European Commission

Systematic assessment of monitoring of other air pollutants not covered under Directives 2004/107/EC and 2008/50/EC

With a focus on ultrafine particles, black carbon/ elemental carbon, ammonia and methane in ambient air.
Service Request No 15 under Framework Contract No ENV.C.3/FRA/2017/0012

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Executive summary

Air pollutants are harmful for human health and the environment. The EU Ambient Air Quality Directives (AAQDs) 2008/50/EC and 2004/107/EC aim to protect human health and the environment from these harmful effects. The Directives therefore set standards such as limit or target values for a certain number of pollutants and define specific responsibilities for EU Member States regarding monitoring and managing air quality as well as on reporting.

Nevertheless, in recent years, scientific knowledge emerged and increased about possible health and environmental impacts of additional air pollutants. Such air pollutants, not explicitly covered so far, include ultrafine particles (UFP), black carbon (BC) / elemental carbon (EC)[1], ammonia (NH_3) and methane (CH_4).

On 22 September 2021 the World Health Organization (WHO) published updated WHO Global Air Quality Guidelines, which include so-called good practice statements for UFP and BC/EC *(as well as for sand and dust storms)*[2]. These good practice statements ask for integrating monitoring of these pollutants into existing air quality monitoring networks next to technical requirements for UFP monitors, reporting, emission inventories for BC and exposure assessments.

Objectives

This study aims at identifying pollutants of emerging concern based on scientific recommendations, specifically aiming at the following objectives:

1. To provide an overview of current scientific recommendations and good practice for monitoring of other air pollutants not covered by the EU Ambient Air Quality Directives;
2. To collate comprehensive information on the monitoring of ultrafine particles, black carbon/elemental carbon, ammonia and methane (plus other relevant air pollutants) in all EU Member States;
3. To assess the distance to meeting WHO good practice statements for measuring ultrafine particles, and for measuring black carbon/elemental carbon in ambient air in all Member States;
4. To provide recommendations on steps needed to meet current scientific recommendations in all Member States, including estimates of the costs this would imply and for whom.

Methodology

To fulfil these objectives, as a first step scientific recommendations, studies and/or good practice statements regarding monitoring of air pollutants that are suggested to have possible health or ecosystem impacts or act as precursors for the formation of secondary air pollutants were searched. The search included scientific literature, studies, activities of environmental agencies and a request to international scientific networks.

In a next step, from the vast number of relevant air pollutants, several additional pollutants, besides UFP, BC/EC, NH_3 and CH_4 that were specifically requested in the technical

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[1] According to Annex IV of Directive 2008/50/EC monitoring of EC and OC in $PM_{2.5}$ is required at rural background locations in EU Member States.

[2] WHO (2021).

specifications for this study, were selected for further investigation by applying a set of criteria such as a risk highlighted by several institutions or studies, a possible ubiquitous occurance and availability of data.

Next, Member States experts were contacted to provide information on current monitoring practices of selected additional air pollutants not yet covered by the AAQDs, including associated costs, and the distance to fulfilling the WHO good practice statements.

Finally, based on the replies from Member States, the characteristics of the additional pollutants, existing studies and strategies, as well as general criteria and objectives for air quality monitoring the study proposes specific monitoring strategies for these pollutants.

Results

The selected pollutants for investigation are:

- Ultrafine particles (UFP)
- Black carbon (BC) / elemental carbon (EC)
- Ammonia (NH_3)
- Methane (CH_4)
- 1,3-Butadiene (C_4H_6)
- Formaldehyde (HCHO)
- Manganese (Mn)
- Vanadium (V)
- Oxidative potential of particulate matter (PM)

25 Member States provided information on monitoring practices: 19 Member States already monitor NH_3, 16 monitor EC, 15 monitor BC, 13 monitor UFP, and 8 monitor CH_4. The oxidative potential of PM is analysed by two Member States.

A gap analysis with regards to the WHO good practice statement showed the following results:

UFP and BC are already monitored in around half of the Member States; thus further Member States would need to establish systematic monitoring of UFP and BC at stations relevant for exposure assessments as well as size-segregated real-time measurements of particle number concentrations to meet WHO good practice statements. In addition, reporting would need to be adapted to distinguish between different concentrations of UFP by almost all Member States. Emission inventories for BC are reported for almost all Member States. Exposure assessments and source apportionment studies would need to be undertaken by all Member States, the former ideally in close cooperation with scientific networks related to health impacts of air pollutants.

The following monitoring strategies are proposed for the nine selected pollutants, which are based on the replies from Member States, the characteristics of the additional pollutants, existing studies and strategies, as well as general criteria and objectives for air quality monitoring. Generally, it is recommended to review monitoring practices and results, as well as the underlying strategies, after three years.

Ultrafine particles (UFP)

UFP monitoring should focus on human exposure assessment as it is of relevance mainly for human health. Therefore, the proposed number of sampling points is derived from the population in agglomerations similar to monitoring of particulate matter. Further sampling points should be considered for large airports and ports, as both aircrafts and ships are relevant sources of UFP. In addition, sampling points in rural background should provide general concentration levels, which are helpful to distinguish urban contributions from sources outside cities. Overall, around 460 sampling points are proposed for Member States in total from which at least 70 already exist. Typical costs[3] of an UFP instrument for the monitoring of particle number concentrations are currently around 40 000 €.

Black Carbon (BC) / Elemental Carbon (EC)

Sources and characteristics of Black Carbon (BC) are similar to UFP; therefore a similar focus and a comparable number of sampling points is proposed as for UFP. Monitoring of Elemental Carbon (EC) is already obligatory for large Member States at rural background sites.[1] Nevertheless, it is recommended that the focus should be on BC, which is the parameter more commonly used for health impact or climate change assessments. However, a standard method for BC monitoring still needs to be defined. The characteristics of BC suggests additional monitoring in forestry areas prone to wildfires and in pristine areas (e.g. glaciers, the Arctic circle), as well as monitoring of the impact of shipping. Typical average costs[3] of an BC instrument are 37 500 €.

Ammonia (NH_3)

The main focus of ammonia (NH_3) monitoring should be on rural background sampling points, especially in or near nature areas and areas with high NH_3 emission densities, in line with the guidance on site selection of Directive 2016/2284. However, monitoring at urban/suburban/traffic sites should also be considered. Monitoring should mainly be done with passive samplers, supported by continuous monitoring systems with a high temporal resolution. One passive sampler for monitoring for two weeks to one month costs around 25 €; a continuous instrument, for which a standard still needs to be defined, depending on the method costs[3] at least some 10 000 €.

Methane (CH_4)

Methane (CH_4) is mainly known for its impact on climate change; however, CH_4, is also a precursor for ozone formation. Monitoring should focus on rural background sites not disturbed by local sources. This is already undertaken within scientific networks. Nevertheless, the geographical distribution of the sampling points should be improved, since the current coverage of monitoring sites in southern and eastern Europe is limited.

Oxidative potential of PM

The oxidative potential of PM has been suggested to be one of the many possible drivers of the acute health effects of PM. However, there is currently no common or standardised method to monitor this parameter. Therefore, it is recommended that Europe-wide monitoring at urban background stations is undertaken in a coordinated way within research projects in close cooperation with the health community.

1,3-Butadiene, formaldehyde

[3] Cost for purchasing and installation (one-off) without maintenance, repair etc.

Monitoring of 1,3-butadiene and formaldehyde is already recommended according to Directive 2008/50/EC as ozone precursor substances. Therefore, monitoring should be undertaken together with further ozone precursors at both urban and rural background sampling points. In addition, human health related monitoring of 1,3-butadiene should be undertaken at locations relevant for exposure near specific industrial plants.

Manganese (Mn), Vanadium (V)

Selected metals (Lead, Arsenic, Cadmium, Nickel) are already covered under the AAQDs and measured in the EU.[4] Therefore, manganese and vanadium can easily be covered by these existing monitoring networks, as the analytical instruments usually cover a wide range of metals. Monitoring should be undertaken close to specific industrial plants, at traffic-orientated sites and at urban background locations for exposure assessments; and at rural background sites to get information on background levels.

0. Introduction

0.1. Context

The EU Ambient Air Quality Directives 2008/50/EC and 2004/107/EC (AAQDs) cover a number of air pollutants. Nevertheless, in recent years, scientific knowledge emerged and increased about possible health and environmental impacts of additional air pollutants. Such air pollutants, not explicitly covered so far, include ultrafine particles (UFP), black carbon (BC) / elemental carbon (EC)[5], ammonia (NH_3) and methane (CH_4).

On 22 September 2021 the World Health Organization (WHO) published updated WHO Global Air Quality Guidelines, which include so-called good practice statements for UFP and BC/EC *(as well as for sand and dust storms)*[6]. These good practice statements for UFP and BC/EC recommend *inter alia* to put in place systematic measurements of UFP (and of size-segregated real-time particle number concentrations) and BC and/or EC. In the rationale to the good practice statements WHO provides an overview of current monitoring methods for both UFP and BC/EC.

Already during the 2011-2013 review of the EU clean air policy[7], the inclusion of CH_4 was discussed, as it is a relevant precursor for ozone. Next to that, CH_4 also acts as an important greenhouse gas and as such contributes to climate change.

Furthermore, NH_3 is regarded as a relevant pollutant due to its contribution to secondary inorganic particles and its impact on ecosystems. A recent publication in *Science*, estimated about 39% of the global $PM_{2.5}$ to be derived from NH_3[8]. NH_3 is also known for its impact on ecosystems both for ecosystems exposed to high levels of ammonia concentration in the air, as well as for high levels of reduced nitrogen deposition.

Additional pollutants are investigated in the scientific literature and in expert groups such as AQUILA.

[4] Lead monitoring is required according to Directive 2008/50/EC; Arsenic, Nickel and Cadmium monitoring according to Directive 2004/107/EC

[5] For elemental carbon, there is a limited provision on monitoring in Annex IV of Directive 2008/50/EC

[6] WHO (2021).

[7] https://ec.europa.eu/environment/air/clean_air/review.htm (last viewed on 07.03.2022)

[8] Gu, et al. (2021).

0.2. Objectives

For a number of air pollutants the Service Request the present study responds to asks for a systematic assessment of the way in which these pollutants are monitored in different EU Member States, including UFP, BC/EC, NH_3 and CH_4, as well as a limited number of (not yet specified) other pollutants not covered under Directives 2004/107/EC and 2008/50/EC.

With the main objective of assessing the monitoring of these air pollutants, the work for this Service Request aims at the following four specific objectives:

1. To provide an overview of current scientific recommendations and good practice for monitoring of other air pollutants not covered by the EU Ambient Air Quality Directives;
2. To collate comprehensive information on the monitoring of ultrafine particles, black carbon/elemental carbon, ammonia and methane (plus other relevant air pollutants) in all EU Member States;
3. To assess the distance to meeting WHO good practice statements for measuring ultrafine particles, and for measuring black carbon/elemental carbon in ambient air in all Member States;
4. To provide recommendations on steps needed to meet current scientific recommendations in all Member States, including estimates of the costs this would imply and for whom.

1. Task 1: Current scientific recommendations

In a first step, this study summarises current scientific recommendations, studies and/or good practice statements regarding monitoring of pollutants that are suggested to have possible health or ecosystem impacts or to be of relevance as precursors for the formation of secondary pollutants (e.g. ozone, PM), which are not covered under Directives 2004/107/EC and 2008/50/EC.

The following sources of information were used to identify relevant additional pollutants:

- scientific literature, studies and activities of environment agencies such as the US EPA;
- contacts to national focal points of the EEA;
- contacts to international scientific networks (EEA, ACTRIS, EMEP, GAW and AQUILA).

The results of the research about priorities for additional pollutants is summarised in the following.

1.1. Scientific literature

The scientific literature search was based on key words such as “ambient air”, “outdoor air”, “atmosphere”, “emerging pollutant”, “novel pollutant”. In addition, part of the literature cited in the ANSES study was analysed as well[9]. Nevertheless, it has to be mentioned that a systematic review of the scientific literature is beyond the scope of this study. The main articles are shortly summarised below.

Enyoh et al. 2020: An overview of emerging pollutants in air: Method of analysis and potential public health concern from human environmental exposure

A study by Enyoh et al. provided a list of pollutants of emerging concern[10].:

- VOC:
    - Acrylonitrile,
    - 1,3-butadiene,
    - Chloroform,
    - Dichloromethane,
    - Ethylene oxides,
    - Formaldehyde,
    - Toluene,
    - Trichloroethylene,
    - 1,4-Dioxane.

[9] ANSES (2018).

[10] Enyoh, et al. (2020).

- Metals:
    - Arsenic,
    - Manganese, and
    - Vanadium.
- PM:
    - Ultrafine particles,
    - Micro- and nano- plastics,
    - engineered nanoparticles,
    - Diesel/black carbon and
    - Bioaerosols.

Robichaud, 2020: An overview of selected emerging outdoor airborne pollutants and air quality issues: The need to reduce uncertainty about environmental and human impacts

A study by Robichaud for Environment and Climate Change Canada provided a prioritisation via a cumulative score, which depends on the substance's known impacts on human health, appearance on different lists of chemicals of concern, concentrations found in measurement campaigns and their level above background levels, impact on climate change, and whether a compound has been selected for future regulations by the WHO[11]:

Table 1: Proposed selection of the most critical emerging outdoor pollutant

After[12]

Cumulative score achieved	Number of compounds achieving this score	List of compounds selected according to the cumulative score	Prioritization level
6	2	Acrylonitrile, 1,3-Butadiene	1
5	4	Arsenic, Tetrachloroethene, Toluene, Trichloroethylene	2
4	4	Ethylene oxide, Formaldehyde, Manganese, Nickel	3
3	6	Acrolein, Chloroform, Dichloromethane, Naphthalene, Cadmium, Vanadium.	4
2	24	1,2,4-Trimethylbenzene,1,3,5-Trimethybenzene, Anti-mony, Carbon disulfide, Chrome, Copper, Cyclohexane, Dimethyl disulfide, Dimethyl sulfide, Ethylbenzene, Hydrogen sulfide, Iron oxide, MEK, methylcyclohexane, m-p-Xylene, n-Bu-tane, n-Heptane, n-Hexane, n-Octane,	5

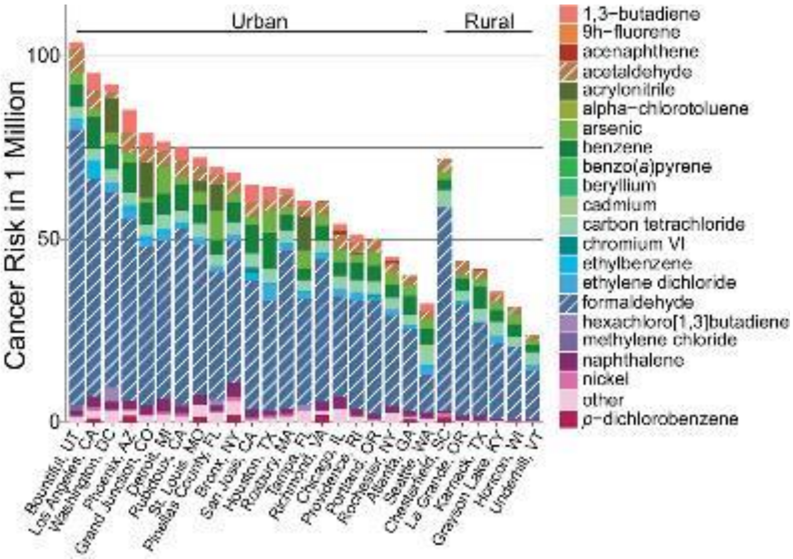
[11] Robichaud (2020).

[12] Robichaud (2020).

		n-Propylbenzene, o-Xylene, Platine, Propene, Styrene (candidate for future selection)	
1	222	Not selected for critical prioritization	6
0	More than 4000	Not selected for critical prioritization	7

Weitekamp et al., 2021: An Examination of National Cancer Risk Based on Monitored Hazardous Air Pollutants

A study by Weitekamp et al. conducted a more detailed analysis of the 2014 US National Air Toxic Assessment (see section 1.3)[13]. The following figure from this study shows an assessment of cancer risks of a number of pollutants for different urban locations.



The largest contribution come from the following pollutants (in alphabetical order):

- 1,3-butadiene
- Acrylonitrile
- Arsenic
- Benzene
- Carbon tetrachloride
- Formaldehyde
- Naphtalene

[13] Weitekamp, et al. (2021).

1.2. International organisations

ACTRIS

The national focal points (NFP) of the ACTRIS[14] network were asked for information regarding additional pollutants to be monitored and their priorities. In their replies UFP, particle number size distribution (PNSD), aerosol composition (including BC/EC) were named as pollutants which are of interest to ACTRIS and for which the ACTRIS network aims at harmonising monitoring.

In addition, contact was established to the project RI-URBANS[15], which aims at innovative urban air quality service tools, complementing existing air quality monitoring networks in selected cities, and providing innovative tools to better quantify the impact of atmospheric species most harmful to human health. Next to this, the importance was highlighted to monitor biogenic VOC as ozone precursor by an ACTRIS NFP.

AQUILA

AQUILA[16] is the European Network of National Air Quality Reference Laboratories. Working Group 6 under AQUILA currently discusses additional pollutants as well, which include:

- Fine combustion particles (Black Carbon, Elemental Carbon, Organic Carbon, Levoglucosan) at urban sites
- Tracer for non-exhaust emissions of traffic, esp. metals such as Mn
- Ammonia (NH_3) in areas where critical loads for eutrophication are largely exceeded
- Ultrafine particles (UFP) and size distribution at urban super-sites
- Particulate matter oxidative potential (urban sites under research projects)
- Nitro-PAH (mainly from diesel engines, in areas where high concentrations are expected)
- Pesticides (in areas where high concentrations are expected)

EMEP

The co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (EMEP)[17] under the UNECE Air Convention[18] has developed a monitoring strategy[19], which covers a large set of pollutants that should provide consistent and adequate observational data supporting the EMEP objectives. These include *inter alia*:

- Concentrations and deposition fluxes to assess exposure and impacts on health, ecosystems, vegetation, materials;

[14] Aerosol, Clouds and Trace Gases Research Infrastructure, https://www.actris.eu/ (last viewed on 07.03.2022)

[15] https://riurbans.eu/ (last viewed on 07.03.2022)

[16] https://ec.europa.eu/jrc/en/aquila, https://ec.europa.eu/environment/air/quality/legislation/pdf/aquila.pdf (last viewed on 07.03.2022)

[17] https://emep.int/ (last viewed on 07.03.2022)

[18] https://unece.org/environment-policy/air (last viewed on 07.03.2022)

[19] https://projects.nilu.no/ccc/monitoring_strategy/ (last viewed on 07.03.2022)

- Investigation of atmospheric processes driving transport and transformation of pollution, to guide model improvements and to enable the analysis of individual pollution events.

