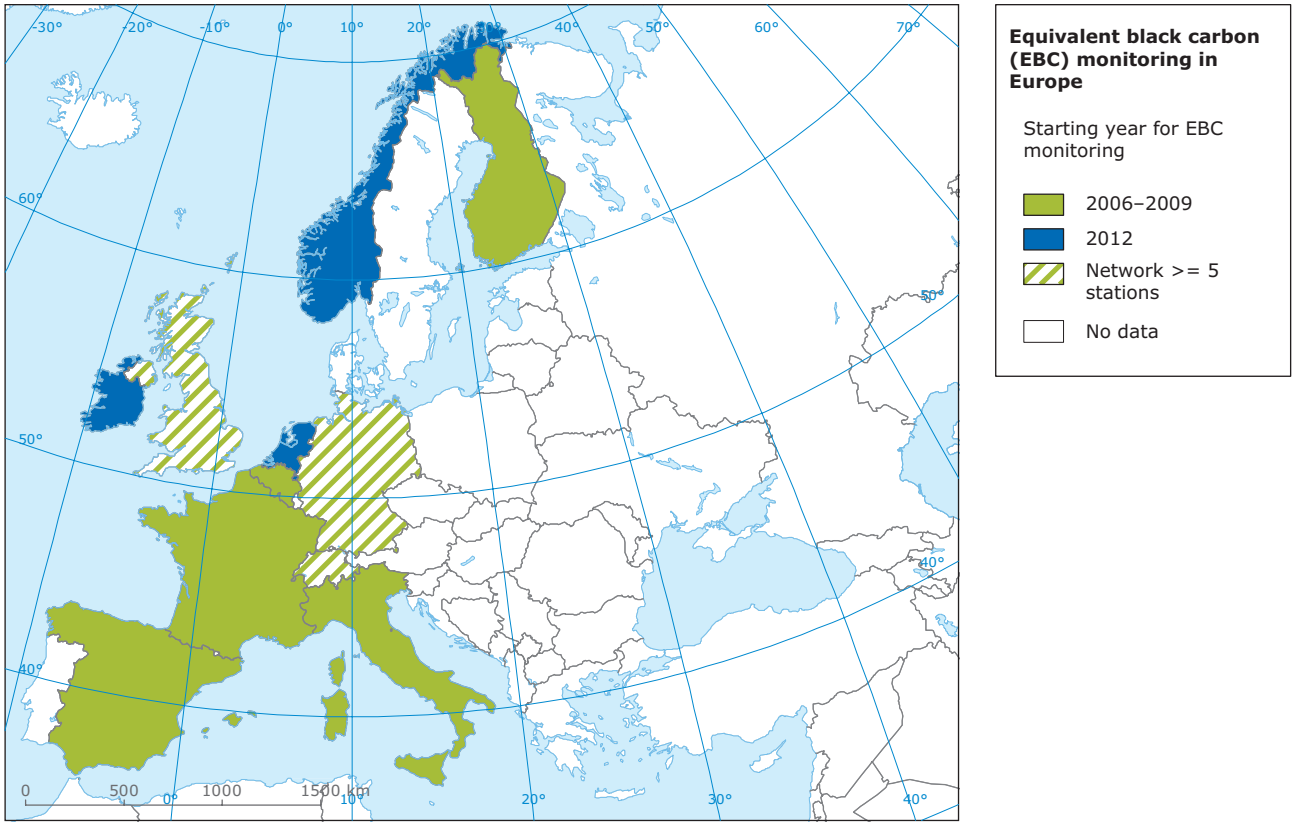
More details on basic measurement principles of the aethalometer and MAAP instruments can be found respectively in Hansen et al. (1982 and 1984) and Petzold et al. (2005 and 2013). Other filter-based instrument types are seldom used within European networks. In Norway, the EMEP monitoring site is equipped with a Particle Soot Absorption Photometer (PSAP), which registers the attenuation

change of a light beam over a filter while the filter is loaded with an aerosol sample. The instrument currently has one wavelength, but is due to be upgraded to a three-wavelength instrument. The absorption coefficient can be converted to an EBC concentration by assuming a mass absorption cross-section (Genberg et al., 2013).

For PM_{10} and $PM_{2.5}$, regulated under the EU's AQ Directive and measured as mass concentrations, no automated technologies ([15]) are available to date that are considered suitable as reference methods to replace the current manual reference methods, without this leading to a significant change to the metrics (see, for example, discussions within the Aquila ([16]) network (Aquila, 2013)). Absorption coefficients can be measured in real time by aethalometry and absorption photometry, and those coefficients may be calibrated in situ using thermal-optical methods to obtain equivalent EBC concentrations. In addition, such measurements may be combined with online non-mineral carbon (nmC) monitoring, to yield full information on the OC and EC fractions (see also Box 3.1). However, online nmC monitoring techniques are not currently available, even though these kinds of data would be of great value in urban air quality networks. This recommendation has also been made by the AirMonTech project (AirMonTech, 2013a and 2013b).

To investigate aerosol light absorption, sophisticated research studies have taken

Map 3.1 Starting year for urban EBC monitoring in European countries



Note: A diagonally lined background indicates the presence of EBC networks, with at least five stations (arbitrary threshold set for the definition of 'network') monitoring EBC in a coordinated manner and with comparable instrumentation within the same country.

In the networks shown here, optical BC measurements are converted into EBC by correcting the online measurements with filter-based EC concentrations determined by thermo-optical analysis.

Source: EEA after Viana et al., 2012.

([15]) Continuous ambient particulate monitor to measure particulate matter mass concentrations are for example so-called Tapered Element Oscillation Microbalance (TEOM) — Filter Dynamic Measurement Systems (FDMS).
([16]) The Network of National Air Quality Reference Laboratories in the EU.