The monitoring strategy differentiates between three levels, which go from basic chemical and physical measurements of atmospheric parameters at Level 1 sites to a more extensive set of parameters at Level 2 and atmospheric research orientated measurements at Level 3 sites. The aim of the strategy is that at least 30 Level 2 sites are operated in the EMEP domain. All these parameters are listed in the EMEP monitoring strategy[19].

GAW

The Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO) operates according to the GAW Implementation Plan 2016-2023[20]. The GAW programme currently focuses on six groups of variables (also called focal areas):

- Greenhouse Gases
- Ozone
- Aerosol
- Selected Reactive Gases
- Total Atmospheric Deposition
- Ultraviolet (UV) Radiation

GAW recommends measuring the following variables (among others):

- **Greenhous Gases**: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated compounds and sulfur hexafluoride (SF_6)
- **Reactive Gases**: Volatile Organic Compounds (VOC), including Ethane, Propane, Acetylene, Isoprene, Formaldehyde, Terpenes, Acetonitrile, Methanol, Ethanol, Acetone, Dimethyl sulfide, Benzene, Toluene, iso/normal Butane, iso/normal Pentane
- Aerosol number concentration and number size distribution

JRC

A study by the Joint Research Centre (JRC) of the European Commission discusses the following pollutants[21]:

- Black Carbon / Elemental Carbon
- Ammonia (NH_3)
- Ultrafine particles
- Methane

[20] https://library.wmo.int/doc_num.php?explnum_id=3395 (last viewed on 07.03.2022)

[21] Monforti-Ferrario, et al. (2022).

- Levoglucosan

1.3. United States Environmental Protection Agency

1.3.1. National Air Toxics Assessment

The United States Environmental Protection Agency (US-EPA) undertakes a so-called "National Air Toxics Assessment"[22], which is an on-going review of a large number of air toxics. So far, EPA has completed six assessments, which includes nationwide long-term cancer risk estimates and noncancer hazards of air toxics. The latest, the 2014 NATA[23], was released in 2018. This assessment named the following pollutants, which are of specific concern:

- **National cancer risk driver**: Formaldehyde
- **Regional cancer risk drivers**: Ethylene oxide, Chloroprene
- **National cancer risk contributors**: 1,3-butadiene, Acetaldehyde, Benzene, Carbon tetrachloride, Naphthalene
- **Regional cancer risk contributors**: 1,4-dichlorobenzene, Arsenic compounds, Chromium VI compounds, Coke oven emissions, Ethylbenzene
- **National noncancer hazard drivers**: None
- **Regional noncancer hazard drivers**: Chlorine, Hexamethylene diisocyanate

1.3.2. Photochemical Assessment Monitoring Stations

The US EPA operates a so called Photochemical Assessment Monitoring Stations (PAMS) network to develop a database for ozone precursors and support ozone model development.[24] In addition, the PAMS network allows to monitor the trends of ozone precursors. Next to NO, NO_2, total reactive oxidized nitrogen (NO_y)[25] and O_3 sampling the following VOCs are required (Table 2, Table 3). Currently, the PAMS network comprises around 40 sites.

All the VOCs are monitored on a hourly basis, except for carbonyl samples, where three 8-hour averaged samples per day on a 1 in 3 day schedule are required, or hourly averaged formaldehyde sampling.

The priority and optional compounds include a larger number of VOC substances compared to Annex X B of Directive 2008/50/EC.[26] The only two substances that are included in Annex X B but not part of PAMS monitoring are i-Hexane and i-Octane.

[22] https://www.epa.gov/national-air-toxics-assessment (last viewed on 07.03.2022)

[23] https://www.epa.gov/national-air-toxics-assessment/2014-nata-assessment-results (last viewed on 07.03.2022)

[24] https://www.epa.gov/amtic/photochemical-assessment-monitoring-stations-pams (last viewed on 17.03.2022)

[25] NO, NO_2, NO_3, N_2O_5, HNO_3, HONO, peroxyacetyl nitrate (PAN) and further reactive nitrogen species

[26] The substances included in Annex X B of Directive 2008/50/EC are marked by "e" in Table 2 and Table 3.

Table 2: Priority compounds for US Photochemical Assessment Monitoring Stations

Source: US EPA[27]

Priority Compounds	
1,2,3-trimethylbenzene [a,e]	n-hexane [b,e]
1,2,4-trimethylbenzene [a,e]	n-pentane [e]
1-butene	o-ethyltoluene [a]
2,2,4-trimethylpentane [b]	o-xylene [a,b,e]
Acetaldehyde [b,c]	p-ethyltoluene [a]
Acetone [c,d]	Propane [e]
Benzene [a,b,e]	Propylene [e]
c-2-butene e	Styrene [a,b]
Ethane [d,e]	Toluene [a,b,e]
Ethylbenzene [a,b]	t-2-butene [e]
Ethylene [e]	
Formaldehyde [b,c,e]	
Isobutane [e]	
Isopentane [e]	
Isoprene	
m&p-xylenes [a,b,e]	
m-ethyltoluene [a]	
n-butane e	

[a] Important SOAP (Secondary Organic Aerosols Precursor) Compounds

[b] HAP (Hazardous Air Pollutant) Compounds

[c] Carbonyl compounds

[d] Non-reactive compounds, not considered to be VOC for regulatory purposes

[27] Technical Note: Guidance for Photochemical Assessment Monitoring Stations (PAMS). Required Network Implementation Plans and Enhanced Monitoring Plans (EMPs), https://www.epa.gov/sites/default/files/2019-11/documents/pams_monitoring_network_and_emp_plan_guidance.pdf (last viewed on 17.03.2022)

[e] Included in Annex X B of Directive 2008/50/EC

Table 3: Optional compounds for US Photochemical Assessment Monitoring Stations

Source: US EPA[27]

Optional Compounds	
1,3,5-trimethylbenzene [e]	m-diethlybenzene
1-pentene [e]	Methylcyclohexane
2,2-dimethylbutane	Methylcyclopentane
2,3,4-trimethylpentane	n-decane
2,3-dimethylbutane	n-heptane [e]
2,3-dimethylpentane	n-nonane
2,4-dimethylpentane	n-octane [e]
2-methylheptane	n-propylbenzene [a]
2-methylhexane	n-undecane
2-methylpentane	p-diethylbenzene
3-methylheptane	t-2-pentene
3-methylhexane	α/β-pinene
3-methylpentane	1,3 butadiene [b,e]
Acetylene [e]	Benzaldehyde [c]
c-2-pentene [e]	Carbon tetrachloride [b]
Cyclohexane	Ethanol
Cyclopentane	Tetrachloroethylene [b]
Isopropylbenzene [b]	

[a] Important SOAP (Secondary Organic Aerosols Precursor) Compounds

[b] HAP (Hazardous Air Pollutant) Compounds

[c] Carbonyl compounds

[e] Included in Annex X B of Directive 2008/50/EC

1.3.3. Chemical Speciation Network

The US Chemical Speciation Network (CSN) comprises around 140 monitoring sites where $PM_{2.5}$ samples are chemically analysed on a 1-in-3 day or 1-in-6 day sampling schedule.[28] The objectives and analysed components are similar to those required by Annex IV of Directive 2008/50/EC, except for a much larger set of metals and other elements[29].

1.4. OECD and further countries

Further information on considerations regarding additional pollutants were collected from selected OECD[30] member countries[31].

1.4.1. Australia

The Austrialian National Environment Protection (Air Toxics) Measure[32] includes monitoring and reporting requirements for the following additional pollutants:

- Formaldehyde
- Toluene
- Xylenes (as total of ortho, meta and para isomers)

The monitoring methods are the same as those required by the US EPA.

1.4.2. Israel

Israel has laid down an extensive set of air pollutants in the Clean Air Law of 2008.[33] Annex 2 provides the so-called clean air values, which are target values, ambient values and alert values, in detail. The additional pollutants covered are shown in the table below.

[28] https://www.epa.gov/amtic/chemical-speciation-network-csn (last viewed on 17.03.2022)

[29] Antimony (Sb), Arsenic (As), Aluminum (Al), Barium (Ba), Bromine (Br), Cadmium (Cd), Calcium (Ca), Chromium (Cr), Cobalt (Co), Copper (Cu), Chlorine (Cl), Cerium (Ce), Cesium (Cs), Iron (Fe), Lead (Pb), Indium (In), Manganese (Mn), Nickel (Ni), Magnesium (Mg), Phosphorous (P), Selenium (Se), Tin (Sn), Titanium (Ti), Vanadium (V), Silicon (Si), Silver (Ag), Zinc (Zn), Strontium (Sr), Sulfur (S), Rubidium (Rb), Potassium (K), Sodium (Na), Zirconium (Zr). https://www.epa.gov/sites/default/files/2020-07/documents/csn_aqs_parameters_july_2020.pdf (last viewed on 17.03.2022)

[30] Organisation for Economic Co-operation and Development

[31] Next to EU Member States and EEA countries, these are Australia, Canada, Chile, Colombia, Costa Rica, Israel, Japan, South Korea, Mexico, New Zealand, United Kingdom, and United States. A search at the websites of the respective Ministries of Environment for Chile, Colombia, and Costa Rica revealed no relevant information.

[32] https://www.legislation.gov.au/Details/F2011C00855 (last viewed on 08.03.2022)

[33] https://www.gov.il/en/departments/legalInfo/clean_air_law_2008 (last viewed on 07.03.2022)

Table 4: Pollutants for which clean air values are laid down in the Israel Clean Air Law 2008

Source: Ministry of Environmental Protection, Israel

Pollutant	CAS RN
1,2 Dichloroethane	107-06-2
Dichloromethane (Methylene Chloride)	75-09-2
Tetrachloroethylene	127-18-4
Trichloroethylene	79-01-6
Hydrogen Sulphide	7783-06-4
Styrene	100-42-5
Formaldehyde	50-00-0
Sulphate salts in PM	
Vanadium	
Chromium	
Mercury	

1.4.3. Japan

The environmental standards[34] for air pollutants in Japan include a number of additional pollutants not covered by the EU AAQDs.

Table 5: Environmental standards for additional air pollutants in Japan

Source: Ministry of the Environment, Japan

Pollutant	Environmental conditions	Measuring method
Trichlorethylene	Annual average value is 0.13 mg/m³ or less. (Notification of H30.11.19)	A method of measuring a sample collected by a canister or a collection

[34] https://www-env-go-jp.trans-late.goog/kijun/taiki.html?_x_tr_sch=http&_x_tr_sl=ja&_x_tr_tl=en&_x_tr_hl=de&_x_tr_pto=wapp (last viewed on 07.03.2022)

Tetrachlorethylene	Annual average value is 0.2 mg/m^3 or less. (Notification of H9.2.4)	tube with a gas chromatograph mass spectrometer, or a method recognized as having equivalent or higher performance.
Dichloromethane	Annual average value is 0.15 mg/m^3 or less. (Notification of H13.4.20)	
Dioxins	Annual average value is 0.6 pg-TEQ/m^3 or less. (Notification of H11.12.27)	A method of measuring a sample collected by an air sampler with a collection tube equipped with polyurethane foam attached to the back of the filter paper with a high-resolution gas chromatograph mass spectrometer.
NMVOC	3-hour mean of non-methane volatiles from 6 am to 9 am ranges from 0.20 ppmC to 0.31 ppmC, which corresponds to a daily maximum hourly value of 0.06 ppm for photochemical oxidants (S51.8.13 notification)	

Environmental standards do not apply to industrial areas, roadways and other areas or places where the general public does not normally live.

1.4.4. New Zealand

The updated air quality guidelines[35] for New Zealand of 2002 includes a number of pollutants, next to pollutants covered in the AAQDs (Table 6).

Table 6: Air quality guidelines for additional pollutants in New Zealand

Source: Ministry of Environment, New Zealand

Contaminant	Guideline value	Averaging time
1,3-Butadiene	2.4 µg/m^3	Annual
Formaldehyde	100 µg/m^3	30 minutes
Acetaldehyde (CAS RN: 75-07-0)	30 µg/m^3	Annual
Mercury (inorganic)	0.33 µg/m^3	Annual
Mercury (organic)	0.13 µg/m^3	Annual
Chromium VI	0.0011 µg/m^3	Annual
Chromium metal and chromium III	0.11 µg/m^3	Annual
Arsine (AsH_3) (CAS RN: 7784-42-1)	0.05 µg/m^3	Annual

[35] https://environment.govt.nz/publications/ambient-air-quality-guidelines-2002-update/ (last viewed on 07.03.2022)

1.4.5. South Korea[36]

National ambient air quality standards in South Korea for air quality are laid down for the main air pollutants.[37] Currently, the main focus lies on PM, especially identification of long-range transport, alerts in case of elevated levels of PM, and how to reduce emissions of PM. Heavy metal, VOCs, PAHs, precipitation pollutants, CFC, CH_4, ion and ingredient of PM are monitored for research purposes. Up-to-date data of Pb, Ca, Mn, Ni, Zn in particulate matter is reported via a dedicated website.[38] Monitoring of ozone, aerosol, NO_2, SO_2, HCHO via satellite has recently been started.[39]

1.4.6. Taiwan

Monitoring of air pollution in Taiwan is described at a dedicated website of the Environmental Protection Administration of Taiwan.[40] Monitoring comprises classical pollutants at different types of monitoring stations. There are two main differences compared to air quality monitoring in the EU. The Environmental Protection Administration operates so called Photochemical Assessment Monitoring Stations, which aim to better understand the formation of O_3. Hence, next to O_3 and NO_x, VOC are monitored at these sites. This concept was taken from the US EPA.[41] There are four types of stations:[42]

- Upwind and Background Characteristics (Type 1)
- Maximum Ozone Precursor Concentration (Type 2)
- Maximum O_3 Concentration (Type 3)
- Far Downwind (Type 4)

Secondly the Environmental Protection Administration undertakes so called traffic monitoring, which includes monitoring of CO, HC, NO_x, SO_2, O_3, PM_{10} and $PM_{2.5}$. These sites are situated in heavily trafficked roads and their objective is to protect pedestrians from air pollution.[43]

CH_4 is monitored as well; however, this data is not yet publicly available.

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[36] Personal communication Pilmu Ryu, WHO Technical Officer.

[37] $PM_{2.5}$, PM_{10}, O_3, NO_2, CO, SO_2, Pb, Benzene, see https://www.airkorea.or.kr/eng/link?pMENU_NO=160 (last viewed on 14.03.2022)

[38] https://www.airkorea.or.kr/web/metalComponents?pMENU_NO=110 (last viewed on 14.03.2022)

[39] https://nesc.nier.go.kr/ (last viewed on 14.03.2022)

[40] https://airtw.epa.gov.tw/ENG/Default.aspx (last viewed on 16.3.2022)

[41] https://www.epa.gov/amtic/photochemical-assessment-monitoring-stations-pams (last viewed on 16.3.2022)

[42] https://airtw.epa.gov.tw/ENG/TaskMonitoring/Photochemical/PhotochemicalBack.aspx (last viewed on 16.3.2022)

[43] https://airtw.epa.gov.tw/ENG/TaskMonitoring/Traffic/TrafficIntro.aspx (last viewed on 16.3.2022)

1.4.7. United Kingdom

The United Kingdom runs a number of specific automatic and non-automatic networks for additional air pollutants. An environmental objective[44] of 2.25 µg/m³ was laid down for 1,3-Butadiene for the running annual mean, which is monitored within the automatic hydrocarbon network[45] for ozone precursor monitoring.

Particle Numbers and Concentrations Network

This network[46] consists of four sites, where next to PM and the chemical composition of PM, particle number concentrations[47], i.e. UFP, particle size distribution[48] and aerosol chemical speciation[49] are monitored.

National Ammonia Monitoring Network

A national ammonia monitoring network[50] (NAMN) is operated within the the United Kingdom Eutrophying & Acidifying Network[51] (UKEAP). The NAMN consists currently of around 70 sites where monthly NH_3 concentrations are monitored on a long-term basis. The goal of the network is to examine responses to changes in the agricultural sector and to verify compliance with targets set by international agreements.

Black Carbon network

BC monitoring started in 2006; currently 14 sites are operated.[52] The sites include regional background, urban background and urban traffic locations.

Toxic Organic Micro Pollutants (TOMPs) networks

The TOMPs network[53] includes the following substances:

- polychlorinated biphenyls (PCBs, 37 congeners, 4 coplanar congeners),
- polychlorinated-p-dioxins (PCDDs, 7 congeners),
- polychlorinated dibenzofurans (PCDFs, 10 congeners),
- polybrominated diphenyl ethers (PBDEs, 22 congeners),
- decabrominated diphenyl ether (decaBDE),

[44] https://uk-air.defra.gov.uk/assets/documents/Air_Quality_Objectives_Update.pdf (last viewed on 07.03.2022)

[45] https://uk-air.defra.gov.uk/networks/network-info?view=hc (last viewed on 07.03.2022)

[46] https://uk-air.defra.gov.uk/networks/network-info?view=particle (last viewed on 07.03.2022)

[47] CPC - Condensation Particle Counter

[48] SMPS - Scanning Mobility Particle Sizers

[49] ACSM – Aerodyne Aerosol Chemical Speciation Monitor

[50] https://uk-air.defra.gov.uk/networks/network-info?view=nh3 (last viewed on 07.03.2022)

[51] https://uk-air.defra.gov.uk/networks/network-info?view=ukeap (last viewed on 07.03.2022)

[52] https://uk-air.defra.gov.uk/networks/network-info?view=ukbsn (last viewed on 07.03.2022)

[53] https://uk-air.defra.gov.uk/networks/network-info?view=tomps (last viewed on 07.03.2022)

- hexabromocyclododecane (HBCDD)

Heavy metals network

The heavy metals network[54] includes the following pollutants next to pollutants covered in the AAQDs:

- Chromium (Cr),
- Cobalt (Co),
- Copper (Cu),
- Iron (Fe),
- Manganese (Mn),
- Selenium (Se),
- Vanadium (V) and
- Zinc (Zn)

1.5. Replies, literature from Member States

The EIONET national focal points (NFP) were contacted and asked whether a list of additional pollutants was prepared in their country. In addition, the experts were asked about their views on priorities or an approach regarding prioritisation of additional pollutants. Overall, 16 Member States[55] replied to this request.

According to the responses the following pollutants should be considered next to the pollutants covered by the AAQDs:

- UFP
- BC / EC
- NH_3
- Total Carbon (sum of organic carbon, OC, and EC)
- VOC
- H_2S (regarding smell)
- Mercaptane (regarding smell)
- Formaldehyde (regarding smell)
- TSP

[54] https://uk-air.defra.gov.uk/networks/network-info?view=metals (last viewed on 07.03.2022)

[55] Belgium, Cyprus, Germany, Denmark, Estonia, Spain, Finland, France, Hungary, Croatia, Ireland, Italy, Luxembourg, Malta, Sweden, and Slovakia. In addition, the EEA countries Norway and Türkiye replied to the request. The views of Austria, Greece and the Netherlands are covered by the members of the consortium.