Box 3.1 Black carbon monitoring in combination with elemental and organic carbon measurements

As the sum of total OC and EC, total carbon (TC) is influenced by direct traffic and biomass burning emissions (through EC and BC), as well as by secondary formation from pollutants emitted by traffic, biomass burning, biogenic processes and industries (through OC). In the coming years, BC levels are expected to decrease strongly as a consequence of the implementation of new Euro regulations (Euro standards ([17])) at EU level. At present, ambient OC concentrations are not declining proportionally to BC concentrations; they seem to be governed by secondary aerosol processes (de Gouw and Jiménez, 2008) rather than by emission sources (as is the case of BC). However, it is also known that the secondary organic aerosol (SOA) fraction may be toxic for humans (Krudysz et al., 2008). However, OC monitoring in networks is a complex issue, which might thus be solved by the combined monitoring of TC and BC (the difference being OC). The combination of these two parameters would yield complete information on the two main carbon components (OC and EC) with potential impact on human health, covering all the major emission sources. One limitation of this approach would be the influence of mineral carbon, mainly present in southern European environments ('African dust' contributions; see, for instance, EEA (2012b)). If we consider that, in southern regions, TC is the sum of OC, EC and mineral carbon, this approach would overestimate the organic fraction given that TC-EC = OC + mineral carbon (nmC). If nmC was monitored instead of TC, it would be possible to overcome this limitation. However, no instruments are currently available for online TC or nmC monitoring.

advantage of photo-acoustic techniques to avoid filter sampling and related artefacts (Arnott et al., 2005). Such a methodology might be envisaged soon for monitoring activities, as some manufacturers are currently developing simple photo-acoustic instruments to be used for this purpose.

3.2 Black carbon monitoring at regional background measurement sites

Measurements at monitoring sites of the EMEP network (see Box 3.2) under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) include both:

- EC monitoring based on thermo-optical analysis, giving a measure of the (carbon) mass concentration, and
- BC monitoring based on the absorption of light using spectroscopic methods. As described above, the latter gives a measure of the aerosol optical properties (Tørseth et al., 2012).

Within the two EU infrastructure projects, European Supersites for Atmospheric Aerosol Research (EUSAAR, 2011) and Aerosols, Clouds, and Trace gases Research InfraStructure Network (ACTRIS, 2013) both BC and EC were or are monitored for a large number of European rural sites (> 20 sites). The data are reported to the EBAS database (EBAS, 2013; see also Box 3.2), where it is publicly available. The instrumentation used is fairly similar to the one deployed in urban networks (see below), and inter-comparison exercises are regularly carried out within the research network. These inter-comparisons provide very valuable information that is also pertinent to urban air quality networks.

When addressing climate change issues, air measurements should have a concerted focus on climate forcing. This includes measurements of absorption, scattering and extinction of radiation, together with trace gases and aerosol chemical composition at one measurement site. And this is the objective of the monitoring sites operated within the EMEP network, in cooperation with the WMO Global Atmosphere Watch (GAW) programme (GAW-WDCA, 2013) ([18]). The aim is also to harmonise the measurement approaches and efforts related to climate forcers on a global scale, via the World Data Centre on Aerosols. The EMEP strategy covers all relevant SLCFs

([17]) The Euro standards regulate emissions of nitrogen oxides (NO_x), hydrocarbons (HCs), carbon monoxide (CO), particulate matter (PM), and particle numbers (PNs). There are separate regulations for light vehicles (less than 3.5 tonnes) and heavy-duty vehicles.
([18]) The World Data Centre for Aerosols (WDCA) is now hosted by EBAS (2013).

Box 3.2 EMEP observational network: regional background stations

The EMEP monitoring sites are located so as to minimise significant local influences (local emission sources, local sinks, topographic features, etc.), with the site criteria being defined in the EMEP manual. The basic idea is that the data should be representative for a larger region. EMEP monitoring focuses on species and parameters which are important for understanding the sources and exposure/fluxes of pollutants, as well as of atmospheric processes in general. Data for more than 600 different variables have been reported to the EBAS database at the EMEP Chemical Coordination Centre ([19]) (EMEP-CCC, 2013a). This number is growing as new methodologies become available, and novel environmental challenges are identified (Tørseth et al., 2012; EMEP-CCC, 2013b; EMEP-CCC, 2013c; EMEP-CCC, 2013d).

(EMEP, 2013). The focus is clearly on a few high-quality 'regional background super sites', where it is also possible to apply and/or compare several measurement methods in parallel. The recommended detailed measurement programme is defined in the UNECE EMEP monitoring strategy document, which covers the period 2010 to 2019 (UNECE, 2009). The strategy entered into force in 2010.

The EMEP and WMO/GAW WDCA monitoring database (EBAS) included EC and OC data from twenty-one stations in thirteen European countries over the period 2010–2012. Twenty two European rural background stations reported absorption coefficient data for the same period. These stations are not all consistent with those measuring EC and OC; nine stations have co-located absorption and EC/OC measurements (EBAS, 2013).

([19]) The EMEP-CCC is a centre under the UNECE Convention on Long-range Transboundary Air Pollution (established in 1979), and here under the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP).

Units, acronyms and abbreviations

6EAP	Sixth Environment Action Programme (of the European Union).
ACTRIS	Aerosols, Clouds, and Trace gases Research InfraStructure Network; ACTRIS is an EU funded research project aiming at integrating European ground-based stations equipped with advanced atmospheric probing instrumentation for aerosols, clouds, and short-lived gas-phase species.
AirBase	The European-wide air quality database contains validated air quality monitoring information for more than 30 participating countries throughout Europe. AirBase is managed by the ETC/ACM on behalf of the EEA.
AirMonTech	Current and Future Air Quality Monitoring; AirMonTech is an EU funded research project
AQ	Air quality
AQG	Air quality guideline, term used by the World Health Organization (WHO) for air quality standards
Aquila	The Network of National Air Quality Reference Laboratories was founded in 2001. The secretariat is organized by European Commission's Joint Research Centre (JRC). The main task of the Network is related to improving measurement methods and related uncertainties and the harmonization of measurement techniques.
BC	Black carbon (for definition see Box 2.1; and the glossary)
CCC	EMEP Chemical Coordination Centre under the UNECE Convention on long-range Transboundary Air Pollution (see also below under EMEP)
CEN/TC	European Committee for Standardisation (Comité Européen de Normalisation) — Technical Committee
CLRTAP	Convention on Long-range Transboundary Air Pollution
CM	Carbonaceous material
CO	Carbon monoxide
CO_2	Carbon dioxide
CTM	Chemical transport model (air quality model)
DPF	Diesel particle filter
EAP	Environment Action Programme of the European Union

EBAS	Database at the Norwegian Institute for Air Research (NILU) hosting observation data of atmospheric chemical composition and physical properties submitted by data originators in support of a number of national and international programmes ranging from monitoring activities to research projects
EBC	Equivalent black carbon (for definition see Box 2.1)
EC	Elemental carbon (for definition see Box 2.1; and the glossary)
EC	European Commission; the EC is the executive body of the European Union
EEA	European Environment Agency
Eionet	European Environmental Information and Observation Network of the EEA
EMEP	European Monitoring and Evaluation Programme: Cooperative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe under the UNECE LRTAP Convention
ETC/ACM	EEA's European Topic Centre for Air Pollution and Climate Change Mitigation
EU	European Union
EUSAAR	European Supersites for Atmospheric Aerosol Research) is an EU-funded I3 (Integrated Infrastructures Initiatives) project carried out in the EU's FP6
FENO	Fractional exhaled nitric oxide
FP6	Sixth Framework Programme for EU research
FP7	Seventh Framework Programme for EU research
GAINS	Greenhouse Gas–Air Pollution Interactions and Synergies Model developed by the International Institute for Applied Systems Analysis (IIASA)
GAW	Global Atmosphere Watch; GAW programme of World Meteorological Organization (WMO), a partnership involving the Members of WMO, contributing networks and collaborating organizations and bodies.
Gg	Gigagram (1 000 000 000 grams)
IIASA	International Institute for Applied Systems Analysis; IIASA is a non-governmental research organisation located in Austria
IMPROVE	Interagency Monitoring of PROtected Visual Environments (IMPROVE) network focusing on source apportionment studies and to evaluate quartz-fiber filter adsorption of organic vapors (United States)
INECE	International Network for Environmental Compliance and Enforcement ; INECE is an international partnership promoting compliance and enforcement of domestic and international environmental laws
IPCC	Intergovernmental Panel on Climate Change, the leading international body for the assessment of climate change, established by the United Nations Environment Programme (UNEP) and the World.
JRC	Joint Research Centre of the European Commission

LRE	Laser reflector experiment
LRTAP Convention	Convention on Long-range Transboundary Air Pollution (UNECE)
m^3	Cubic metre
MAAP	Multi-Angle Absorption Photometer
MAE	Mass absorption efficiency, a factor for converting absorption measurements of BC to BC mass concentrations
MARPOL	International Convention for the Prevention of Pollution from Ships
MS	Member State (of the EU)
NEC	National Emission Ceilings (set in a respective EU Directive of 2001)
NH_3	Ammonia
NH_4NO_3	Ammonium nitrate
NIOSH	The National Institute for Occupational Safety and Health (United States of America)
NO	Nitric oxide
nmC	Non-mineral carbon
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
$(NH_4)_2SO_4$	Ammonium sulphate
NPL	National Physical Laboratory, Teddington (United Kingdom)
O_3	Ozone
OC	Organic carbon (for definition see Box 2.1; and the glossary)
PAH	Polycyclic aromatic hydrocarbon
PCIA	Partnership for Clean Indoor Air
PM	Particulate matter (in the air)
PM, coarse fraction	Defined as PM_{10} minus $PM_{2.5}$ (see below)
PM_{10}	PM with an aerodynamic diameter of 10 μm or less
$PM_{2.5}$	PM with an aerodynamic diameter of 2.5 μm or less
PNC	Particle number concentration
PJ	Petajoule (energy unit; 1.0×10^{15} joules)
Ppb	Parts per billion; commonly used as a measure of small levels of pollutants in (for example) the air

PSAP	Particle Soot Absorption Photometer
REVIHAAP	Review of EVIdence on Health Aspects of Air Pollution'; a project jointly funded by WHO and the European Commission, finalised in April 2013
SLCF	Short-lived climate forcing/forcers
SNP	Single nucleotide polymorphisms
SOA	Secondary organic aerosol
SO_2	Sulphur dioxide
SIA	Secondary inorganic aerosol
TC	Total carbon
TSAP	Thematic Strategy on Air Pollution
UBA	Federal Environment Agency, Dessau (Germany)
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
VOC	volatile organic compound
WDCA	World Data Centre for Aerosols
WHO	World Health Organization (WHO European Centre for Environment and Health, Bonn, Germany)
WMO	World Meteorological Organization
μg	Microgram; 1μg = 0.0000010000g

Glossary

This Glossary is based on the one published in the 'Report to Congress on Black Carbon', United States Environmental Protection Agency (US EPA, 2012).

Aerosol
A mixture of gases and suspended solid and/or liquid particles, with a typical size between 0.01 and 10 micrometres and residing in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Often the term is used interchangeably with 'particle' or 'particulate matter.'

Aerosol optical depth
A quantitative measure of light extinction within a vertical column of atmosphere due to aerosol absorption or scattering. Pollution and cloud-free portions of the atmosphere have a low aerosol optical depth, while highly polluted or densely cloudy skies have a high optical depth.

Albedo
The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Light-coloured surfaces (such as those covered by snow and ice) have a high albedo; dark surfaces (such as dark soils, vegetation and oceans) have a low albedo.