- N_2O

In addition, a Member State recommended so-called supersites[56] at which specific pollutants are monitored to address process and/or source-receptor issues in the context of exposure, health risks or ecosystem protection.

The French Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (ANSES) published an opinion in 2018 regarding emerging pollutants that are currently not covered by air quality monitoring legislation[57]. The highest priorities are given to (in descending priority):

- 1,3-butadiene
- Manganese
- Hydrogen sulfide
- Acrylonitrile
- 1,1,2-trichloroethane
- Copper
- Trichlorethylene
- Vanadium
- Cobalt
- Antimony
- Naphthalene

In addition, in 2020 ANSES published a report regarding pesticides in ambient air that require further assessment, based on the results of a one-year campaign performed by air quality monitoring networks (AASQA), the French Laboratoire Central de Surveillance de la Qualité de l'Air (LCSQA) and ANSES[58]. The presence of pesticides in ambient air has been investigated in some countries in Europe as well.

Furthermore, LCSQA has published a list of pollutants of national interest[59]. Next to all pollutants covered in the AAQDs, this document include:

- 75 pesticides,
- major chemical species of the fine fraction of PM (in real time): Black Carbon, Sulphate, Ammonium, Nitrate, Organic matter (implemented in the French CARA program[60]),
- UFP as particle number concentrations (PNC)"

[56] The concept of supersites seems to have been introduced by US EPA in 1998 for a PM monitoring programm to better understand source-receptor relationships and atmospheric processes leading to PM accumulation on urban and regional scales, see Solomon, Hopke (2008).

[57] ANSES (2018).

[58] ANSES (2020); LCSQA (2020a).

[59] LCSQA (2021b).

[60] Favez, et al. (2021).

For the purpose of environmental permitting, Estonia has developed a list of pollutants and established limit or target values[61].

Table 7: National air quality limit and target values in Estonia

Selection

Name	CAS RN	Formula	Limit / target value [µg/m³]		
			1h	24h	annual
Hydrogen chloride	7647-01-0	HCl	600	200	
Formaldehyde	50-00-0	$HCHO$	150	50 / 30*	
Xylene (dimethylbenzen)		$(CH_3)_2C_6H_4$	300	100	
Toluene	108-88-3	$C_6H_5CH_3$	600	200	
Phenol	108-95-2	C_6H_5OH	30	10	
Styrene	100-42-5	$C_6H_5CH=CH_2$	140	50	
Ethyl acetate	141-78-6	$CH_3COOC_2H_5$	3000	1000	
Dichloromethane	75-09-2	CH_2Cl_2	1350	450	
Ethylbenzene	100-41-4	C_8H_{10}	600	200	
Glycol monoethyl ether	110-80-5	$C_2H_5OCH_2CH_2OH$	150	50	
Methanethiol	74-93-1	CH_3SH	0.2		
Butyl acetate	123-86-4	$CH_3COO(CH_2)_3CH_3$	1950	650	
1-Propanol, 2-Propanol	71-23-8 67-63-0	C_3H_7OH	3000	1000	
Acetone	67-64-1	CH_3COCH_3	1050	350	
Manganese	7439-96-5	Mn		1	0.15
Chromium(VI)	7440-47-3	Cr		0.1	0.01
Tin	7440-66-6	Zn		50	
Vanadium	1314-62-1 (V_2O_5) 7440-62-2	V		1	

[61] https://www.riigiteataja.ee/aktilisa/1060/3201/9012/KKM_m8_lisa1.pdf (last viewed on 07.03.2022)

	(V)				
Copper	7440-50-8	Cu		2	
1,2-Dichloroethane	107-06-2	$ClCH_2CH_2Cl$	150	50	
Tetrachloroethylene	127-18-4	CCl_2=CCl CCl_2	180	60	
Hydrogen sulfide	7783-06-4	H_2S	8		

* target value

The German Umweltbundesamt published an opinion paper on "Considerations on the Revision of the Air Quality Directive 2008/50 EU" in June 2022[62]. The paper recommends inter alia establishing supersites[56], which should improve the scientific understanding of air pollution, and mandatory monitoring of NH_3, UFP and BC.

1.6. Selected pollutants

The information on priorities described in section 1.1 to 1.5 was taken as a basis for the discussion at the kick-off meeting on 28 January 2022 with DG ENV to decide on the pollutants to be covered within this study, next to UFP, BC/EC, NH_3 and CH_4. The following criteria were considered, which allowed to choose the additional pollutants:

- Pollutant named by several institutions or studies to substantiate the selection;
- Health and environmental impacts based on a preliminary literature research;
- Relevance not only for specific industrial or agricultural areas;
- Information and data available in Europe.

Based on the priorities described in section 1.1 to 1.5 and these criteria, it was decided at the kick-off meeting to focus on the following additional air pollutants:

- 1,3-Butadiene;
- Formaldehyde;
- Manganese;
- Vanadium;
- Oxidative Potential of PM.

In addition, it was agreed to reflect on the following pollutants and group of pollutants to shortly describe why these pollutants are of concern for human health and / or the environment, and the reasons why they were not included in the above list of additional pollutants (section 1.7):

[62] Umweltbundesamt Dessau (2022).

- Acrylonitrile;
- Pesticides;
- N_2O;
- Ultrafine Particle number size distribution;
- Bio-aerosols.

1.6.1. Ultrafine particles (UFP)

UFP are generally considered as particulates with a diameter less than or equal to 0.1 µm (100 nm). In contrast to PM_{10} and $PM_{2.5}$, UFP are monitored as particle number concentrations (PNC), typically number of particles per cm^3. The main sources of UFP are combustion processes from vehicles, aviation, shipping, industrial and power plants, and residential heating. In addition, UFP originate from volatile organic compounds (VOC) from both anthropogenic and natural sources via photochemical processes[63]. This process is usually called “new particle formation”.

The technical specification CEN/TS 16976:2016 “Ambient air - Determination of the particle number concentration of atmospheric aerosol” describes monitoring of UFP.

The WHO Air Quality Guidelines state that a number of studies demonstrated short-term effects of exposure to UFP, including mortality, emergency department visits, hospital admissions, respiratory symptoms, and effects on pulmonary/systemic inflammation, heart rate variability and blood pressure; and long-term effects on mortality (all-cause, cardiovascular, IHD and pulmonary) and several types of morbidity[64]. However, these studies analysed various UFP size ranges and exposure metrics, which prevented a thorough comparison of results across studies[65]. Therefore, it was concluded in the WHO Air Quality Guidelines that the body of epidemiological evidence was not yet sufficient to formulate an Air Quality Guideline level[66]. Nevertheless, the WHO Air Quality Guidelines include so-called “good practice statements”, see section 3.

1.6.2. Black Carbon / Elemental Carbon

Black carbon (BC) is a measure of airborne soot-like carbon that is determined with optical monitoring methods. It is closely related to the mass concentration of elemental carbon (EC), which is monitored by thermo-optical methods. BC/EC is typically formed through the incomplete combustion of fossil fuels, biofuel and biomass, and is emitted from both anthropogenic and natural sources[67].

Due to the ambiguity of different names, definitions and monitoring methods for BC/EC and further carbonaceous matter, a recommended terminology was developed[68]:

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[63] Xiao, et al. (2021).

[64] WHO (2021).

[65] US EPA (2019).

[66] WHO (2021).

[67] WHO (2021).

[68] 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.

These definitions were included in the WMO/GAW aerosol measurement procedures guidelines[69]. Monitoring of BC is done via optical methods (Multi Angle Absorption Photometer and so-called Aethalometer). So far, there is no standard for monitoring of BC. For EC (and OC), a standard for a thermo-optical method is laid down in EN 16909:2017-06 “Ambient air - Measurement of elemental carbon (EC) and organic carbon (OC) collected on filters”. According to Annex IV of Directive 2008/50/EC monitoring of EC and OC in $PM_{2.5}$ is required at rural background locations in EU Member States.

BC can include known carcinogens and other toxic species[70]. In addition, BC is a so-called short-lived climate forcer, as BC absorbs heat in the atmosphere and reduces albedo (the ability to reflect sunlight) when deposited on snow and ice[71].

WHO has formulated good practice statements for BC /EC, see section 3.

1.6.3. Ammonia (NH_3)

In higher concentrations, NH_3 irritates the eyes and respiratory tract. However, correspondingly high concentrations in ambient air are not to be expected. NH_3 reacts relatively quickly with sulfur dioxide (SO_2) and nitrogen oxides (NOx), forming the secondary inorganic particles ammonium sulfate and ammonium nitrate. In many regions, these account for a large proportion of $PM_{2.5}$.

Nitrogen is an essential nutrient of plants. Only high concentrations and inputs of reactive nitrogen compounds lead to damage. High concentrations of ammonia, which is an important reactive nitrogen compound, cause direct damage to leaves (lichens are

[69] WMO (2016).

[70] WHO (2021).

[71] UNEP (2011).

particularly sensitive). Depending on the amount and duration, climatic, soil and vegetation-specific properties, long-term excessive inputs of nitrogen lead to ecosystem effects. NH_3 and NH_3 compounds can acidify soil and water and lead to eutrophication of sensitive ecosystems. As a result, nutrient imbalances in trees can restrict their growth and stress tolerance, and increased nitrate losses into the groundwater can occur. Eutrophication is also partly responsible for the significant decline in biodiversity[72].

Under the UNECE Air Convention so-called critical levels were developed for NH_3[73].

Table 8: Critical levels for NH_3 (µg/m³)

Source:[74]

Vegetation type	Critical level NH_3 [µg/m³]	Time period
Lichens and bryophytes (including ecosystems where lichens and bryophytes are a key part of ecosystem integrity)	1	Annual mean
Higher plants (including heathland, grassland and forest ground flora)	3*	Annual mean
Provisional critical level		
Higher plants	23	Monthly mean

* An explicit uncertainty range of 2-4 µg/m³ was set for higher plants (including heathland, semi-natural grassland and forest ground flora). The uncertainty range is intended to be useful when applying the critical level in different assessment contexts (e.g. precautionary approach or balance of evidence.)

NH_3 can be monitored by passive (diffusive) samplers, denuders and continuous methods. An European standard was developed for diffusive samplers, EN 17346:2020: Ambient air - Standard method for the determination of the concentration of ammonia using diffusive samplers.

While there is no obligation under the AAQDs to monitor atmospheric ammonia concentrations, there are provisions to monitor ammonia under Art 9. of Directive (EU) 2016/2284.

Denuders are coated diffusion separators, which are partly used at EMEP stations.

There is no reference method yet available for continuous monitoring of NH_3, even though a standard is under development[75]. Continous monitoring methods are e.g. the so-called cavity ring-down spectroscopy (CRDS) or spectrometer with an open light path and special lasers as a light source[76].

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[72] CCE, RIVM (2011).

[73] CLRTAP (2017).

[74] CLRTAP (2017).

[75] http://www.metnh3.eu/typo3/ (last viewed on 10.08.2022)

[76] EMRP (2017).

The main source of NH_3 is agriculture[77].

1.6.4. Methane (CH_4)

CH_4 is an important precursor for tropospheric ozone formation, see e.g.[78]. Next to that, CH_4 also acts as an important greenhouse gas and as such contributes to climate change[79].

The main sources of CH_4 in the EU are agriculture, waste, and energy supply.[80] In December 2021 the European Commission published a proposel to reduce and monitor emissions of the energy sector.[81]

Measurements of CH_4 can be performed with a gas chromatograph equipped with flame ionization detector (FID)[82]. The sampling can be done directly from the air inlet to the GC-FID or by collecting air samples in steel canisters or tedlar bags. Online CH_4 analyzers based on spectroscopic technologies (e.g. Cavity Ring-Down Spectroscopy, CRDS) are available since 2005.

1.6.5. 1,3-Butadiene

1,3-Butadiene (CAS RN 106-99-0) is a colorless gas with a mild odor similar to gasoline, and it is highly flammable.[83] The primary use of 1,3-Butadiene is in the manufacturing of plastic and rubber products. The sources of 1,3-Butadiene are exclusively anthropogenic (manufacture of rubbers, resins, latex-styrene-butadiene and neoprene emulsions, automobile engine exhaust, cigarette smoke, combustion of plastics and rubber).

A summary of the sources and health impacts of 1,3-Butadiene is provided e.g. in the report by ANSES on emerging pollutants, the study by Robichaud for Environment Canada as well as the US EPA NATA documentation, further documentation[83] and the Integrated Risk Information System[84] (IRIS)[85].

The main health impacts can be described as following[83][86]:

- Acute Effects: irritation of the eyes, nasal passages, throat, and lungs. Neurological effects at very high exposure levels.
- Chronic Effects (Noncancer): increase in cardiovascular diseases, effects on the blood.

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[77] EEA (2021).

[78] Fiore, et al. (2008).

[79] IPCC (2021).

[80] https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer (last viewed on 07.03.2022)

[81] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_6684, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A805%3AFIN&qid=1639665806476 (last viewed on 3.8.2022)

[82] https://library.wmo.int/index.php?lvl=notice_display&id=139#.Yh36AujMK70 (last viewed on 07.03.2022)

[83] https://www.epa.gov/aegl/13-butadiene-results-aegl-program, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-13-butadiene, https://www.epa.gov/sites/default/files/2016-08/documents/13-butadiene.pdf (last viewed on 07.03.2022)

[84] https://www.epa.gov/iris, https://iris.epa.gov/ChemicalLanding/&substance_nmbr=139, https://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=54499 (last viewed on 07.03.2022)

[85] ANSES (2018); Robichaud (2020); US EPA (2020).

[86] IARC (2008); IARC (2012); ANSES (2018).

- Cancer Risk: risk of leukemia, respiratory, bladder, stomach, and lymphato-hematopoietic cancers. IARC has classified 1,3-Butadiene as carcinogenic to humans (Group 1)[87]. EPA has classified 1,3-butadiene as carcinogenic in human by inhalation[83].
- Mutagenicity: European Chemicals Agency (ECHA) (Classification, Labelling and Packaging, CLP): cat. 1B[88]

Monitoring of 1,3-Butadiene can be done online (in-situ) using an automatic gas chromatograph, as it is done in the UK Automatic Hydrocarbon Network for currently 29 parameters[89]. Alternatively, the sampling can be done with steel canisters or with sampling tubes. Analyses are performed with a gas chromatograph in the laboratory.

1.6.6. Formaldehyde

Formaldedhyde[90] (CAS RN 50-00-0) is a gaseous pollutant from many outdoor and indoor sources[91]. Major sources of formaldehyde include power plants, manufacturing facilities (e.g. manufacture of composite wood products), incinerators and automobile exhaust emissions. Forest fires and other natural sources of combustion are also sources of formaldehyde. In addition, it is formed naturally during the oxidation of VOC, which react with hydroxyl radicals and O_3 to form formaldehyde and other aldehydes as intermediates in a series of reactions that ultimately lead to the formation of carbon monoxide and dioxide, hydrogen and water[92].

Formaldehyde is carcinogenic to humans (Group 1)[93].

In addition, formaldehyde is a precursor for tropospheric O_3.

The most widely used technique for the monitoring of formaldehyde in ambient air is active sampling of ambient air through DNPH[94] cartridges. Analyses in the laboratory is done with high performance liquid chromatography (HPLC).

1.6.7. Manganese

Manganese (Mn, CAS RN 7439-96-5) is a transition metal; its anthropogenic sources are mainly industrial (production of ferro-alloys, foundries, combustion of fossil fuels). A natural source for Mn is entrainment of soil particles[95].

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[87] IARC (2008); IARC (2012).

[88] https://echa.europa.eu/substance-information/-/substanceinfo/100.003.138, https://echa.europa.eu/brief-profile/-/briefprofile/100.003.138 (category mutagenicity 1B: section 3.5.2 of Annex I, Regulation (EC) No 1272/2008, http://data.europa.eu/eli/reg/2008/1272/oj) (last viewed on 07.03.2022)

[89] https://uk-air.defra.gov.uk/networks/network-info?view=hc (last viewed on 07.03.2022)

[90] see also: https://www.epa.gov/formaldehyde (last viewed on 07.03.2022)

[91] IARC (2006b).

[92] IARC (2006b).

[93] IARC (2006b).

[94] 2,4-Dinitrophenylhydrazine

[95] ANSES (2018).

Mn is an essential human dietary element; however, at higher exposure levels Mn can also cause neurological disorder[96].

Existing scientific information cannot determine whether or not excess manganese can cause cancer[97].

Monitoring campaigns undertaken before the ANSES assessment of emerging pollutants showed exceedance of so called toxicological reference values[98] (VTR, 0.3 µg/m^3[99]) in the vicinity of installations classified for the protection of the environment[100][101].

Mn in ambient air is usually determined in PM_{10} or $PM_{2.5}$ samples.

Mn is a marker for non-exhaust traffic emissions.

1.6.8. Vanadium

Vanadium (V, CAS RN 7440-62-2) is a transition metal, whose main anthropogenic sources are industrial emissions (ferrous alloys and steels, non-ferrous alloys production) and fuel combustion (oil refineries, power plants). Natural sources are entrainment of soil particles, marine aerosols and volcanic emissions. Vanadium pentoxide is the major commercial product of vanadium.

IARC classifed Vanadium pentoxide as possibly carcinogenic to humans (Group 2B)[102].

Monitoring campaigns undertaken before the ANSES assessment of emerging pollutants showed exceedance of so called toxicological reference values[103] (VTR, 0.1 µg/m^3[104]) in the vicinity of installations classified for the protection of the environment[105][106].

V in ambient air is usually determined in PM_{10} or $PM_{2.5}$ samples.

V is a marker for non-exhaust traffic emissions.

1.6.9. Oxidative Potential of PM

The oxidative potential (OP) is a measure of the capacity of PM to oxidize target molecules. OP has been suggested by a number of studies to be one of the many possible drivers of the acute health effects of PM. However, the link remains uncertain[107].

Several methods for measuring OP have been developed. However, there is no common or standardised method[108]. Assays used to assess OP include electron spin resonance with

[96] ANSES (2018); ATSDR (2012a).

[97] ATSDR (2012a).

[98] VTR : valeurs toxicologiques de référence

[99] ATSDR (2012a).

[100] ICPE : installations classées pour la protection de l'environnement

[101] ANSES (2018).

[102] IARC (2006a).

[103] VTR : valeurs toxicologiques de référence

[104] ATSDR (2012b).

[105] ICPE : installations classées pour la protection de l'environnement

[106] ANSES (2018).

[107] Daellenbach, et al. (2020); Fang, et al. (2019); Gao, et al. (2020); Øvrevik (2019); Weichenthal, et al. (2016).

[108] Janssen, et al. (2014).

5,5-dimethylpyrroline-N-oxide as a spin trap which measures the ability of PM to induce hydroxyl radicals in the presence of H_2O_2, the ability of PM to deplete antioxidants such as ascorbic acid and glutathione, and the consumption of dithiothreitol[109]. A more detailed overview is provided in the table below[110].