Atmospheric lifetime or residence time
The approximate amount of time it would take for the atmospheric concentration of a pollutant to return to its natural level (assuming emissions cease) as a result of either being converted to another chemical compound or being taken out of the atmosphere via a sink. This time depends on the pollutant's sources and sinks as well as its reactivity. Average lifetimes for air pollutants can vary from days to weeks (black carbon and ozone) to more than a century (e.g. chlorofluorocarbons and carbon dioxide).

Atmospheric transport
The movement of chemical species through the atmosphere as a result of large-scale atmospheric motions. Transport distances are a function of atmospheric lifetimes, emission location, and overall meteorological activity.

Biofuels
Biofuels are non-fossil carbon-based fuels derived from organic materials (biomass), including plant materials and animal waste.

Biomass
In the context of energy, the term biomass is often used to refer to organic materials, such as wood and agricultural wastes, which can be burned to produce energy or converted into a gas and used for fuel.

Black carbon
General definition: A solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths. Black carbon is the most effective form of particulate matter, by mass, at absorbing solar energy, and is produced by incomplete combustion.

Black smoke
The term used since the 1950s to describe carbon-containing particulate matter resulting from incomplete combustion (e.g. from coal); also refers to a measurement that quantified the concentration of ambient particulate matter. The term has been used as a synonym for soot.

Brown carbon
A class of particulate organic carbon compounds that absorb ultraviolet and visible solar radiation. Brown carbon can be directly emitted as a product of incomplete combustion, or it can be formed in the atmosphere as pollutants age.

Carbon dioxide equivalent
A metric used to compare the emissions from various greenhouse gases based upon their global warming potential. It is the calculated equivalent amount of carbon dioxide emissions that would result in the same radiative effect as a pulse of emissions of another greenhouse gas. Carbon dioxide equivalents are commonly expressed as 'million metric tons of carbon dioxide equivalents' ($MMTCO_2eq$).

Carbonaceous particulate matter
A general term for carbon-based compounds found in particles, including black carbon and organic carbon. Primary combustion particles are largely composed of carbonaceous particulate matter.

Diesel particulate filter
Exhaust emissions control device used to reduce diesel particulate matter; also called a diesel particulate trap. The diesel particulate filter consists of a porous honeycomb structure that physically captures and oxidizes the diesel particulate matter.

Diesel particulate matter
The particulate component of diesel exhaust, which includes a mixture of black carbon, organic carbon, sulphates, metals, and trace elements. Black carbon is a major constituent of diesel particulate matter.

Elemental carbon
A descriptive term for carbonaceous particles that is based on chemical composition rather than light-absorbing characteristics. Often used as a synonym for *black carbon*.

Filter-based techniques
One of several ways to quantify the amount of particulate matter in ambient (outdoor) air. Filter-based measurement methods use samplers that consist of a vacuum pump calibrated to draw in a fixed volume of air per minute through a filter that captures particles. The average concentration of particulate matter in the air can be calculated by weighing the filter before and after the run, and correlating the particulate weight to the volume of air drawn through the pump.

Flaming
The stage of combustion when fuel gases are rapidly oxidized. Under oxygen-limited and relatively low-temperature conditions, soot is emitted.

Fossil fuels
Fuels derived from coal, oil, and natural gas.

Global warming potential
An index, based upon radiative properties of well-mixed greenhouse gases, measuring the radiative forcing of a unit mass of a given pollutant in the present-day atmosphere integrated over a chosen time horizon (often 100 years, or GWP100), relative to that of carbon dioxide (CO_2 always has a global warming potential of 1). The global warming potential represents the combined effect of the differing times these pollutants remain in the atmosphere and their relative effectiveness in absorbing radiation.

Greenhouse gas
Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapour, carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, hydro-chlorofluoro-carbons, ozone, hydro-fluoro-carbons, per-fluoro-carbons, and sulphur hexa-fluoride.

Incomplete combustion
Combustion where only a partial burning of a fuel occurs. Combustion in practice is almost always incomplete due to insufficient oxygen or low temperature during the combustion process preventing the complete oxidation of the fuel to CO_2.

Intergovernmental Panel on Climate Change
Established in 1988 by the World Meteorological Organization and the United Nations Environment Programme, the Intergovernmental Panel on Climate Change is responsible for providing the scientific and technical foundation for the United Nations Framework Convention on Climate Change, primarily through the publication of periodic assessment reports.

Light-absorbing carbon
Carbonaceous particles that absorb light, including black carbon plus brown carbon.

Light-absorbing particulate matter
Refers to particles that tend to absorb light, which represents energy added to the Earth's system and leads to climate warming.

Light-scattering particulate matter
Refers to particles that tend to reflect or scatter light, which generally leads to increased reflection of light back to space, causing climate cooling.

Long-lived climate forcer
A pollutant like CO_2 that has a positive radiative forcing effect on climate and a long atmospheric lifetime (decades to centuries).

Net radiative forcing
The total *radiative forcing* due to the presence of a pollutant in the atmosphere, accounting for both the positive (warming) and negative (cooling) forcing associated with different radiative effects of the pollutant. For particles, this includes accounting for direct, indirect (cloud), and snow/ice albedo effects.

Open biomass burning
Open burning of vegetative material; includes agricultural burning, prescribed burning, and wildfires.

Organic carbon
The mix of compounds containing carbon bound with other elements; e.g. hydrogen and oxygen. Organic carbon may be a product of incomplete combustion, or formed through the oxidation of VOCs in the atmosphere. Both primary and secondary organic carbon possesses radiative properties that fall along a continuum from light-absorbing to light-scattering.

Organic carbon to black carbon ratio
The ratio of the mass of organic carbon to black carbon.

Particulate matter
A complex mixture of small particles and liquid droplets suspended in the atmosphere. Particulate matter (PM) is made up of a number of components, including acids (such as nitrates and sulphates), organic chemicals, metals, and soil or dust particles. For purposes of air quality and health studies, PM is typically measured in two size ranges: PM_{10} and $PM_{2.5}$.

PM_{10}
Particulate matter with an aerodynamic diameter less than or equal to a nominal 10 micrometres. PM_{10} includes $PM_{2.5}$.

$PM_{2.5}$
Fine particulate matter with an aerodynamic diameter less than or equal to 2.5 micrometres. $PM_{2.5}$ includes $PM_{0.1}$.

$PM_{0.1}$
Fine particulate matter with an aerodynamic diameter less than or equal to 0.1 micrometres. It is also termed ultrafine PM. In the case of the ultrafine PM fraction, the mass when determined in $\mu g/m^3$ is only a small fraction of PM_{10} or $PM_{2.5}$. However, the number of particles in that ultrafine fraction dominates the total number in the $PM_{2.5}$ and PM_{10} fractions. Thus, the particle number concentration (PNC) is frequently measured to complement the characterisation of PM, i.e. expressed as the total number of airborne particles per unit volume of air, without distinction based on their sizes. The unit commonly used is # particles/m^3.

Primary particulate matter
A particle that is emitted directly from a source.

Pyrolysis
The heating of solid fuels in the absence of oxygen. Pyrolysis induces the evaporation of volatile gases from the solid fuel needed to support combustion. Thermal breakdown of portions of the solid fuel provide additional fuel gases. Pyrolysis is used to produce charcoal and biochar, a residual form of carbon in solid form.

Radiative forcing
The change in the energy balance between incoming solar radiation and exiting infrared radiation, typically measured in watts per square meter ($W\ m^{-2}$), due to a change in concentration (generally the change since preindustrial conditions in 1750). Positive radiative forcing tends to warm the surface of the Earth, while negative forcing generally leads to cooling. A pollutant that increases the amount of energy in the Earth's climate system is said to exert 'positive radiative forcing', which leads to warming. In contrast, a pollutant that exerts 'negative radiative forcing' reduces the amount of energy in the Earth's system and leads to cooling.

Secondary organic aerosols
Carbonaceous aerosols that are produced in the atmosphere rather than being directly emitted. Precursor gases (such as aromatic hydrocarbons, mono-terpenes) undergo chemical reactions and condensation to form secondary organic aerosols.

Secondary inorganic aerosol
A particle (e.g. sulphate or nitrate) that is formed in the atmosphere from the oxidation of gaseous precursors like sulphur dioxide, nitrogen oxides, and volatile organic compounds or through the transformation of directly emitted particles. The acids resulting from the oxidation of these compounds attract water vapour to form tiny droplets (fine particulate matter).

Short-lived climate forcer
A pollutant, such as black carbon, ozone, or methane, that has a positive radiative forcing effect on climate but a relatively short atmospheric lifetime (days to years).

Snow/ice albedo effect
Decrease in reflectivity (and increase in absorption) of solar radiation that occurs as a result of the darkening of snow and ice through aerosol deposition.

Snow/ice albedo forcing
Positive radiative forcing resulting from the deposition of black carbon on snow and ice, which darkens the surface and decreases reflectivity (albedo), thereby increasing absorption of solar radiation (light) and accelerating melting.

Soot
A complex mixture of mostly black and organic carbon that is the primary light-absorbing pollutant emitted by the incomplete combustion of fossil fuels, biofuels, and biomass.

Source apportionment
The use of ambient and/or emissions data along with statistical modelling to determine the contribution of a specific emissions source category to measured ambient concentrations of air pollutants like $PM_{2.5}$.

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Annex 1 Black carbon as a proxy for traffic exhaust