The French Laboratoire Central de Surveillance de la Qualité de l'Air (LCSQA) published a bibliographic summary on the measurement of oxidative potential for the assessment of oxidative stress of PM in 2020[111].

Table 9: Assays for detection of the oxidative potential (OP) in cell-free/abiotic systems

Source:[112]

Assay	Species Detected
AA-depletion	Used to measure oxidative potential of transition metals ($^\bullet OH$ from H_2O_2). Interacts with several other reactive species.
GSH-depletion	Most ROS as well as peroxides, alkenals, protein disulfides and sulfenic acids
Congo Red	Hydroxylic, peroxide and hydroperoxide radicals
DCF (DCFH-DA)	$^\bullet NO_2$, $^\bullet OH$, $ONOO^-$, peroxyl, aloxyl and carbon-centered radicals, peroxides. Can be used to measure H_2O_2 in presence of a peroxidase catalyst (HRP). Prone to photooxidation.
2-deoxyribose	$^\bullet OH$ and $^\bullet OH$-like species (used as a simple and inexpensive substitute for ESR).
DHE	Can be specific for $O_2^{\bullet -}$ (require separation of products by HPLC). Interacts with several other reactive species.
DTT	Diverse range of free radicals and reactive species. Reduced by transition metals and quinones, in PM.
ESR (or EPR)	ESR with DMPO as spin-trap measures production of $^\bullet OH$, and is often used in combination with H_2O_2. ESR without spin-trapping can be used to measure surface radicals on particles (measures unpaired electrons).
Luminol	HOCl, H_2O_2 and $ONOO^-$

Abbreviations: AA—ascorbic acid; DCF—dichlorofluorescin; DCFH-DA—dichlorodihydrofluorescein diacetate; DHE—dihydroethidium; DMPO—5,5-dimethyl-pyrroline N-oxide; EPR—electron paramagnetic resonance; ESR—electron spin resonance; DTT—dithiothreitol; GSH—reduced glutathione; H_2O_2—hydrogen peroxide; HOCl—hypochlorous acid; HPLC—High-performance liquid chromatography; MDA—malondialdehyde; $^\bullet NO_2$—nitrogen dioxide; $O_2^{\bullet -}$—superoxide anion; $^\bullet OH$—hydroxyl radical; $ONOO^-$peroxynitrite; PM—particulate matter; ROS—reactive oxygen species.

[109] Janssen, et al. (2014); Øvrevik (2019).

[110] Øvrevik (2019).

[111] LCSQA (2020c).

[112] Øvrevik (2019).

1.7. Reflection on further pollutants

1.7.1. Acrylonitrile

Acrylonitrile (CH_2CHCN, CAS RN 107-13-1) belongs to the family of amines and its emission sources are strictly anthropogenic. The main sources are textile industry and in the fabrication of polymers, rubber, resins, and plastic materials[113]. Acrylonitrile is a category 2B carcinogenic according to the International Agency for Research on Cancer and it is toxic at low dosis[114]. According to US-EPA, acrylonitrile is categorised as “B1, Probable human carcinogen”[115]. A comprehensive list of impacts on human health is provided in the report by ANSES[116].

In the report by ANSES, acrylonitrile was given the 4th highest priority, in the article by Robichaud the prioritization level was “1” together with 1,3-Butadiene. Nevertheless, as acrylonitrile is associated with specific industrial activities, it is more appropriate to monitor acrylonitrile around industrial facilities, but less so Europe-wide.

Acrylonitrile monitoring is done in line with analysis of VOC, i.e. via gas chromatography–mass spectrometry (GC-MS).

1.7.2. Pesticides

Pesticides were named in the AQUILA working group 6 (section 1.2) and are included in the French list of air pollutants of national interest[117]. In addition, a number of studies have found elevated levels of pesticides in ambient air in specific regions[118].

The French Laboratoire Central de Surveillance de la Qualité de l'Air (LCSQA) published a monitoring strategy for pesticides in ambient air (41 other ref: LCSQA. Stratégie de suivi national du niveau d’imprégnation de fond des pesticides dans l’air ambiant, Verneuil-en-Halatte, 2022). This strategy is based on the recommendations published by ANSES in 2017 (41) and a collaborative work between AASQA, LCSQA & ANSES. Long-term monitoring started in summer 2021.[119]

ANSES published a monitoring strategy for pesticides[120]. This strategy includes also a description how to monitor pesticides. France has developed standards for sampling and analysis of pesticides, which is not straightforward as pesticides may be present in ambient air in gaseous phase, in aerosol or particulate phase, or even both depending on the compound, as well as in fog or rain. The active sampling of pesticides in ambient air is governed by standard XP X43-058 (AFNOR 2007a). Air is drawn at a known rate through a filter that retains the particulate phase, followed by an adsorbent material, such as polyurethane foam (PUF), to retain the gas phase. The two phases are most often combined

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[113] Robichaud (2020); ANSES (2018).

[114] IARC (1999).

[115] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=206 (last viewed on 07.03.2022)

[116] ANSES (2018).

[117] LCSQA (2021b).

[118] Coscollà, et al. (2010); Désert, et al. (2018); Linhart, et al. (2019); Linhart, et al. (2021).

[119] https://www.lcsqa.org/fr/actualite/pesticides-dans-lair-lancement-dun-suivi-annuel-et-national and https://www.ineris.fr/sites/ineris.fr/files/contribution/Documents/Ineris%20lancement_suivi_annuel_pesticides_juillet%202021.pdf (last viewed on 15.09.2022)

[120] ANSES (2017).

to be analysed together. The analysis is then carried out according to standard NF X43 059 (AFNOR 2007b).

Currently, the standards are developed further to be able to measure further pesticides not listed in the annexes of these standards, especially of polar substances such as glyphosate.

A prioritisation of pesticides to be monitored was recently published in a scientific article[121].

Due to the large number of pesticides used in different countries, the limited areas and times pesticides are deployed, dedicated monitoring campaigns are deemed to be more useful than Europe-wide activities.

1.7.3. Nitrous oxide (N_2O)

N_2O is a strong greenhouse gas with a Global Warming Potential (GWP) of 273 on a 100-year basis relative to CO_2 and contributes to the depletion of the stratospheric ozone layer. The lifetime of N_2O is 109 years[122]. N_2O is a non-flammable, colourless gas commonly called "laughing gas" and is used e.g., as an anaesthetic agent, and it is not considered as a direct air pollutant, although e.g., breathing difficulty is associated with high N_2O inhalation. N_2O may deplete the stratospheric ozone layer when concentrations of halocarbons reduce[123] and hence N_2O is regarded as an indirect air pollutant, since depletion of the stratospheric ozone layer increases cancer-causing UVB radiation at the surface of the Earth. N_2O may be induced by some exhaust emission control devices, e.g., Diesel Oxidation Catalyst (DOC), Lean NO_x Trap (LNT), Diesel Particulate Filter (DPF), Selective Catalytic Reduction (SCR). For example, unreacted NH_3 can be transformed to N_2O across a mild oxidising catalyst[124]. Current Euro 6/VI but also upcoming Euro 7 regulations require significant reductions in NO_x, which are achieved by the extensive use of very efficient NO_x removal devices like SCR and LNT. Unless N_2O is specifically considered by the regulations, increased amounts of N_2O may be produced as a side effect of the operation of such devices. Therefore, the efficiency of these regulations should be monitored additionally in ambient air close to traffic. Thereby any deviations could be detected in a timely manner.

Measurement guidelines for N_2O are available within the GAW programme (GAW Report No. 185[125]). Monitoring of N_2O is done with a gas chromatograph equipped with an electron capture detector (ECD). The sampling can be done directly from the air inlet or by collecting air samples in flasks.

Online N_2O analyzers based on spectroscopic technologies (e.g. Cavity Ring-Down Spectroscopy, CRDS) are used recently for monitoring.

1.7.4. Ultrafine particle number size distribution

To better understand the characteristics of UFP, monitoring of the particle number size distribution (PNSD) is undertaken by various agencies and research institutes. In addition, monitoring of PNSD is recommended by ACTRIS and GAW. Technical details for monitoring PNSD are e.g. described in the Technical Specification CEN/TS 17434:2020

[121] Hulin, et al. (2021).

[122] IPCC (2021).

[123] Portmann, Daniel, Ravishankara (2012).

[124] Guan, et al. (2014); Nevalainen, et al. (2018).

[125] https://library.wmo.int/index.php?lvl=notice_display&id=139#.Yh36AujMK70 (last viewed on 07.03.2022)

"Ambient air - Determination of the particle number size distribution of atmospheric aerosol using a Mobility Particle Size Spectrometer (MPSS)" and in the JRC report[126].

PNSD is currently mainly used within research activities such as ACTRIS to better understand atmospheric processes of particle formation. JRC suggests PNSD monitoring for specific health impact studies. Next to the considerably higher costs compared to PNC monitoring the huge amount of data provided by the instruments might be difficult to manage by air quality network operators.

Therefore, PNSD is deemed to be currently more suitable for research orientated networks, but less for networks implemented according to the AAQDs.

1.7.5. Bio-aerosols

Bio-aerosols are a broad category for components such as pollen, fungal spores, bacteria, viruses, or fragments of plant and animal matter[127]. Bio-aerosol can originate from a broad range of sources, both anthropogenic and natural. Increased attention was brought to bio-aerosols due to the COVID-19 pandemic[128]. A number[129] of studies have been already published, analysing SARS-CoV-2 RNA in ambient air, see e.g.[130]. However, even though transmission via aerosol between people in close contact is believed to be the main path for spreading the infection[131], possible transmission by particulate matter named in some of these articles is still under discussion[132].

Sampling and analysis of bio-aerosols was summarised in recent scientific articles[133]. In short, this includes taking a representative bio-aerosol in ambient air, depositing the sample into/onto a sampling medium and then make it available for analysis by culturing, microscopy, flow cytometry, ATP-based bioluminescence, quantitative polymerase chain reaction (qPCR), gene sequencing and other methods.

As there is yet no standard protocol for sampling and analysis[134], it is deemed premature to recommend bio-aerosol for Europe-wide monitoring.

[126] Monforti-Ferrario, et al. (2022).

[127] Humbal, Gautam, Trivedi (2018).

[128] Enyoh, et al. (2020).

[129] Actually, until May 2021, almost 6000 peer reviewed studies were published covering the SARS-CoV-2 and pollution related search terms (European Parliament (2021))

[130] Kayalar, et al. (2021); Santurtún, et al. (2022); Pena, et al. (2021); Nor, et al. (2021).

[131] https://www.who.int/news-room/questions-and-answers/item/coronavirus-disease-covid-19-how-is-it-transmitted, https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/sars-cov-2-transmission.html (last viewed on 10.08.2022)

[132] Ishmatov (2022); European Parliament (2021); WMO (2021).

[133] Mainelis (2020); Kumar, et al. (2021).

[134] Mainelis (2020).

2. Task 2: Information on the monitoring of additional pollutants

Section 2.1 and Annex 1 summarise the data for all selected pollutants (section 1.6), which is available in the EEA[135] and EBAS[136] databases (as of March 2022).

To get more insight into on-going monitoring activities and associated costs, a request was sent to Member States in March 2022, asking for additional information (see Annex 3). The request to Member States covered UFP, BC/EC, NH_3, CH_4 and the oxidative potential of PM. Section 2.2 summarises the responses and the data available in the EEA and EBAS database, which was the basis for the analysis of the distance to meeting WHO good practice statements for UFP and BC/EC (chapter 3) and the recommendations for future monitoring strategies in the EU (chapter 4).

2.1. Available data for the list of additional pollutants

For the list of pollutants selected and described in section 1.6, we collected available data from the EEA and EBAS databases for monitoring data of atmospheric pollutants. The former includes air quality data from EU Member States, mainly reported under Commission Implementing Decision 2011/850/EU[137] and scattered data of further pollutants for which there is no reporting requirement. The EBAS database includes mainly datasets from GAW, ACTRIS and EMEP stations, i.e. rural background stations, for both air pollutants and greenhouse gases as well as further parameters relevant for atmospheric physics and chemistry research.

As the oxidative potential of PM is not a pollutant per se, it is thus not available in both databases.

So far, UFP or Particle Number Concentrations (PNC) were not included in the EEA database; however, in April 2022 EEA added the possibility to report UFP.

Table 10 below provides an overview of monitoring and monitoring results of additional pollutants in EU Member States. It has to be noted, that much more data is available at Member State level, which is not reported to EEA (see section 2.2).

Annex 1 shows these data in more detail per pollutant.

[135] https://eeadmz1-cws-wp-air02.azurewebsites.net/index.php/users-corner/statistics-e1a-table/. The data was downloaded with the setting "data coverage: yes" (last viewed on 07.03.2022)

[136] http://ebas-data.nilu.no/ (last viewed on 07.03.2022). Stations are considered if data for 2020 and / or 2021 is available

[137] http://data.europa.eu/eli/dec_impl/2011/850/oj (last viewed on 10.08.2022)

Table 10: Monitoring of additional pollutants in EU Member States reported to EEA

Source: EEA database

Pollutant	Member States reporting	Years	Number per sampling point type[*]									Total no. sampling points	Median 2020
			RB	RI	RT	SB	SI	ST	UB	UI	UT		[$\mu g/m^3$]
1,3-Butadiene	8 (BE, DE, ES, FR, LT, NL, PL, SE)	Since 2005	19			6	2		12		2	41	0.1
BC	4 (BE, FI, NL, SE)	Since 2011	16	4	1	4	6	1	19	2	19	72	0.75
CH_4	4 (DE, ES, IT, NL)	Since 1997	5	4		3	6	2	6	3	12	42	1382[‡]
EC	18[†]	Since 2008	40			2			12		19	73	0.2
HCHO	4 (ES, FR, PL, RO)	Since 1999	3			3			6	1	5	18	1.5
Mn	7 (CY, DE, DK, ES, FR, IT, SE)	Since 1993	60				1		20	5	12	98	4.2 ng/m^3
NH_3	8 (BG, DE, ES, HR, IT, NL, RO, SE)	Since 1997	26	1		2	5		13	6	10	63	1.1
UFP	No information in EEA database												
V	5 (CY, DE, DK, FR, SE)	Since 2002	19				1		18	2	5	45	0.4 ng/m^3

[*] R: rural, S: suburban, U: urban, B: background, I: industrial, T: traffic

[†] Austria, Belgium, Croatia, Cyprus, Denmark, Finland, France, Germany, Hungary, Ireland, Lithuania, Malta, Netherlands, Poland, Portugal, Slovenia, Spain, Sweden

[‡] the reported concentrations for CH_4 are in several cases not plausible, probable due to wrong units (ppb or ppm instead of $\mu g/m^3$ as reported in the EEA database). All annual means that are below the global mean (https://gml.noaa.gov/ccgg/trends_ch4/, last viewed on 07.03.2022) were discarded for the calculation of the median.

Table 11 summarises monitoring data from the EBAS database, including the sampling and analytical methods. Mainly, these are additional datasets[138] that are not reported to the EEA database.

Table 11: Monitoring of additional pollutants in EU Member States reported to the EBAS database

Source: EBAS database

Pollutant	Member States reporting	Years	Number of sampling points	Instrument types, sampling
1,3-Butadiene	2 (DE, FR)	Since 2008	3	Online GC, GC-FID, Sampling with steel canister
BC*	6 (DE, ES, FI, GR, IT, LT)	Since 2001	10	Filter absorption photometer: MAAP, Aethalometer: Magee (AE31, AE33) Sampling with high vol sampler & Metrohm-Analyzer
CH_4	1 (MT)	Since 2015	1	Picarro CRDS analyzer
EC	9 (CZ, DE, ES, FR, GR, IT, NL, PL, SE)	Since 2013	25	Sampling: High vol sampler, low vol sampler Online thermal-optical analysis: Sunset Lab EC/OC-Analyzer
HCHO	3 (EE, ES, FR)	Since 2011	3	Sampling with adsorption tubes, analyses with HPLC-UV
Mn	6 (BE, CY, DE, FI, IT, SE)	Since 2009	16	Sampling: high vol sampler, low vol sampler, filter pack method
NH_3	11 (BE, DE, DK, ES, FI, HU, LV, NL, PL, SE, SK)	Since 1993	30	Denuder, filter pack method, passive sampler
UFP	3 (AT, FR, IE)	Since 2015	6	Condensation particle counter (CPC): TSI Model 3775, 3776, 3772, 3010; Palas ENVI-CPC

[138] Stations listed in the EBAS database that are also named in the EEA database: EC: station PL0005R. Formaldehyde: ES0001R. Mn, V: stations CY0002R, SE0005R, SE0014R.

V	6 (CY, CZ, DE, FI, IT, SE)	Since 2009	17	Sampling: high vol sampler, low vol sampler, filter pack method

* equivalent Black Carbon, equivalent Black Carbon mass (IT). However, data available only for several months

2.2. Detailed information from Member States

Member States were addressed at the end of February / beginning of March 2022 and asked for providing more detailed information on monitoring practices for UFP, BC/EC, NH_3, CH_4 and the oxidative potential of PM. The latter type of pollutant was chosen in discussion with DG ENV. The detailed list of questions sent to the Member States is shown in Annex 3. The distribution list was based on the replies to the request in Task 1, contacts provided in Dataset B[139] sent to EEA and an email sent to national EIONET health and airpollution contacts by EEA.

2.2.1. Overview

Overall, 25 Member States replied to these questions and sent detailed information about current monitoring practices. The detailed replies from Member States have been collected in an Microsoft Excel document (Annex 4).

Currently, 19 Member States monitor NH_3, 16 monitor EC, 14 monitor BC, 13 monitor UFP, and 8 monitor CH_4. The oxidative potential is analysed by two Member States (France and Italy).

NB: as EOI codes[140] are not available for all sampling points that have been named by Member States, a direct comparison with those stations provided in EEA and EBAS database is not possible.

Table 12: Overview monitoring of additional pollutants

Source: Member States, EEA and EBAS database

Member State	UFP	BC	EC	NH_3	CH_4	ox. P. PM
AT	yes	yes	yes	yes	yes	no
BE	yes	yes	no	yes	no	no
BG	no	no	no	yes	yes	no
CY	no	no	no	no	no	no
CZ	yes	yes	yes	yes	yes	no
DE	yes	yes	yes	yes	yes	no
DK	yes	no	yes	yes	no	no
EE*	no	no	no	no	no	no

[139] https://eeadmz1-cws-wp-air02.azurewebsites.net/index.php/users-corner/zones-b-table/ (last viewed on 10.08.2022)

[140] Unique Exchange of Information (EoI) code for monitoring stations.

ES	no	yes	yes	yes	no (not active anymore)	no (not active anymore)
FI	yes	yes	yes	yes	yes	no
FR	yes	yes	yes	yes	no	yes
GR	no	no	no	no	no	no
HR	no	yes	yes	yes	yes	no
HU	no	no	yes	yes	no	no
IE	no	no	no	yes	no	no
IT	yes	yes	yes	yes	yes	yes
LT	yes	yes	no	yes	no	no
LU	yes	no	no	yes	no	no
LV	no	no	yes	yes	no	no
MT	no	yes	yes	no	no	no
NL	yes	yes	yes	yes	no	no
PL	no	no	yes	no	no	no
PT	no	yes	no	no	no	no
RO	no	no	no	yes	no	no
SE	yes	yes	yes	yes	yes	no
SI	yes	yes	yes	no	no	no
SK*	no	no	no	no	no	no
Sum (active monitoring)	13	14	16	19	8	2

* no reply to questions, no data provided in EEA or EBAS database for these pollutants

2.2.2. Ultrafine particles

Ultrafine particles (UFP) are monitored in 13 out of the 25 Member States[141], which replied to the questions. Overall, Member States reported around 70 active monitoring stations/sampling points for UFP, mainly within permanently operated stations, and a few campaigns.

Monitoring is done by national or regional environment agencies.

Monitoring objectives named by Member States are mainly the determination of the impact on human health and in some cases source apportionment and PM precursors.

For monitoring of UFP, the following types of devices and methods are reported by the Member States:

- Condensation particle counter (CPC), partly according to CEN/TS 16976:2016
- Scanning mobility particle sizer (SMPS), partly according to CEN/TS 17434:2020

In additon to particle number concentration, particle number size distribution is monitored by 11 of the 13 Member States.

One Member State named a data quality objectives of 10 %, another Member State of 20 % for the uncertainty, other Member States referred to the CEN/TS 16976:2016, the EMEP manual for sampling and analysis[142] and to ACTRIS, which undertakes intercomparisons and provides guidance and recommendations for monitoring.

In general, Member States report data to the public and the scientific community. In some cases monitored data is available only upon request and on annual basis.

Only Denmark and Latvia use the data for assessment of exposure to and health impacts of UFP.

Table 13: Current status of UFP monitoring in Member States

Source: Member States, EEA and EBAS database

UFP	Overview
Number of Member States monitoring UFP	13 Member States (out of 25)
Number of stations	Around 70 active stations
Main types	Mostly at permanently operated stations, no information on station type in EEA data base, mainly rural background stations in EBAS
Institutions	National or regional environment agencies
Monitoring objectives	Impact on human health, additionally source apportionment, PM precursors

[141] Austria, Belgium, Czechia, Germany, Denmark, Finland, France, Italy, Latvia, Luxembourg, Netherlands, Slovenia, Sweden.

Estonia and Slovakia, which did not reply, did not report UFP data to EEA or EBAS.

[142] https://projects.nilu.no/ccc/manual/index.html (last viewed on 10.08.2022)

Methods	Condensation Particle Counter (CPC) and Scanning Mobility Particle Sizer (SMPS)
Data quality objectives	10% - 20% uncertainty, CEN/TS 16976:2016, EMEP manual, ACTRIS guidance and recommendations
Availability of data	Mainly publicly available. In some cases, if requested or in annual reports only.
Thresholds	Used in Finland[143] only
Assessment of exposure, health impacts	Mainly no assessment is done

2.2.3. Black Carbon

Black Carbon (BC) is currently monitored by 15 out of the 25 Member States[144] that answered to the questions. Overall, around 190 stations are actively monitoring BC, mainly at urban traffic and urban background, but also at rural background stations. This is a considerably larger number of stations than that reported to EEA or EBAS (Table 10, Table 11). BC devices are largely used for permanent assessment; campaigns are conducted only in few cases.

Monitoring is done by a variety of institutions or administrations such as research institutes, universities, environment agencies, (hydro-)meteorological institutes and regional administrations or agencies.

Monitoring objectives named by Member States are mainly the determination of the impact on human health and for source apportionment, partly also as part of networks such as ACTRIS.

Monitoring devices used for BC assessment are aethalometers, multi-spectrum BC monitors, Multi Angle Absorption Photometer (MAAP) and optical transmissometer.

Only a few data quality objectives were named by Member States, namely recommendations by ACTRIS, or an data quality objective of 10 % or 25 % for the uncertainty.

Most of the data is made publicly available through general national monitoring websites, EEA or EBAS databases; some only on request.

Two Member States, namely Belgium and Finland, provide a distinction between different levels of BC concentrations. In Belgium a scale index ranging from 1 to 10 (1= good, 10 extremely bad) is used. The scale for BC is based on the scales used for NO_2 and the correlation between NO_2 and BC. A distinction is made between short-term (24 h) and long-term values (annual mean). In Helsinki, a 5-step classification is utilized.[143]

One Member State (Italy) mentioned that epidemiological studies were made for BC. France uses BC data for source apportionment studies.

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[143] In the Helsinki metropolitan area, 5-step AQ classification is already utilized for BC and LDSA (and for PNC preliminary) in air quality visualisation (i.e. colour scale from good to poor air quality). Thresholds according to WHO Good Practise Statements for PNC concentrations are used in Air Quality report for Helsinki and Tampere.

[144] Austria, Belgium, Croatia, Czechia, Finland, France, Germany, Italy, Latvia, Malta, Netherlands, Portugal, Slovenia, Spain, Sweden

Table 14: Current status of Black Carbon monitoring in Member States

Source: Member States, EEA and EBAS database

Black Carbon	Overview
Number of Member States monitoring BC	15
Number of stations	195 active stations
Main types	Mainly urban traffic and urban background, some rural background
Institutions	Research institutes, universities, environment agencies, (hydro-) meteorological institutes and regional administrations or agencies
Monitoring objectives	Impact on human health, source apportionment, part of scientific networks (ACTRIS)
Methods	Aethalometers, multi-spectrum BC monitors, Multi Angle Absorption Photometer (MAAP), optical transmissometer
Data quality objectives	10 %, 25 %, ACTRIS guidance and recommendations
Availability of data	National monitoring websites; EEA, EBAS databases; some on request
Thresholds	Two Member States (BE, FI) use thresholds (no concentration levels provided)
Assessment of exposure, health impacts	One Member State (FI)

2.2.4. Elemental Carbon

Elemental carbon (EC) is the second most monitored pollutant of the pollutants covered by this study. In total, 16 out of the 25 Member States[145], which replied to the questions, monitor EC. Overall, Member States named around 130 active monitoring stations/sampling points for EC, mainly within permanently operated stations, and a few campaigns. This is a considerably larger number of stations than that reported to EEA or EBAS (Table 10, Table 11).

Monitoring is done mainly by national or regional environment agencies, research institutes, and universities at all types of stations.

Monitoring objectives of Member States are the monitoring of natural and anthropogenic influences on atmospheric composition, the understanding of the processing and sources affecting the variability of aerosol properties, the determination of the impact on human health, environment and climate, and source apportionment.

[145] Austria, Czechia, Germany, Denmark, Finland, France, Croatia, Hungary, Italy, Latvia, Malta, Poland, Slovenia, Slovakia, Spain, Sweden.

Estonia and Slovakia, which did not reply, did not report EC data to EEA or EBAS.

For measurement of EC, the main types of devices and methods reported by the Member States are the following:

- High volume sampling of $PM_{2.5}$ and then analysis by thermo-optical method (EN 16909:2017)
- High volume sampling of PM_{10} and/or $PM_{2.5}$ and then analysis by thermo-graphic method (VDI 2465-2)
- Semi-continuous EC/OC with commercial analyzer (Sunset Lab – NIOSH 5040 method)
- Combination of high volume sampling and NIOSH 5040 method
- OC/EC analysis with thermo-optical method in lab (EUSAAR-2)

Different data quality objectives were named by Member States, ranging from 12% to 16% for the uncertainty, one Member State named an objective for data capture of 90%. Some Member States referred to the EN 16909:2017.

In general, Member States provide data and additional information to the public and the scientific community. In few cases monitored data is available only upon request.

Most Member States do not use the data for assessment of exposure to and health impacts of EC. France uses EC data for source apportionment studies; one regional authority of Italy stated that epidemiological studies were done.

Table 15: Current status of Elemental Carbon monitoring in Member States

Source: Member States, EEA and EBAS database

Elemental Carbon	Overview
Number of Member States moni-toring EC	16 Member States (out of 25)
Number of stations	Around 130 active stations (permanent and campaigns)
Main types	Regional background, urban background, urban traffic
Institutions	National or regional environment agencies, research institutes, univer-sities
Monitoring objectives	Requirement of Dir. 2008/50/EC, EMEP monitoring, impact on human health/ecosystem, verification of modelling methods, source appor-tionment, environmental studies
Methods	Thermo-optical method
Data quality objective	12 % to 16%, objective for data capture of 90%. Reference to EN 16909:2017
Availability of data	Mainly publicly available. In some cases, if requested.
Thresholds	No

Assessment of exposure, health impacts	Mainly no assessment is done, data is used for source apportionment in one Member State

2.2.5. Ammonia

Ammonia is monitored in 19 out of the 25 Member States[146] which replied to the questions. Overall, Member States named around 270 active monitoring stations/sampling points[147] for ammonia, mainly within permanently operated station. According to the EEA database, Ammonia is monitored mainly at rural background stations. Again, a large number of data is not reported to the EEA database.

Monitoring is done by national or regional environment agencies.

Monitoring objectives of Member States are mainly the determination of the impact on human health and ecosystems, source apportionment and PM precursors.

Monitoring methods named by Member States are rather diverse and include passive samplers, denuders and filter pack sampling. Continuous monitoring devices are either based on chemiluminiscence, differential optical absorption spectroscopy (mini DOAS) or cavity ring-down spectroscopy (CRDS).

Different data quality objectives were named by Member States, ranging from 10 % for the measurement uncertainty and 90 % to 95% for data capture. One Member State referred to the VDI 3869-4, others to the EMEP manual for sampling and analysis[142].

In general, Member States provide data to the public. In some Member States monitored data is available only upon request and on annual basis.

The UNECE critical levels for ecosystems are used in some Member States as thresholds[148].

Only Denmark and Latvia use the data for assessment of exposure to and health impacts of ammonia. France uses the data for source apportionment studies.

Table 16: Current status of ammonia monitoring in Member States

Source: Member States, EEA and EBAS database

Ammonia	Overview
Number of Member States monitoring NH_3	19+1 Member States (Slovakia did not reply to questions, but reports data to EBAS)
Number of stations	About 275 stations (permanent stations and campaigns)

[146] Austria, Belgium, Bulgaria, Czechia, Germany, Denmark, Spain, Finland, France, Croatia, Hungary, Ireland, Italy, Latvia, Luxembourg, Lithuania, Netherlands, Romania, Sweden.

Estonia, which did not reply, did not report NH_3 data to EEA or EBAS. Slovakia reports NH_3 by filter pack sampling to EBAS

[147] The Netherlands operate next to 6 monitoring stations with continuous NH_3 monitors a large number of passive sampling points, see https://www.clo.nl/indicatoren/nl0461-ammoniak as well as a monitoring network in nature protection areas (https://man.rivm.nl/). (last viewed on 10.08.2022)

[148] CLRTAP (2015).

Main types	Rural background: 41 %. Urban background: 21 %. Urban traffic: 16 % (Source: EEA data base. Types of stations reported by MS only partly available)
Institutions	National or regional environment agencies
Monitoring objectives	Mainly impact on human health and ecosystems, source apportionment, precursors for PM
Methods	Diffusive samplers, filter pack sampling, denuders, continuous methods (chemiluminiscence, mini DOAS, cavity ring-down spectroscopy)
Data quality objective	10 % for the measurement uncertainty and 90 % to 95 % for data capture. VDI 3869-4, EMEP manual for sampling and analysis
Availability of data	Mainly publicly available. In some cases, if requested or on an annual basis
Thresholds	Comparison with UNECE critical levels in few Member States
Assessment of exposure, health impacts	Mainly no assessment is done

2.2.6. Methane

Methane is currently monitored by 8 out of the 25 Member States[149] that answered to the questions. Overall, more than 50 stations are actively monitoring CH_4, mainly at rural background locations, but also at urban background and urban traffic stations. Monitoring is done mainly within permanently operated stations, and a few campaigns.

Monitoring is done by a variety of instutions or administrations such as research institutes, environment agencies, (hydro-)meteorological institutes and regional administrations or agencies.

Monitoring objectives named by Member States are rather diverse, ranging from the determination of the impact on climate change, impact on human health and ecoystems, source apportionment to monitoring being part of the EMEP monitoring strategy or ICOS monitoring.

Monitoring devices are either based on cavity ring-down spectroscopy (CRDS) or gas chromatography flame ionization detector (GC-FID).

Different data quality objectives were named by Member States, ranging from ~ 20% to 2 ppb for the uncertainty, or a precision of < 1 ppb and reproducibility of < 0.5 ppb. One Member State named the WMO intercompatibility goal[150] of ± 2 ppb.

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[149] Austria, Bulgaria, Croatia, Czechia, Finland, Germany, Italy, Sweden

[150] WMO provides the following data quality objectives (WMO (2009)):

(i) The repeatability of CH_4 measurements should be ≤ 2.0 ppb, and the reproducibility ≤ 3.0 ppb.

(ii) The combined standard uncertainty for an ambient CH_4 measurement calculated using reproducibility (± 3 ppb), uncertainty in high-level standards (±1 ppb), and ability of a lab to propagate high-level standards to working standards (± 2 ppb) should be no larger than ± 3.7 ppb. Using optimized modern analytical methods should give uncertainties on order ± 2.2 ppb at the 66% confidence level.

(iii) The uncertainties defined above will determine the network or interlaboratory comparability of GAW CH_4 measurements.

The data is only partly reported to EEA or EBAS as the focus is more on CH_4 as a greenhouse gas; thus data is reported to organisations such as the WMO-GAW World Data Centre for Greenhouse Gases[151] and / or ICOS[152]. Some Member State provide the data only if requested.

No thresholds are currently used to distinguish between different levels of CH_4. In addition, no assessment of exposure and health impacts of CH_4 is done by Member States.

Table 17: Current status of methane monitoring in Member States

Source: Member States, EEA and EBAS database

Methane	Overview
Number of Member States monitoring CH_4	8
Number of stations	54
Main types	Mainly rural background locations, some urban background and urban traffic stations
Institutions	Research institutes, environment agencies, (hydro-)meteorological institutes, regional administrations / agencies
Monitoring objectives	Impact on climate change, EMEP or ICOS monitoring
Methods	Cavity ring-down spectroscopy (CRDS) or gas chromatography flame ionization detector (GC-FID)
Data quality objective	~ 20% to 2 ppb, or a precision of < 1 ppb and reproducibility of < 0.5 ppb. WMO intercompatibility goal of ± 2 ppb
Availability of data	Scientific databases, partly only on request
Thresholds	No thresholds used
Assessment of exposure, health impacts	No assessment done

2.2.7. Oxidative Potential of PM

Oxidative potential of PM is the least common monitored pollutant of the pollutants covered in this study. Only France and Italy reported that they analyse the oxidative potential of PM. Overall, the oxidative potentatial of PM was monitored at 13 monitoring stations/sampling points within campaigns, starting from 2013.

In the answer to the questions provided by Member States, two research institutes and one university were named for Italy being responsible for monitoring the oxidative potential of PM. In France, samplings on filters are performed occasionally at few sites by local air

[151] https://gaw.kishou.go.jp/ (last viewed on 10.08.2022)

[152] Integrated Carbon Observation System, https://www.icos-cp.eu/ (last viewed on 10.08.2022)

quality monitoring networks (AASQA) and analysed by research institutes in the framework of a program led by the LCSQA about PM chemical composition and sources in urban environments (CARA program[153]).

The monitoring objective named is the impact on human health.

AA, DDT, and DCFH assays are used for the analysis of the oxidative potential (see also section 1.6.9 and Table 9).

Data is publicly available through websites[154] and public reports[155].

No information about data quality objectives were provided by Member States.

No thresholds are used to distinguish between low, medium and high levels of concentrations.

Table 18: Current status of the analysis of the oxidative potential of PM in Member States

Source: Member States, EEA and EBAS database

Oxidative potential of PM	Overview
Number of Member States moni-toring oxidative potential of PM	2 Member States
Number of stations	13 stations
Main types	Campaigns
Institutions	Research institutes, universities, local air quality monitoring networks
Monitoring objectives	Impact on human health, the environment and climate.
Methods	Acellular tests in parallel (AA, DDT, DCFH), DTT assay with UV-VIS absorption (additional assays – DCFH, AA - are performed by collabo-rating Institutions for some sites)
Data quality objective	-
Availability of data	Yes, via websites and public reports
Thresholds	No
Assessment of exposure, health impacts	For source apportionment.

[153] Favez, et al. (2021).

[154] https://www.lcsqa.org/fr/rapport/synthese-bibliographique-sur-les-metriques-devaluation-de-la-toxicite-des-pm-mesure-du (last viewed on 10.08.2022)

[155] Calas, et al. (2019); LCSQA (2020c).

3. Task 3: Distance to meeting WHO good practice statements

3.1. Introduction

On 22 September 2021 the World Health Organization (WHO) published updated WHO Global Air Quality Guidelines, which include so-called good practice statements for UFP and BC/EC *(as well as for sand and dust storms)*[156].

3.1.1. Ultrafine particles

For UFP the WHO provides four good practice statements:

1. *Quantify ambient UFP in terms of particle number concentration (PNC) for a size range with a lower limit of ≤ 10 nm and no restriction on the upper limit.*
2. *Expand the common air quality monitoring strategy by integration of UFP monitoring into existing air quality monitoring. Include size-segregated real-time PNC measurements at selected air monitoring stations in addition to, and simultaneously with, other airborne pollutants and characteristics of PM.*
3. *Distinguish between low and high PNC to guide decisions on the priorities of UFP source emission control. Low PNC can be considered < 1000 particles/cm³ (24-hour mean). High PNC can be considered > 10 000 particles/cm³ (24-hour mean) or 20 000 particles/cm³ (1-hour).*
4. *Utilize emerging science and technology to advance approaches to the assessment of exposure to UFP for application in epidemiological studies and UFP management.*

Regarding good practice statement 1, it has to be noted that the Technical Specification CEN/TS 16976:2016 "Ambient air - Determination of the particle number concentration of atmospheric aerosol" requires a lower limit of 7 nm. However, the WMO/GAW guidelines and recommendations for aerosol measurements foresee a lower limit of 10 nm[157]. In addition, ACTRIS recommends already the use of Condensation Particle Counter (CPC) with an 50% lower detection efficiency diameter of 10 nm.[158] A harmonization of lower limits and a standard in general is crucial to obtain comparable data throughout Europe. For reporting of UPF to EEA, which is possible since March 2022, the lower limit should be reported as a detection limit.