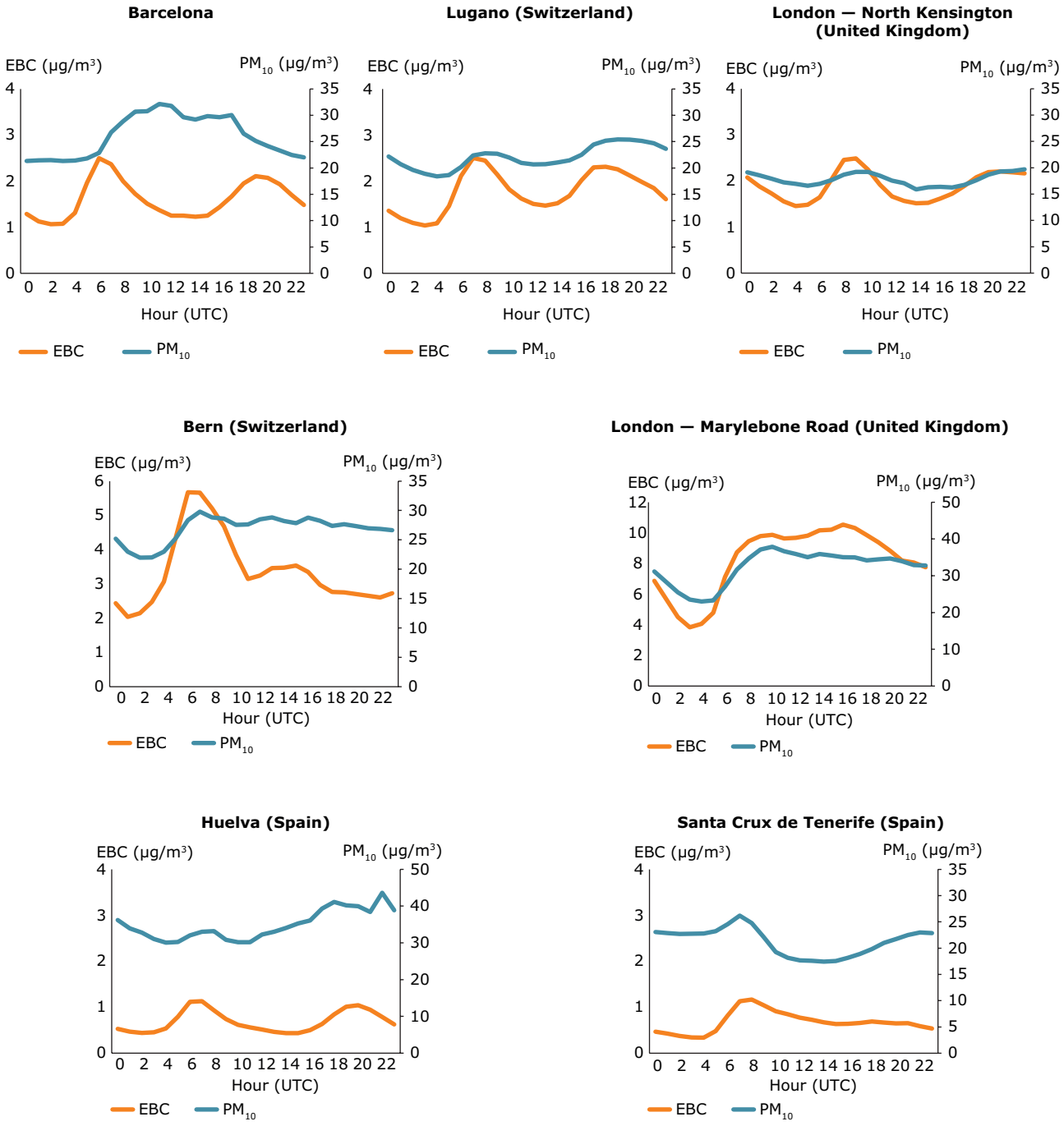
A recent work by Reche et al. (2011) assessed the variability of levels of PM, EBC, PNC and a number of gaseous pollutants at seven selected urban air quality monitoring sites in southern, central and northern Europe. The results showed that PM_{10} concentrations at European urban background and traffic stations do not always co-vary with road traffic emissions, which are characterised by morning and evening rush hour maxima (Figure A1.1). PM_{10} concentrations at these sites are mostly governed by the pattern of the traffic flow and midday atmospheric dilution (see the Lugano and North Kensington patterns). PM_{10} levels at the traffic sites remained nearly constant from the morning until the evening peak, due to the effects of PM re-suspension processes. In the case of Barcelona, concentrations increase at midday when sea breezes are at their strongest and transport the re-suspended mineral material from the city towards the monitoring site. Similar results were reported in earlier studies (e.g. Querol et al., 1998; Querol et al., 2001 and 2005; Charron and Harrison, 2005). In contrast, PM_{10} concentrations in Huelva reach the highest values at night due to the seaward transport of aged particulate pollutants. During daylight, winds blow inland from the Atlantic Ocean carrying emission plumes with gaseous pollutants from industrial estates (Sánchez de la Campa et al., 2007), accounting for the different daily cycle of PM and gaseous pollutants.

The study by Reche et al. also evidenced that the daily cycle of measured particle number concentration (PNC) showed significant differences between cities with different meteorological conditions, whereas EBC levels reproduced in a more stable manner the variability of road traffic contributions (Figure A1.2). However, EBC concentrations distinctly reproduce road traffic (exhaust) variability on an hourly level across different European regions (Figure A1.2). Irrespective of the mean BC levels in the different cities, and whether the stations are representative of traffic emissions or the urban background. The characteristic daily pattern with morning and evening maxima coincident with traffic rush hours is evident at all sites.

Furthermore, on a weekly scale, the daily evolution of EBC for each day of the week and each station indicates that this evolution was not the same at weekends as the morning road traffic maximum disappeared, and a relatively smoother daily evolution in EBC concentrations during daytime was observed. However, it must be highlighted that BC may also be emitted by biomass-burning activities, and this may affect both the daily cycles of this pollutant and the NO_2/EBC, CO/EBC and OC/EBC ratios across Europe as a function of the different biomass burning emission sources.