Regarding size segregation (Particle Number Size Distribution, PNSD) it has to be noted that there are no official definitions of size resolutions available yet. CEN/TS 17434:2020 describes a standard method for determining PNSD in ambient air in the size range from 10 nm to 800 nm and requires ≥ 16 geometrically evenly distributed size channels per size decade. The recommended particle size resolution by ACTRIS[158] within this size range is 16 to 32 bins/decade. A higher particle size resolution is not recommended due to the poor counting statistics for atmospheric measurements.

[156] WHO (2021).

[157] WMO (2016).

[158] https://www.actris-ecac.eu/actris-gaw-recommendation-documents.html (last viewed on 4.8.2022)

Based on questions sent to Member States (see section 2 and Annex 3) it was assessed in the following, whether the monitoring methods used for UFP monitoring have a lower limit of ≤ 10 nm and no restriction on the upper limit (good practice statement 1).

Furthermore, it was investigated whether existing UFP monitoring in the Member States is part of AAQD monitoring network, or, alternatively, part of a national or international research network, or neither of these (good practice statement 2). In addition, the state of current activities was collected regarding size-segregated measurements at existing monitoring stations where other pollutants, PM and its constituents are monitored as well.

Regarding good practice statement 3, it was assessed, whether Member States, in particular those where monitoring is embedded in AAQD networks, are distinguishing between low and high PNC according to WHO.

As described in the rationale for good practice statement 4 (section 4.3.4 of the updated WHO AQGs), the estimation of the exposure to UFP is rather complex due to the large temporal and spatial variability and the variety of instruments. Personal exposure assessments and modelling tools can help in this respect. Therefore, it is assessed what activities the Member States are undertaking regarding exposure assessments and modelling.

3.1.2. Black Carbon / Elemental carbon

For BC/EC WHO provides the following good practice statements, which are relevant for this Task 3:

1. *Make systematic measurements of black carbon and/or elemental carbon. Such measurements should not replace or reduce the existing monitoring of pollutants for which guidelines currently exist.*
2. *Undertake the production of emission inventories, exposure assessments and source apportionment for BC/EC.*

Information was collected from Member States on the extent systematic measurements of BC or EC are undertaken within the existing AAQD networks. In principle, according to Annex IV of Directive 2008/50/EC monitoring of *inter alia* EC is required in rural background stations, at one station for every 100 000 km². However, it is noted that rural background stations are not aimed at human exposure assessments, which is the primary goal of WHO AQGs and its good practice statements. It is therefore assessed whether the stations named by Member States (Task 2, section 2.2.3) provide information for human exposure assessments as well (good practice statement 1).

Regarding good practice statement 2, it was assessed, whether Member States are undertaking or are planning to undertake exposure assessments of BC and/or EC. In addition, it is analysed whether source apportionment studies are undertaken for BC and/or EC. The status of BC emission inventories are available and summarised at the CEIP website[159].

Overall, 25 Member States answered to the questions, see section 2 and Annex 3, wherefrom 19 Member States monitor either UFP or BC/EC and replied to the questions specific for the WHO good practice statements.

[159] EMEP Centre on Emission Inventories and Projections, https://www.ceip.at/ (last viewed on 2.5.2022)

3.2. Distance to meeting UFP good practice statements

The requirement of the WHO good practice statement regarding a lower limit of ≤ 10 nm is fulfilled by all Member States[160]. Strictly speaking, the requirement that there is no upper limit of the particle sizes to be counted is fulfilled only by 7 Member States. However, the difference is deemed to be rather small as the particle number concentration is dominated by small particles (good practice statement 1).

Out of the 13 countries that monitor UFP, all but two Member States named measurements being systematic[161]. Monitoring takes place at regular air quality monitoring and thus can be regarded as being integrated in existing monitoring networks (good practice statement 2).

Additional PM metrics is monitored in all Member States that undertake UFP monitoring, mainly $PM_{2.5}$ and PM_{10} monitoring. Four Member States[162] are additionally monitoring PM_1, 11 Member States[163] monitor particle number size distributions. In addition, lung depositable particle surface is monitored by three Member States[164]. The chemical composition of PM was named by two Member States (good practice statement 2). However, it can be expected that a number of further Member States regularly undertake chemical analysis of PM samples, which is on the one hand required according to Annex IV of Directive 2008/50/EC for rural background stations, where one station shall be installed every 100 000 km^2. In addition, source apportionment or receptor modelling studies for PM, which are undertaken in a number of Member States, often rely on the chemical composition of PM samples[165]. Furthermore, Directive 2004/107/EC requires chemical analysis of selected heavy metals and benzo(a)pyrene.

A distinction between low and high levels of PNC is done by one Member State, namely Finland, within local networks. France conducted a bibliography of UFP levels in Europe to compare the levels in France to those of other countries[166]. The French study provides typical levels for rural background, urban background and urban traffic station, both for France and other European countries (good practice statement 3).

Seven countries[167] utilise the monitoring results for exposure and health impact assessment of UFP, at least for projects and scientific studies (good practice statement 4). A recent study assessed mortality due to exposure to UFP in Barcelona, Helsinki, London and Zurich[168]. A systematic review of the health impacts of UFP, which together with a study from US EPA was the basis for the WHO AQGs, mentions altogether 26 studies for UFP in Europe until 2018[169]. It is beyond the scope of this study to go into detail of all these studies; nevertheless, we assessed which of the UFP stations named by Member States are in principle suitable for exposure assessments based on the classification[170]. This is the case

[160] The Italian region of Piedmont uses UFP devices with a lower limit of 20 nm. The other regions, which are currently monitoring UFP and replied to this question, use devices with lower limits.

[161] As stated in the request to Member States (see Annex 3), measurements are considered „systematic“ when covering different site types – traffic, urban background, rural background – representative for major parts of the country

[162] Austria, Italy, Luxembourg, Spain

[163] Austria, Belgium, Czechia, Germany, Denmark, Finland, France, Italy, Latvia, Luxembourg, Sweden.

[164] Finland, France, Germany

[165] Thunis, Clappier, Pirovano (2020); Viana, et al. (2008); Daellenbach, et al. (2020); Millán-Martínez, et al. (2021); Putaud, et al. (2010).

[166] LCSQA (2021a).

[167] Czechia, Denmark, Finland, France, Italy, Latvia, Lithuania

[168] Rivas, et al. (2021).

[169] Ohlwein, et al. (2019); US EPA (2019).

[170] in some cases, the classification was done based on the coordinates by the authors of this study, in case, the station is not listed in the EEA database

for urban or sub-urban background stations, which are mainly used for exposure studies, see e.g. the “European study of cohorts for air pollution effects” (ESCAPE) project[171], or the “Study on Air Pollution And Lung Disease In Adults” (SAPALDIA) project[172]. Urban traffic stations can be used as well but require a more detailed analysis of the population that is exposed to pollutant levels measured at the station. The stations named by Member States are classified as following (Table 19). Out of 71 stations, for which a classification was available, 39 are classified as urban or suburban background and could therefore be used for exposure assessment; 13 stations are classified as urban or suburban traffic and thus can be used when further analysis is done.

It is worth mentioning that five stations are located close to airports, which are known as a substantial source for UFP, see e.g.[173]. Additional stations close to airports are known to be operated e.g. around Frankfurt airport[174].

Shipping can be a major source for UFP as well, however, there is no information available that UFP monitoring is done close to major ports save from campaigns[175].

Detailed information for all Member States can be found in Table 21.

Table 19: Classification of UFP monitoring stations

Source: Member States, EEA

Classification	Number
Rural Background	17
Suburban Background	11 (1 close to an airport)
Suburban Industrial	1 (close to an airport)
Suburban Traffic	3 (all close to airports)
Urban Background	28
Urban Industrial	1
Urban Traffic	10

Table 20: Overview distance to meeting WHO good practice statements for UFP

Source: Member States

[171] http://www.escapeproject.eu/index.php (last viewed on 2.5.2022)

[172] https://www.swisstph.ch/en/topics/non-communicable-diseases/human-biomonitoring/sapaldia/ (last viewed on 2.5.2022)

[173] Bendtsen, et al. (2021); Costabile, et al. (2015); TNO (2019); Stacey, Harrison, Pope (2020); Stafoggia, et al. (2016); Vorage (2018); Lorentz, et al. (2021).

[174] https://www.hlnug.de/themen/luft/luftqualitaet/sondermessprogramme/ultrafeine-partikel, https://www.hlnug.de/fileadmin/dokumente/luft/luftqualitaet/sondermessprogramme/ufp/UFP-Bericht-4.pdf, https://www.hlnug.de/messwerte/datenportal/ufp (last viewed on 4.8.2022)

[175] Karl, et al. (2020); Lopes, et al. (2019); Merico, et al. ; van der Zee, et al. (2012).

WHO good practice statement	Overview
Quantify ambient UFP in terms of particle number concentration (PNC) for a size range with a lower limit of ≤ 10 nm and no restriction on the upper limit	Lower limit fulfilled by all the 13 Member States that replied and monitor UFP Upper limit fulfilled by 7 Member States (implication negligible)
Expand the common air quality monitoring strategy by integration of UFP monitoring into existing air quality monitoring	UFP monitoring is undertaken systematically and integrated in existing networks by all 13 MS
Include size-segregated real-time PNC measurements at selected air monitoring stations in addition to, and simultaneously with, other airborne pollutants and characteristics of PM	PNSD is monitored by 11 MS $PM_{2.5}$, PM_{10}: 13 MS PM_1: four MS Chemical composition of $PM_{2.5}$: At rural background stations most of the MS according to Annex IV of Dir. 2008/50EC. Heavy metals, PAH according to Dir. 2004/107/EC. Chemical analysis, receptor modelling undertaken in several MS[176]
Distinguish between low and high PNC to guide decisions on the priorities of UFP source emission control	Within local networks of 1 MS
Utilize emerging science and technology to advance approaches to the assessment of exposure to UFP for application in epidemiological studies and UFP management.	7 MS, partly within projects and scientific studies

Table 21: Distance to meeting WHO good practice statements for UFP for individual Member States

Source: Member States

Member State	Lower limit / upper limit	Integration in networks	Size-segregated PNC measurement	Distinction low / high PNC	Exposure assessment
Austria	yes/yes	no	yes	no	no
Belgium	yes/no	yes	yes	NA	NA
Bulgaria	NA	no	no	NA	NA
Croatia	NA	no	no	NA	NA
Cyprus	NA	no	no	NA	NA
Czechia	yes/no	yes	yes	no	yes

[176] Thunis, Clappier, Pirovano (2020); Putaud, et al. (2010); Daellenbach, et al. (2020); Millán-Martínez, et al. (2021).

Denmark	yes/no	yes	yes	no	yes
Estonia	NA	NA	no	NA	NA
Finland	yes/yes	yes	yes	yes (2 local net-works)	yes
France	yes/yes	yes	yes	no	yes
Germany	yes/no	yes	yes	no	no
Greece	NA	no	no	NA	NA
Hungary	NA	no	no	NA	NA
Ireland	NA	no	no	NA	NA
Italy	yes/yes	yes	yes	no	yes
Latvia	NA	yes	no	NA	yes
Lithuania	yes/yes	yes	yes	no	yes
Luxembourg	yes/no	no	yes	no	no
Malta	NA	yes	no	NA	no
Netherlands	yes/yes	no	no	no	no
Poland	NA	no	no	NA	no
Portugal	NA	no	no	NA	no
Romania	NA	no	no	NA	NA
Slovakia	NA	NA	no	NA	NA
Slovenia	yes/yes	no	no	no	no
Spain	NA	no	no	NA	NA
Sweden	yes/no	yes	yes	no	no

3.3. Distance to meeting BC / EC good practice statements

Out of the 16 countries that monitor BC and / or EC, respectively, all countries named measurements being systematic[177] (good practice statement 1). In addition, EC monitoring is required by Annex IV of Directive 2008/50/EC at rural background stations.

Emission inventories for BC were submitted to CEIP for all EU Member States except by Austria and Luxembourg (good practice statement 2). EC is not included in the EMEP/EEA air pollutant emission inventory guidebook 2019 and therefore not part of national emission inventories[178].

Eight Member States[179] undertake exposure assessments for either BC or EC (good practice statement 2).

Twelve Member States[180] undertake source apportionment studies, at least within projects (good practice statement 2).

Out of the around 190 BC monitoring stations, for which a classification was available[181], 80 (43%) are classified as urban or suburban background and could therefore be used for exposure assessment; 42 (22%) stations are classified as urban or suburban traffic and thus can be used when further analysis is done.

Out of the around 100 EC monitoring stations, 50% are classified as rural background stations, 30% as suburban or urban background and 15% as urban or suburban traffic. The remaining stations are classified as industrial stations (Table 22). Hence around 45% of the stations can be used for exposure assessments.

Table 23 provides an overview of the distance to meeting the WHO good practice statements for BC and / or EC, Table 24 provides the results per Member State.

Table 22: Classification of BC and EC monitoring stations

Source: Member States, EEA

Classification	Number BC	Number EC
Rural Background	42	49
Rural Industrial	5	
Rural Traffic	1	
Suburban Background	16	11
Suburban Industrial	9	2

[177] As stated in the request to Member States (see Annex 3), measurements are considered „systematic“ when covering different site types – traffic, urban background, rural background – representative for major parts of the country

[178] EEA (2019).

[179] Czechia, Denmark, Finland, France, Italy, Latvia, Lithuania, Sweden.

[180] Czechia, Denmark, Finland, France, Germany, Italy, Latvia, Lithuania, Malta, Portugal, Slovenia, Sweden.

[181] For some stations, an estimate of the classification was derived from the coordinates provided by Member States. France provided an overall distribution between urban background and rural background of the around 30 stations.

Suburban Traffic	2	1
Urban Background	64	19
Urban Industrial	4	1
Urban Traffic	40	15

Table 23: Overview distance to meeting WHO good practice statements for BC / EC

Source: Member States

WHO good practice statement	Overview
Make systematic measurements of black carbon and/or elemental carbon. Such measurements should not replace or reduce the existing monitoring of pollutants for which guidelines currently exist.	BC / EC monitoring is undertaken systematically and integrated in existing networks of 12 and 16 Member States, respectively. There are no indications, that monitoring of these pollutants replaces monitoring of other pollutants
Undertake the production of emission inventories, exposure assessments and source apportionment for BC/EC.	Emission inventories for BC are reported by all Member States except Austria and Luxembourg. Exposure assessments and source apportionment studies are undertaken by a number of Member States

Table 24: Distance to meeting WHO good practice statements for BC / EC for individual Member States

Source: Member States, CEIP

Member State	Systematic measurements	Emission inventory	Exposure Assessment	Source apportionment
Austria	no	no	no	no
Belgium	yes	yes	no	NA
Bulgaria	no	yes	NA	NA
Croatia	yes	yes	NA	NA
Cyprus	no	yes	NA	NA
Czechia	yes	yes	yes	for projects
Denmark	yes	yes	yes	yes
Estonia	NA	yes	NA	NA
Finland	yes	yes	yes	Scientific studies

France	yes	yes	yes	yes
Germany	yes	yes	yes	no
Greece	no	yes	NA	NA
Hungary	no	yes	NA	NA
Ireland	no	yes	NA	NA
Italy	yes	yes	yes	yes
Latvia	yes	yes	yes	yes
Lithuania	yes	yes	yes	yes
Luxembourg	no	no	NA	no
Malta	yes	yes	yes	no
Netherlands	yes	yes	no	no
Poland	yes	yes	no	no
Portugal	yes	yes	no	no
Romania	no	yes	NA	NA
Slovakia	NA	yes	NA	NA
Slovenia	yes	yes	yes	no
Spain	yes	yes	NA	NA
Sweden	yes	yes	yes	yes

3.4. Gaps in meeting good practice statements

3.4.1. Gaps for UFP

Based on the analysis described in section 3.2, the gaps to fulfill the WHO good practice statements for UFP can be summarised as following:

- Good practice statement 1: Currently, about half (i.e. 13) of the EU Member States monitor UFP. Thus to fulfill the good practice statements, further Member States would need to establish systematic monitoring of UFP at stations relevant for exposure assessments.

- Good practice statement 2: Size-segregated real-time measurements of PNC is undertaken by 11 Member States and would therefore need to be extended to further Member States, especially at supersites in case those will be established.
- Good practice statement 3: A distinction between low and high PNC is done only by one Member State. In addition, not all data is currently reported. Therefore, the distinction would need to be established in the other Member States. It is recommended, that in order to benefit from the information at EU level and e.g. for future studies on health impacts, continuous reporting on national websites and to the EEA would need to be ensured as well, including a distinction of PNC levels according to WHO good practice statements.
- Good practice statement 4: Projects and scientific studies to assess the exposure to UFP are undertaken by seven Member States. It is recommended that further studies are undertaken in close cooperation with scientific networks related to health impacts of air pollutants such as the Air Convention's Joint Task Force on the Health Aspects of Air Pollution[182].

3.4.2. Gaps for BC / EC

Based on the analysis described in section 3.3, the gaps to fulfill the WHO good practice statements for BC / EC, which are relevant for this study, can be summarised as following:

- Good practice statement 1: Currently, 12 and 16 Member States monitor BC or EC, respectively. Thus to fulfill the good practice statements, further Member States have to establish systematic monitoring of BC or EC at stations relevant for exposure assessments.
- Good practice statement 2: Emission inventories for BC are reported for almost all Member States; the Member States currently not reporting BC would need to develop BC inventories, ideally based on the experience of other Member States and the EMEP/EEA guidebook[183] to ensure comparability of data. Nevertheless, it should be noted that provisions for emission inventories are not laid down in the AAQDs but in Directive (EU) 2016/2284. Exposure assessments and source apportionment studies would need to be undertaken by all Member States, the former ideally in close cooperation with scientific networks related to health impacts of air pollutants. Source apportionment should ideally be based on the guidance developed by JRC[184] to ensure comparable results.

[182] https://www.who.int/europe/initiatives/joint-task-force-on-the-health-aspects-of-air-pollution (last viewed on 4.8.2022)

[183] EEA (2019).

[184] Thunis, Clappier, Pirovano (2020).

4. Task 4: Recommendations

4.1. Introduction

Based on the information gathered and assessed under Task 1 to Task 3 (chapter 1, 2, 3) this chapter provides recommendations on the Europe-wide monitoring of additional pollutants.

Therefore, sections 4.2 and 4.3 outline monitoring strategies for UFP and BC/EC, respectively, comprising recommendations for the number, spatial distribution and location of monitoring sites. Criteria for the placement of monitoring sites take into account the presently available information about concentration levels and their spatial variability, the relevant sources from anthropogenic and natural emissions and from atmospheric formation, and their spatial distribution. The main objective of the monitoring strategy will be obtaining information for the whole EU territory, with a focus on exposure assessment.

Recommendations for a strategy of NH_3 and CH_4 take in a similar way into account levels and spatial distribution of these pollutants in order to provide a proposal for numbers, spatial distribution and location of monitoring sites.

The costs of monitoring UFP, BC/EC, NH_3 and CH_4 are given based on information about current practices gathered under Task 2. The numbers provided include all costs incurred on top of the investment and running costs of existing monitoring stations already in operation for the monitoring of pollutants covered by the current AAQDs. Therefore, only additional costs are considered for an extension of a current monitoring station by one or several of these four pollutants.

For all other air pollutants identified under Task 1 (chapter 1) we provide considerations for a general monitoring strategy in the EU Member States, including the number and location of sites in each Member State.

For all additional pollutants it is recommended that Member States regularly share their experiences regarding monitoring as well as the results of the monitoring activities.

Monitoring of these additional pollutants in general should be accompanied by developing reference methods, quality objective and guidance documents, which was also highlighted in the recent study "Strengthening of air quality monitoring, modelling and plans under the Ambient Air Quality Directives. Service Request 9 under Framework Contract ENV.C.3/FRA/2017/0012"[185].

4.1.1. Methodology

The recommendations for monitoring of the additional pollutants are based on general criteria for siting of sampling points such as information on the sources of these pollutants and their spatial distribution, the expected spatial pattern of concentrations, and synergies with other pollutants' measurements[186].

The recommendations take into account the air pollutant concentration levels in relation to existing guideline levels, standards etc., costs, technical requirements and challenges, and the availability of monitoring stations already existing.

[185] European Commission (2022).

[186] CAFE Working Group on Particulate Matter (2004); European Communities (2001); Technical Working Group on Particles (1997); WMO (2009).

The recommendations also take into account the current status of emission inventories for the specific air pollutant, which are prerequisites not only for siting monitoring sites, but especially for modelling atmospheric concentrations of these pollutants and for air quality management. Modelling at national or regional scale often uses Europe-wide modelling of the pollutants e.g. within EUs Copernicus[187] programme.

Furthermore, this report takes into account on-going discussions on installing so-called supersites[188]. These could be sites similar to level 3 EMEP sites[189], which have been established to "*improve the scientific understanding of the relevant physico-chemical processes in relation to regional air pollution and its control*". However, whereas EMEP sites are situated in rural background locations, such supersites would be situated in urban background locations of large cities. As for EMEP sites, these should be intended for long-term operation and are regarded to be more research orientated at a relatively small number of locations compared e.g. to level 1 or level 2 sites according to monitoring under Directive (EU) 2016/2284. Next to pollutants already covered in the AAQDs, such supersites would monitor further air pollutants either within campaigns or long-term observations to improve the understanding of atmospheric processes and support model development and validation.

4.1.2. Data, information used

The main source of information to develop the recommendations are the replies to the request to Member States (see chapter 2.2). Further sources of information are:

- Position papers, which preceded the provisions of the AAQDs and their successors[190]
- On-going discussions within the Ambient Air Quality Expert Group;
- JRC study,[191];
- Selected national monitoring strategies[192];
- Recommendations for the revision of the AAQDs by FAIRMODE[193] and AQUILA[194];
- Guidance on site selection for monitoring under Directive (EU) 2016/2284[195].

4.1.3. Monitoring objectives in general

Monitoring of ambient air pollutants in general fulfils a number of objectives:

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[187] https://atmosphere.copernicus.eu/ (last viewed on 4.8.2022)

[188] Umweltbundesamt Dessau (2022).

[189] http://www.unece.org/fileadmin/DAM/env/documents/2019/AIR/EB_Decisions/Decision_2019_1.pdf (last viewed on 4.8.2022)

[190] CAFE Working Group on Particulate Matter (2004); European Communities (2001); Technical Working Group on Particles (1997).

[191] Monforti-Ferrario, et al. (2022).

[192] LCSQA (2020b); LCSQA (2021b); ANSES (2017); US EPA (2008); Scheffe, et al. (2009).

[193] Thunis, et al. (2022).

[194] AQUILA (2021a).

[195] Ecologic Institute (2022).

- Assessment of ambient concentrations, in relation to air quality standards (such as limit/target values), guideline values (such as by the WHO) or information and alert thresholds;
- Information to the public;
- Identification and, if possible, source apportionment;
- Check of emission reduction strategies efficiency;
- Check of emission inventories consistency;
- Understanding of atmospheric chemical and physical processes;
- Input for exposure and health assessments;
- Validation of modelling (dispersion, chemical, forecast).

4.2. Ultrafine particles

This section covers the particle number concentrations (PNC) of ultrafine particles. For the particle number size distribution see section 1.7.4.

The main sources of ultrafine particles (UFP) are incomplete processes from on-road and off-road traffic, residential heating, power plants and industry[196]. In addition, nucleation of condensable gases from natural and anthropogenic sources can contribute to UFP number concentrations (see section 1.6.1).

Monitoring of UFP is already undertaken at around 70 sampling points in 13 Member States; a technical specification for particle number concentrations (PNC) of UFP was published by CEN in 2016. The need for additional monitoring requirements is highlighted in a recent study within the revision of the AAQDs as well[197].

The following table provides an overview of characteristics of UFP, including the current status of monitoring, modelling and reporting, as well as the costs. Furthermore, it provides information about the status of standardisation and considerations for QA/QC.

Table 25: Overview of characteristics, monitoring, modelling, reporting and QA/QC considerations of UFP

Source: this study, Member States

UFP	Criteria, characteristics
Objective	The main objective is the assessment of exposure to UFP and the assessment of health impacts, in addition identification of sources and understanding of atmospheric processes
Main sources	Incomplete combustion processes (e.g. traffic, residential heating, power plants, industry), nucleation of condensable gases from natural and anthropogenic sources[198]
Number of existing sampling points	Around 70 sampling points in 13 Member States
Types of existing sampling points	Mainly urban or suburban background[199] (39 stations, 55%), followed by rural background (17 stations, 24 %) and urban or sub-urban traffic (13 stations, 18%). UFP close to airports are monitored in at least four Member States
Monitoring methods	Particle number concentrations (PNC) of UFP: Condensation particle counter (CPC), partly according to CEN/TS 16976:2016 Particle number size distribution: Scanning mobility particle sizer (SMPS), partly according to CEN/TS 17434:2020
Time coverage	Continuous monitoring (same as PM monitoring)
Time resolution	1 min to 1 hour. N.B.: a time resolution of 1 hour is the standard for reporting to EEA and the recommended temporal resolution in the EMEP Monitoring Strategy; a higher time resolution may be appropriate for source identification

[196] Kukkonen, et al. (2016).

[197] European Commission (2022).

[198] Monforti-Ferrario, et al. (2022); Dr. Holger Gerwig (2007); Umweltbundesamt (2018); LCSQA (2020b).

[199] The site classification (background/traffic/industrial) refers to PM_{10} or $PM_{2.5}$. The present knowledge about UFP sources and UFP levels does not yet allow a classification according to predominant emission sources. Two of the UFP stations are classified as industrial for PM monitoring.

Status of modelling	Still in initial phase[200]: • No (standardised) emission inventories for UFP are available at present; • Aerosol dynamics is required to estimate mass and size distribution; • Nucleation is currently mainly considered in large scale chemical transport models; • Harmonisation of monitoring and emission inventories of UFP necessary; • Input data for modelling short-term events (e.g. landing and take-off at airports) hardly available.
QA/QC considerations	Development of a common European standard based on the CEN/TS 16976:2016 to provide comparable data, coordination within AQUILA on the traceability of UFP measurements and requirements of the monitoring equipment, consider the establishment of a (few) common reference laboratory(ies) for UFP monitoring. The need for reference methods, data quality objectives is highlighted in a recent study[201].
Reporting	Currently not reported to EEA, reporting possible since beginning of April 2022
Additional investment costs per sampling point	Condensation Particle Counter (CPC) between 20 000 € and 50 000 € Scanning mobility particle sizer (SMPS) between 60 000 € and 150 000 €
Running costs per year (if available)	Large range between Member States, at least 10.000 € (including consumables, personnel costs and QA costs – i.e. data handling (validation, reporting)). The large range results from the different QA/QC steps undertaken by the Member State. Therefore future costs depend on the requirements of the standard, the forthcoming reference method and possible level of cooperation between Member States
Further considerations	Forthcoming standard, harmonisation of a well-defined measuring range (with lower and upper limits of particle size), extensive inventory of the "fit-for-purpose" equipment (brand & model).

Based on the analysis to what extent the WHO good practice statements (see section 3.4.1) are currently fulfiled and the information collected within this study the following recommendations are provided.

To fulfil the WHO good practice statements regarding UFP it is reccommended that:

- Systematic monitoring of UFP should be undertaken in all Member States at sampling points relevant for exposure assessments.
- Size-segregated real-time measurements of PNC should be undertaken by all Member States, especially at supersites[202] in case those will be established.
- A distinction between low and high PNC should be established in Member States.

[200] Lorentz, et al. (2021); AQEG (2018); Zhang, et al. (2020); Kukkonen, et al. (2016).

[201] European Commission (2022).

[202] Umweltbundesamt Dessau (2022).

- Further studies to assess the health impacts of UFP should be undertaken in close cooperation with scientific networks related to health impacts of air pollutants such as the Air Convention's *Joint Task Force on the Health Aspects of Air Pollution* [203].

As the WHO good practice statement regarding UFP require monitoring in all Member States, the following general recommendations for the spatial distribution and siting of UFP sampling points within a Member State are provided. These recommendations are largely in-line with recommendations developed within some Member States[204]:

- The main focus of UFP monitoring should be on urban background sampling points in agglomerations to support exposure and health impact assessments. Dependent on the overall number of sites, additional sampling points should be placed at urban traffic sites, such as at traffic-oriented monitoring stations, relevant for exposure, and at rural background locations to improve the understanding of the spatial distribution of UFP levels in the agglomerations, as well as formation processes, transport and depletion.
- As airplanes and ships are major sources for UFP, it is recommended to monitor UFP at the busiest airports[205] and ports[206] in the EU as well[207].
- In case a supersite is established in an agglomeration, this should be equipped with an UFP monitor (CPC) compliant with current EN standard.
- The investment, personnel and running costs of an SMPS device are rather high. It is thus recommended to install particle number size distribution (SMPS) monitors mainly at urban background supersites. These monitors should be compliant with EN normative documents.
- It is recommended to co-locate UFP measurements (as PNC) with monitoring of $PM_{2.5}$, NO_x and EC/BC as well as OC in case of EC monitoringTR[208].

Regarding legal requirements, the following recommendations are provided:

- Monitoring obligation (comparable to the monitoring obligation for $PM_{2.5}$ compounds in Annex IV of Directive 2008/50/EC) at specified site types (urban/suruban background, in addition urban/suburban traffic, rural background, airport/port), the number of which depends on population and/or area of the Member States;
- Small neighbouring countries could share monitoring sites as long as the specified criteria based on population and/or area are met (e.g. Estonia, Latvia, Lithuania);
- Review of monitoring obligations after 3 years. Information about UFP levels, their spatial distribution, sources and atmospheric formation available by that time should enable the design of a long-term monitoring stategy (comparable to Annex V of Directive 2008/50/EC).

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[203] https://www.who.int/europe/initiatives/joint-task-force-on-the-health-aspects-of-air-pollution (last viewed 25 June 2022)

[204] LCSQA (2020b); Umweltbundesamt Dessau (2022).

[205] https://en.wikipedia.org/wiki/List_of_the_busiest_airports_in_Europe (last viewed 9 May 2022)

[206] https://en.wikipedia.org/wiki/List_of_busiest_ports_in_Europe (last viewed 10 May 2022)

[207] Bendtsen, et al. (2021); Costabile, et al. (2015); TNO (2019); Stacey, Harrison, Pope (2020); Stafoggia, et al. (2016); Vorage (2018); Lorentz, et al. (2021); Karl, et al. (2020); Lopes, et al. (2019); Merico, et al. ; van der Zee, et al. (2012); Kukkonen, et al. (2016).

[208] LCSQA (2020b).

Based on the above provided recommendations the following number and distribution of supplementary sampling points are proposed per Member State (see Table 28 further below).

The number of sampling points per Member State is based on the number of inhabitants in the agglomerations as provided to EEA for 2021.[209] As a starting point, half the sampling points required for the sum of PM_{10} and $PM_{2.5}$ sampling points according to Annex V of Directive 2008/50/EC is proposed for each agglomeration (Table 26).

Table 26: Minimum number of UFP sampling points based on population of agglomerations

Source: this study, Annex V Directive 2008/50/EC

Population of agglomeration (thousands)	PM sampling points (sum of PM_{10} and $PM_{2.5}$) if concentrations are between upper and lower assessment thresholds	Number of UFP sampling points
0-249	1	1
249-499	2	1
500-749	2	1
750-999	2	1
1000-1499	3	2
1500-1999	3	2
2000-2749	4	2
2750-3749	4	2
3750-4749	6	3
4750-5999	6	3
>6000	7	4

The number of sampling points for the remaining territory is based on the number of inhabitants in non-agglomerations in total, which has arbitrarily chosen as following:

- 1 sampling point per 1 mio inhabitants with up to 10 mio inhabitants
- 0.75 sampling points between 10 and 20 mio inhabitants, and
- 0.5 sampling points above 20 mio inhabitants.

Costs for additional sampling points are provided based on the number provided by the respective Member State and for typical cost estimates in general (see Annex 4 for details).

[209] https://eeadmz1-cws-wp-air02.azurewebsites.net/index.php/users-corner/zones-b-table/ (last viewed 10 June 2022). It has to be noted that Bulgaria divided its territory into agglomerations only; whereas Luxembourg named only non-agglomerations.

As typical costs[210] 40 000 € have been chosen, which is the median of costs provided by Member States for a sampling device. When comparing costs based on numbers provided by Member States, it has to be taken into account that these numbers might also differ if the instruments were bought in different years. Table 28 below provides the resulting number of sampling points and associated costs per Member State of the sampling devices. Overall, around 460 UFP sampling points are proposed from which at least 70 already exist in Member States.

Regarding running costs of UFP monitoring the replies from the Member States showed a large variability, ranging from 2 500 € to 18 000 € per sampling point (Table 27)[211]. A very rough estimate of running costs is in the range of 10 000 € per sampling point. Member States not providing specific number stated in general that running costs are roughly equal compared to monitoring of other, already regulated pollutants. The variability of costs results from the different QA/QC steps undertaken by the Member State. Therefore future running costs will depend on the requirements of a standard, the forthcoming reference method and possible level of cooperation between Member States. Technical aspects of data handling and requested informatics and telematics resources have to be taken into account.

Table 27: Running costs for UFP monitoring (PNC only)

Source: Member States

Member State	**Annual running cost estimate** (absolute number or in relation to monitoring other, already regulated pollutants)
AT	lower to equal
DE	equal
FI	around 10 000 €
FR	18 000 €
IT	2 500 to 10 000 €
LU	equal
NL	10 000 €

The numbers used for proposing the number of stations and the estimated investment costs can be easily changed in the Excel table (Annex 5).

The number of sampling points for large airport and ports depends on the local circumstances. Therefore, it is not deemed useful to provide a specific number of sampling points around an airport or harbour. Sampling points should be installed downwind of large airports and ports at the border to adjacent settlements in the main wind directions. A nearby rural or suburban background sampling point should be located in a way to provide information of UFP concentrations without contribution from airport or harbour activities.

[210] Cost for purchasing and installation (one-off) without maintenance, repair etc.

[211] The table does not include Member States that provided both running costs for UFP and PNSD

Information about times of aircraft activities and flightpaths should support the analysis of concentration patterns.

Monitoring around the airports e.g. in Frankfurt/Main[212], Amsterdam Schiphol, London Heathrow, Rome and Zurich[213] can be taken as an example[214]. A review of UFP monitoring at airports by B. Stacey can be of help as well[215].

[212] https://www.hlnug.de/themen/luft/luftqualitaet/sondermessprogramme/ultrafeine-partikel (last viewed 10 June 2022)

[213] https://www.flughafen-zuerich.ch/de/unternehmen/verantwortung/umweltschutz/fachleute (last viewed 10 June 2022)

[214] TNO (2019); Masiol, et al. (2017); Stacey, Harrison, Pope (2020); Costabile, et al. (2015); Stafoggia, et al. (2016); Zhang, et al. (2020).

[215] Stacey (2019).

Table 28: Proposed additional number of UFP sampling points (SP) per Member States

Source: this study, Member States, population: https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en (last viewed on 4.8.2022)

MS	Pop. (mio.)	Pop. ag-glomeration (mio.)	Pop. non-ag-glomeration (mio.)	# SP ag-glomera-tions	# SP non-ag-glomera-tions	Sum	existing SP	additional SP	additional costs device (costs by MS)[1]	additional costs device typical[2]	typical an-nual running costs
Austria	8.9	2.4	6.5	4	7	11	5	6	150 000 €	240 000 €	60 000 €
Belgium	11.6	3.2	8.4	7	8	15	3	12	NA	480 000 €	120 000 €
Bulgaria	6.9	7	0	10	0	10	0	10	NA	400 000 €	100 000 €
Croatia	4	1.5	2.5	4	3	7	0	7	NA	280 000 €	70 000 €
Cyprus	0.9	0.9	0	1	0	1	0	1	NA	40 000 €	10 000 €
Czechia	10.7	2.5	8.2	4	8	12	6	6	300 000 €	240 000 €	60 000 €
Denmark	5.8	1.5	4.3	3	4	7	4	3	NA	120 000 €	30 000 €
Estonia	1.3	0.5	0.8	2	1	3	0	3	NA	120 000 €	30 000 €
Finland	5.5	1.1	4.4	2	4	6	11	0	- €	- €	- €
France	67.7	27.6	40.1	32	20	52	13	39	1 560 000 €	1 560 000 €	390 000 €
Germany	83.2	29	54.2	46	27	73	9	64	2 240 000 €	2 560 000 €	640 000 €

Greece	10.7	4.4	6.3	3	6	9	0	9	NA	360 000 €	90 000 €
Hungary	9.7	2.6	7.1	2	7	9	0	9	NA	360 000 €	90 000 €
Ireland	5	1.4	3.6	3	4	7	0	7	NA	280 000 €	70 000 €
Italy	59.2	24.8	34.4	32	17	49	10	39	1 482 000 €	1 560 000 €	390 000 €
Latvia	1.9	0.6	1.3	1	1	2	0	2	NA	80 000 €	20 000 €
Lithuania	2.8	0.8	2	2	2	4	2	2	NA	80 000 €	20 000 €
Luxem-bourg	0.6	0	0.6	0	1	1	3	0	- €	- €	- €
Malta	0.5	0.2	0.3	1	0	1	0	1	NA	40 000 €	10 000 €
Nether-lands	17.5	5.2	12.3	9	9	18	1	17	680 000 €	680 000 €	170 000 €
Poland	37.8	8.9	28.9	14	14	28	0	28	NA	1 120 000 €	280 000 €
Portugal	10.3	5.1	5.2	10	5	15	0	15	NA	600 000 €	150 000 €
Romania	19.2	5	14.2	14	11	25	0	25	NA	1 000 000 €	250 000 €
Slovakia	5.5	0.7	4.8	2	5	7	0	7	NA	280 000 €	70 000 €
Slovenia	2.1	0.4	1.7	2	2	4	1	3	170 100 €	120 000 €	30 000 €
Spain	47.4	30.7	16.7	57	13	70	0	70	NA	2 800 000 €	700 000 €

Sweden	10.4	3.5	6.9	4	7	11	3	8	NA	320 000 €	80 000 €

SP: Sampling Point

[1] Additional cost for purchasing and installation (one-off) without maintenance, repair etc. based on cost estimate provided by Member States

[2] Additional cost for purchasing and installation (one-off) without maintenance, repair etc. based on typical costs of instruments (median of costs provided by Member States)

4.3. Black Carbon, Elemental Carbon

The main sources of Black Carbon (BC) and Elemental Carbon (EC) are the incomplete combustion of fossil fuels mainly from the transport sector and the industrial activity, the residential heating with biomass and the non-anthropogenic activity in forestry places (e.g., wildfires)[216]. BC/EC is involved in the global warming effect due to its strong light-absorption property, whereas Organic Carbon (OC) is responsible for cooling the atmosphere mainly because it reflects solar radiation[217].