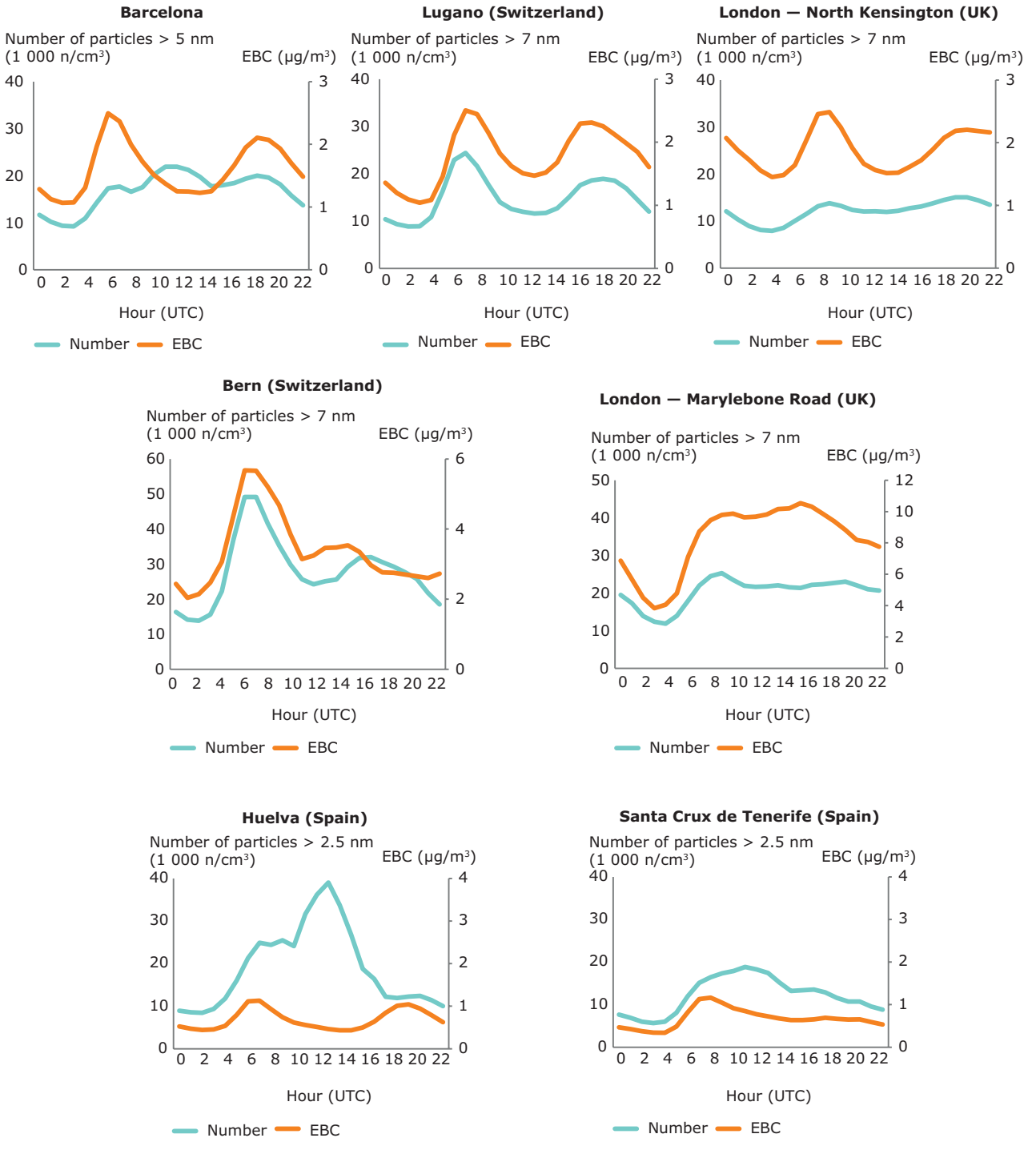
EBC can also be a good tracer indicating the local or external origin of carbonaceous aerosol contributions. Polar plots of EBC concentrations as a function of wind speed and direction allow for the identification of local or external sources of this pollutant (e.g. Querol et al., 2012).

Figure A1.1 Mean daily variability of PM_{10} and EBC concentrations at urban and traffic sites in Europe



Source: After Reche et al., 2011.

Figure A1.2 Mean daily variability of EBC and ultrafine particle number concentrations at urban and traffic sites in Europe



Note: Although in central and northern Europe, PNC and EBC levels tend to vary simultaneously, during rush and non-rush hour traffic in urban background stations in southern Europe, PNC levels are also influenced by nucleation episodes (new particle formation). As a result, PNC variability in different European urban environments is not equally influenced by the same emission sources and atmospheric processes across Europe. Consequently, PNC variability does not always reflect the impact of road traffic on air quality.

Source: After Reche et al., 2011.

Annex 2 Measuring black carbon in air quality monitoring networks: the European experience

Table A2.1 European experience on the measurement of BC in air quality monitoring networks ([a]); for abbreviations please see list below the tables

Country	Location	Operator	Number and type of sites (and starting date when available)	Measurement method	Comment	References
Belgium	Brussels	IBGE — LRE	1 urban background, (2012) 3 traffic sites (2009–20)	Aethalometer (2-wavelengths AE22 model)	Collocated measurements of PM_{10} at 3 sites and of PNC at 2 traffic sites	http://www.bruxellesenvironnement.be/Templates/etat/informer.aspx?id=3196&langtype=2060 Vanderstraeten et al., 2011
Belgium	Flanders	VMM	14 sites including 2 urban background and 1 traffic sites (2007 or 2012) (+ 4 mobile units)	MAAP 5012 TSP inlet	In 2012, collocated with black smoke measurements performed at 5 sites with ETL SX 200 monitors	http://www.vmm.be
Belgium	Wallonia	ISSeP	1 rural, 1 urban traffic and 1 industrial sites (2011) (+ 8 mobile units)	Aethalometer (AE-22 model)	In addition to the historical black smoke network A systematic measurement of BC and total carbon in PM_{10} on a weekly basis will be implemented in 17 locations	
Denmark			No fixed measurements			
Finland	Helsinki	HSY	1 urban background site (2012) + 1 moving station (since 2009) located every year in a special site	MAAP 5012 with PM_1 inlet	Collocated measurements of PNC at the moving station since 2009	http://www.hsy.fi/seututieto/ilmanlaatu/pks/bc/Sivut/viikoittain.aspx
France	Paris area	Airparif (in collaboration with LSCE)	4 urban background (2008) and 1 traffic (2012) sites 7 additional traffic and rural background sites	MAAP Aethalometer (AE31 and AE42 models)	Update to the historical black smoke measurements Evaluation of a possible Low Emission Zone	http://www.airparif.asso.fr/actualite/detail/id/55
Germany	National network (GUAN)	Depends on the site (UBA, IfT, HMGU, LfULG, DWD, IUTA, GAA, UFZ, DWD)	15 sites in Germany including Alpine, rural, urban background and traffic sites (2008)	MAAP with PM_1 or PM_{10} inlet depending on the site Aethalometer at 1 urban site	Collocated measurements of particle mass (1 site), PM_{10} (6 sites), $PM_{2.5}$ (1 site), PNC (8 sites, rural, urban background and traffic)	Birmili et al., 2009 Nordmann et al., 2009
Greece			No fixed measurements			
Hungary			No fixed measurements	Aethalometer with $PM_{2.5}$ inlet	Long-run research studies	
Ireland	Mace Head Site	School of Physics, NUI, Galway	1 regional background site ([b])	MAAP Aethalometer	Collocated measurements of environmental pollutants, aerosol physical and optical properties, aerosol chemistry	http://www.nuigalway.ie/ccaps/mace_head.html

Table A2.1 European experience on the measurement of BC in air quality monitoring networks ([a]); for abbreviations please see list below the tables (cont.)

Country	Location	Operator	Number and type of sites (and starting date when available)	Measurement method	Comment	References
Italy	Cassino laboratory	University of Cassino and Southern Lazio	1 site (2008)	Aethalometer	Research-oriented measurements Collocated PNC measurements	
Netherlands	Amsterdam	GGD	2 urban background and 3 traffic sites (2012)	MAAP	Collocated with black smoke measurements performed from 1998 (4 sites) and 2009 (1 site) with ETL SX-200 monitors	
Norway	Birkeness observa-tory	NILU	1 regional background site	PSAP	Collocated measurements of environmental pollutants, aerosol physical and optical properties, aerosol chemistry	http://www.nilu.no/Milj%C3%B8overv%C3%A5kning/NILUsm%C3%A5lenettverk/M%C3%A5leprogrammerBirkenesobservatoriet/tabid/273/Default.aspx
Portugal		APA	No fixed measurements		BC derived from weekly EC measurements at an urban background site in Lisbon	
Slovenia		ARSO/EARS	No fixed measurements	Aethalometer (AE31 model)	Regular monitoring campaigns in the whole country	
Spain	Barcelona	Regional government and IDAEA-CSIC	1 urban, 1 regional background and 1 continental background site (> 2008)	MAAP	Collocated measurements of environmental pollutants, PNC, aerosol physical and optical properties, aerosol chemistry	
Sweden			No fixed measurements	Aethalometer (series 8100)	Research programmes	
Switzerland	National network (NABEL)	EMPA	8 rural background, rural motorway, suburban background, urban background, urban traffic sites (2006 and later)	MAAP 5012 with $PM_{2.5}$ inlet (5 sites) Aethalometer with $PM_{2.5}$ inlet (AE-31 model)	Collocated measurements of PNC at 4 sites	http://www.bafu.admin.ch/luft/00612/00625/index.html?lang=fr
United Kingdom	National network	NPL	3 rural background, 3 suburban background, 5 urban background, 3 urban traffic sites (2008)	Aethalometer (2-wavelengths AE21 model)	Update to the historical black smoke network. Collocated measurements of PM_{10} (12 sites), PNC 4 sites (rural, urban background and traffic)	http://uk-air.defra.gov.uk/networks/network-info?view=particle http://uk-air.defra.gov.uk/interactive-map?network=ukbsn http://uk-air.defra.gov.uk/reports/cat05/1108251248_2010_BC_Network_Report.pdf

Note: ([a]) The main focus of this report is on urban networks. For more information on rural sites where black carbon and EC are measured, please see for example the ACTRIS network (ACTRIS, 2013).

([b]) This is not an urban site, but a regional background 'super site' (please see Section 3.3).

All abbreviations used in this table are explained in 'Units, acronyms and abbreviations', please see page 45.
Details on the country responses can be found in the ETC/ACM background Technical Paper: Viana et al., 2012 (in the Appendix, page 68 ff.): see http://acm.eionet.europa.eu/reports/ETCACM_TP_2012_6_PNC_BC_AQnetworks.

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Abbreviations used for institutions etc. in Table A2.1

Airparif	Air Quality Monitoring Network; Airparif is a non-profit organisation accredited by the Ministry of Environment to monitor the air quality in Paris and in the Ile de France region (the capital city region).
APA	Portuguese Environment Agency, Amadora (Portugal)
ARSO/EARS	Slovenian Environment Agency, Ljubljana (Slovenia)
BCN	(Airport code for) Barcelona-El Prat Airport
CESAM/UA	University of Aveiro (Universidade de Aveiro Campus Universitario de Santiago), Aveiro (Portugal)
DWD	German Weather Service (Deutscher Wetterdienst), Offenbach (Germany)
EMPA	Swiss Federal Laboratories for Materials Science and Technology
ESFRI	The European Strategy Forum on Research Infrastructures
GAA	Gewerbeaufsichtsamt (industry control office in Germany)
GGD	Association of GGDs (Community Health Services) in the Netherlands
GUAN	German Ultrafine Aerosol Network, atmospheric observation network designed for long-term observations operational since the end of 2008
HMGU	German Research Centre for Environmental Health, München (Germany)
HSY	Helsinki Region Environmental Services Authority (Finland)
IBGE	Institut Bruxellois Pour La Gestion De L'Environement, Brussels Environment
IDAEA-CSIC	Institute of Environmental Assessment and Water Research (Spain)
IfT	Leibniz Institute for Tropospheric Research, Leipzig (Germany)
IGSD	Institute for Governance & Sustainable Development; the international institute is committed to strengthening environmental law and institutions to promote sustainable development
INAIL	Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro, Rome (Italy)
INERIS	French National Institute for Industrial Environment and Risks (Institut national de l'environnement industriel et des risques), Paris (France)
ISSeP	Institut Scientifique de Service Public, Région Wallomie (Belgium)
IUTA	Institute of Energy and Environmental Technology (Instituts für Energie- und Umwelttechnik e.V.), Duisburg (Germany)
LfULG	Ultrafine particles — cooperating with environmental and health policy project; EU-funded project, experts from the fields of environment / air pollution and human health will work together to make a contribution to the environmental policy in Europe (the Clean Air Plan for Europe) for combating the air pollution
LSCE	Laboratoire des Sciences du Climat et de l'Environnement
NILU	Norwegian Institute for Air Research, Kjeller (Norway)
NUI	National University of Ireland, School of Physics, Galway (Ireland)
UBA	Federal Environment Agency, Dessau (Germany)
UFZ	Helmholtz Centre for Environmental Research within the Helmholtz Association of National Research Centres (HGF), Leipzig (Germany)
VMM	Flemish Environment Agency, Erembodegem, Belgium

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