Monitoring of BC has been undertaken at around 267 stations in 15 Member States, where only 195 of them are currently active based on the Member States responses. Monitoring of EC has been undertaken at around 200 stations in 16 Member States, where only 134 of them are currently active. The need for additional monitoring requirements for BC is highlighted in a recent study within the revision of the AAQDs[218].

The following table provides an overview of characteristics of BC/EC, including the current status of monitoring, modelling and reporting, as well as the costs. Furthermore, it provides information about the status of standardization and considerations for QA/QC.

Table 29: Overview of characteristics, monitoring, modelling, reporting and QA/QC considerations of BC/EC

Source: Member States, EEA

BC & EC	Criteria, characteristics
Objective	The main objective is the assessment of human exposure to black carbon pollution (with a view to health impacts) and providing information on contribution of these species to climate change.
Main sources	Incomplete combustion of fossil fuels (transport, industry), residential heating with biomass, non-anthropogenic (e.g., wildfires)
Number of existing sampling points	BC: Around 267 stations (195 active) in 15 Member States EC: Around 200 stations (134 active) in 16 Member States Some stations (number difficult to quantify) measure both BC and EC
Types of sampling points	Both urban and rural sites of monitoring
Monitoring methods	BC: Aethalometers, multi-spectrum BC monitors, Multi Angle Absorption Photometer (MAAP), optical transmissometer EC: Thermo-optical method
Time coverage	Continuous monitoring (same as PM monitoring)
Time resolution	BC – 10 min to 1 hour. N.B.: a time resolution of 1 hour is the standard for reporting to EEA

[216] EEA (2013); Lamarque, et al. (2010); Klimont, et al. (2017); UNEP, WMO (2011).

[217] IPCC (2021).

[218] European Commission (2022).

	EC – 24 hours for reporting to EEA. High time resolution is required to identify sources and peak events but in terms of health effects and climate impacts, ~1 h resolution should be enough. The temporal resolution recommended in the EMEP Monitoring Strategy is 24 hours/7 days
Status of modelling	EC (split in fine and coarse) is part of the EMEP (MSC-W) gridded air quality data. Emission inventories reported to EMEP (CEIP) contain BC information. BC modelling is part of the Copernicus atmospheric monitoring service. Finally, large international policy activities target BC (e.g. IMO strategy for the Arctic, the Arctic Council activities, etc.) modelling and reduction, as well as its global modelling is included in large research activities (e.g.[219]).
QA/QC considerations	BC: lack of a common European standard method. Need of development of a common standard method for measurements. EC: The European Standard EN 16909:2017 gives guidance on the measurement of EC and OC following the requirement for the networks of all EU Member States to measure EC and OC in $PM_{2,5}$ at background sites according to the AAQDs. The method described in EN 16909 is hence seen as the reference method for monitoring EC and OC concentrations in Europe. For the determination of EC and OC in PM_{10} and PM_{coarse} (PM_{10} – $PM_{2.5}$) a Technical Report has been developed by CEN/TC 264/WG 35 (CEN/TR 17554:2020 Ambient air - Application of EN 16909 for the determination of elemental carbon (EC) and organic carbon (OC) in PM10 and PMcoarse).
Reporting	BC emissions are reported to EEA / CEIP by means of annual inventories. EC is reported to EEA by 18 MS, only additional info about stations stored in EBAS database
Additional investment costs per station	Cost of purchase of BC equipment: 12 000 – 70 000 € Cost of purchase of EC equipment: 25 000 – 100 000 €
Running costs per year (if available)	BC: Large range between Member States: 1 500 – 30 000 € EC: Large range between Member States: 3 000 – 20 000 €
Further considerations	BC can better characterize health effects and climate impacts than EC but a standard for each measurement will have to be decided.

For BC/EC WHO provides the following good practice statements, which are relevant for this study (see section 3):

1. *Make systematic measurements of black carbon and/or elemental carbon. Such measurements should not replace or reduce the existing monitoring of pollutants for which guidelines currently exist.*
2. *Undertake the production of emission inventories, exposure assessments and source apportionment for BC/EC.*

Based on the analysis to what extent the WHO good practice statements are currently fulfiled and the information collected within this study the following recommendations are provided:

- Current monitoring is performed either for BC or EC, in different Member States and/or monitoring stations, often using different sampling protocols. WHO good practice statements can be fulfilled by extending the monitoring stations using any

[219] Klimont, et al. (2017).

of the available techniques, especially in Member States where very scarce monitoring of either BC or EC takes place.

- The placement of BC or EC monitoring stations should with priority be in densely populated areas so that concentrations can be representative of what large proportions of population are exposed to. Systematic monitoring of BC or EC should be undertaken in all Member States at stations for exposure assessments.
- As residential heating using biomass is one of the main sources of BC, it is recommended that a sufficient number of monitoring stations is placed e.g. in acricultural communities where biomass burning is frequent to assess population exposure to BC in those areas.
- Member States in which BC inventories are still weak need to advance their understanding based on the experience of other Member States and the EMEP/EEA guidebook[220] to ensure comparability of data.
- Increasing the time resolution (e.g. hourly concentration reporting vs. daily) can lead to better information to assess exposure and to be used for the source apportionment of BC/EC.

Furthermore, the study team could offer the following recommendations to improve the understanding of carbon aerosols:

- It is generally recommended that BC becomes the carbon aerosol to be reported due to its more clear signal in terms of both health and climate impacts, compared to EC. Because of the lack of a common European standard for the monitoring of BC and the accumulated experience and data of Member States in the measurement of EC, it is recommended that EC remains a proxy of BC and equivalence factors are derived until a common European standard method is agreed for BC measurements.
- Until a common European standard method is achieved, EC data according to EN 16909:2017 should be used as a proxy for BC.
- Due to the climatic impacts of BC, it is also recommended that background monitoring stations are placed in rural areas, in order to be able to identify any unforeseen processes of BC emissions as well as to be in the position to assess the impact of emission control and/or BC mitigation measures.
- Special monitoring stations are required in forestry areas to monitor the impact of wild fires and in pristine areas (e.g. glaciers, the Arctic circle) to monitor impacts to ice albedo.
- As ports and in general maritime activity is a big contributor of BC, it is recommended to monitor BC/EC at the busiest ports and in coastal areas in proximity to busy shipping lanes (e.g. coastal areas in south Creta, Sicily, Sardinia affected by the Suez-Gibraltar route, and also the North Sea and the Channel).

In terms of number of stations, BC is atmospherically more stable than UFP number concentration and is largely the result of the same processes producing primary UFP. Hence, it is recommended that the number of urban BC stations has <u>at maximum</u> the same density as the one of UFP. Background BC stations should be selected according to the criteria outlined above.

Typical costs for a BC instrument are 35 000 to 40 000 €. Typical investment costs for EC instruments consist of 15 000 to 30 000 € for the PM sampling device per sampling point

[220] EEA (2019).

and at least 50 000 € for the EC/OC analyzer for the network. Costs for continuous EC instruments range from 70 000 to 100 000 €. When comparing costs based on numbers provided by Member States, it has to be taken into account that these numbers might also differ if the instruments were bought in different years.

Regarding running costs of BC/EC monitoring the replies from the Member States showed a large variability, ranging from 1 500 € to 30 000 € per sampling point and 3 000 € to 20 000 €, respectively (Table 27). A very rough estimate of running costs is in the range of 10 000 € per sampling point. Member States not providing specific numbers stated in general that running costs are roughly equal compared to monitoring of other, already regulated pollutants. The variability of costs results from the different QA/QC steps undertaken by the Member State. Therefore future running costs will depend on the requirements of a standard, the forthcoming reference method and possible level of cooperation between Member States.

Table 30: Running costs for BC/EC monitoring

Source: Member States

Member State	Annual running cost estimate (BC)	Annual running cost estimate (EC)
AT	Lower to equal	About 70 € per filter sample (EN 16909:2017) and 35 € per sample (VDI 2465-2)
CZ	16 000 €	8 000 €
DE	Equal	Equal
ES	2 400 €	10 400 €
FI	Around 15 000 €	See BC
FR	5 000 €	See BC
HR	4 000 €	See BC
HU	NA	3 700 €
IT	3 000€ to 9 500 €	3 000€ to 17 000€ / 24.5€ per sam-ple
LT	30 000 €	NA
LV	NA	9 750 €
MT	9 000 € (incl. EC)	9 000 € (incl. BC)
NL	5 000€-10 000€	see BC
PL	1 500 €	7 500 €
SE	4 000 €	20 000 €

Hence the numbers of sampling points as described in Table 26 for UFP can be chosen for BC as well. The number of sampling points for the remaining territory is based on the number of inhabitats in non-agglomerations in total, which has arbitrarily chosen as following, in-line with the numbers for UFP sampling points:

- 1 sampling point per 1 mio inhabitants with up to 10 mio inhabitants
- 0.75 sampling points between 10 and 20 mio inhabitants, and
- 0.5 sampling points above 20 mio inhabitants.

Costs for additional sampling points are provided based on the number provided by the respective Member State and for typical cost estimates in general. As typical costs 37 500 € have been chosen, which is the median of costs provided by Member States. When comparing costs based on numbers provided by Member States, it has to be taken into account that these numbers might also differ if the instruments were bought in different years. Table 31 below provides the resulting number of sampling points and associated costs per Member State.

Table 31: Proposed number of BC sampling points per Member States

Source: this study, Member States, population: https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en (last viewed on 4.8.2022)

MS	Pop. (mio.)	Pop. agglomeration (mio.)	Pop. non-agglomeration (mio.)	# SP agglomerations	# SP non-agglomerations	Sum	existing SP	additional SP	additional costs device (costs by MS)[1]	additional device costs typical[2]	typical running costs
Austria	8.9	2.4	6.5	4	7	11	2	9	180 000 €	337 500 €	90 000 €
Belgium	11.6	3.2	8.4	7	8	15	40	0	- €	- €	- €
Bulgaria	6.9	7	0	10	0	10	0	10	NA	375 000 €	100 000 €
Croatia	4	1.5	2.5	4	3	7	0	7	NA	262 500 €	70 000 €
Cyprus	0.9	0.9	0	1	0	1	0	1	NA	37 500 €	10 000 €
Czechia	10.7	2.5	8.2	4	8	12	4	8	384 000 €	300 000 €	80 000 €
Denmark	5.8	1.5	4.3	3	4	7	0	7	NA	262 500 €	70 000 €
Estonia	1.3	0.5	0.8	2	1	3	0	3	NA	112 500 €	30 000 €
Finland	5.5	1.1	4.4	2	4	6	8	0	- €	- €	- €
France	67.7	27.6	40.1	32	20	52	30	22	770 000 €	825 000 €	220 000 €
Germany	83.2	29	54.2	46	27	73	23	50	3 000 000 €	1 875 000 €	500 000 €

Greece	10.7	4.4	6.3	3	6	9	0	9	NA	337 500 €	90 000 €
Hungary	9.7	2.6	7.1	2	7	9	0	9	NA	337 500 €	90 000 €
Ireland	5	1.4	3.6	3	4	7	0	7	NA	262 500 €	70 000 €
Italy	59.2	24.8	34.4	32	17	49	30	19	665 000 €	712 500 €	190 000 €
Latvia	1.9	0.6	1.3	1	1	2	0	2	NA	75 000 €	20 000 €
Lithua-nia	2.8	0.8	2	2	2	4	2	2	140 000 €	75 000 €	20 000 €
Luxem-bourg	0.6	0	0.6	0	1	1	0	1	NA	37 500 €	10 000 €
Malta	0.5	0.2	0.3	1	0	1	2	0	- €	- €	- €
Nether-lands	17.5	5.2	12.3	9	9	18	29	0	- €	- €	- €
Poland	37.8	8.9	28.9	14	14	28	0	28	NA	1 050 000 €	280 000 €
Portugal	10.3	5.1	5.2	10	5	15	0	15	180 000 €	562 500 €	150 000 €
Roma-nia	19.2	5	14.2	14	11	25	0	25	625 000 €	937 500 €	250 000 €
Slovakia	5.5	0.7	4.8	2	5	7	0	7	NA	262 500 €	70 000 €
Slovenia	2.1	0.4	1.7	2	2	4	4	0	- €	- €	- €
Spain	47.4	30.7	16.7	57	13	70	4	66	3 498 000 €	2 475 000 €	660 000 €

Sweden	10.4	3.5	6.9	4	7	11	8	3	NA	112 500 €	30 000 €

SP: Sampling Point

[1] Additional cost for purchasing and installation (one-off) without maintenance, repair etc. based on cost estimate provided by Member States

[2] Additional cost for purchasing and installation (one-off) without maintenance, repair etc. based on typical costs of instruments (median of costs provided by Member States)

4.4. Ammonia

Ammonia (NH_3) has an impact on biodiversity and is a key precursor in the formation of $PM_{2.5}$. A consistent monitoring of ammonia across Europe will help in verifying the effectiveness of mitigation measures, help to improve existing models and eventually lay the basis for effective reduction strategies. Agriculture contributes about 94% to the total ammonia emission from EU27, followed by the sector 'Residential, commercial and institutional' (2.1%) and the sector 'Manufacturing and extractive industry' (1.5%)[221]. The need for additional monitoring requirements for NH_3 is highlighted in a recent study within the revision of the AAQDs[222].

The following table provides an overview of characteristics of NH_3, including the current status of monitoring, modelling and reporting, as well the costs. Furthermore, it provides information about the status of standardisation and considerations for QA/QC.

Table 32: Overview of characteristics, monitoring, modelling, reporting and QA/QC considerations of NH_3

Source: this study, Member States

NH_3	Criteria, characteristics
Objective	Formation of secondary inorganic aerosols, impact on human health, acidification and eutrophication of water and soil, impact on biodiver-sity.
Main sources	Agriculture[223]
Number of existing sampling points	About 275
Types of existing sampling points	Mainly rural background (41%, 110 sites), but also urban background (21%, 57 sites) and urban traffic (16%, 44 sites) Types of stations reported by MS to EEA data base are only partly available.
Monitoring methods	Diffusive samplers, filter pack sampling, denuders, continuous meth-ods (chemiluminescence, mini DOAS, cavity ring-down spectroscopy)
Time coverage	Continuous monitoring (same as PM monitoring)
Time resolution	Hour (continuous) – month (passive) Temporal resolution recommended in the EMEP Monitoring Strategy: 24 hours.
Status of modelling	Modelling of ammonia concentrations and deposition is done by means of dispersion and deposition models, ranging from local scale to European (or even global scale). The EMEP model is the standard

[221] EEA (2021).

[222] European Commission (2022).

[223] Monforti-Ferrario, et al. (2022).

	for modelling ammonia for Europe and individual Member States (https://www.emep.int/, last viewed on 10.8.2022).
QA/QC considerations	A European standard is available for determining the concentration of ammonia using diffusive samplers (EN 17346), where also VDI 3869-4 is mentioned by different Member States for the measurement of ammonia in ambient air by means of diffusive samplers. VDI 3869-4. While EN 17346 and VDI 3869-4 deal with passive samplers, the EMEP manual for sampling and analysis also describes continuous measurement systems for ammonia. The study "Strengthening of air quality monitoring, modelling and plans under the Ambient Air Quality Directives" highlights the need for reference methods, data quality objectives for NH_3[224]. An European standard for standardised automated measuring method is not yet available. Possible methods and traceability were studied in the Joint Research Project MetNH3.[225]
Reporting	Eight Member States report NH_3 data to the EEA for a total of 63 monitoring sites. In the context of EU NEC Directive (Directive 2016/2284 - Article 9), ammonia is listed as one of the pollutants recommended to be reported, with the next reporting scheduled in 2023. Different individual NH_3 concentration datasets are stored in the EMEP-EBAS database (https://ebas.nilu.no, last viewed on 10.8.2022)
Additional investment costs per station	15 000 – 150 000 € (continuous) 100 – 500 € (passive)
Running costs per year (if available)	Large range between Member States, with total sum depending on continuous or passive systems. For continuous measurements the costs are ranging from 2 500 € - 25 000 € (including consumables, personnel costs and QA costs), while for passive measurements the costs are dependent on the type and number of samplers used. Typical cost for one passive sampler including analysis is 30 € (excl. handling. Cost ranges from 10 to 50 €, depending on supplier and amount).
Further considerations	Need for standardised automated measuring method and common QA/QC SOP.

The main focus of NH_3 monitoring should be on rural background sampling points, with a special aim at sampling points located in or near nature areas and areas with high ammonia emission densities. This is largely in line with the guidance on site selection[226]. The guidance describes two approaches for site selection: 1) grid based approach and 2) approach based on biogeographical regions and pollution levels. Furthermore, monitoring near urban/suburban areas or traffic is to be established near potential (non-agricultural) sources of ammonia. It is worth mentioning that Directive (EU) 2016/2284 does not prescribe standard methods for ecosystem monitoring even though reference is made to the monitoring manuals[227] developed under the Air Convention. A European standard has been published only for passive monitoring of ammonia (EN 17346:2020). Possible methods for NH_3 and traceability were studied in the Joint Research Project MetNH3.[228]

[224] European Commission (2022).

[225] http://www.metnh3.eu/typo3/ (last viewed on 15.09.2022)

[226] Ecologic Institute (2022).

[227] http://icp-forests.net/page/icp-forests-manual, http://www.icp-waters.no/publications/#icpwmanual, https://icpvegetation.ceh.ac.uk/get-involved/manuals/mapping-manual (last viewed on 15.09.2022)

[228] http://www.metnh3.eu/typo3/ (last viewed on 15.09.2022)

Critical levels for ammonia for vegetation have been established under the Convention on Long Range Transboundary Air Pollution. These critical levels are 1 µg $NH_3.m^{-3}$ for lichens and bryophytes and 3 µg $NH_3.m^{-3}$ for higher plants.

Using passive samplers can determine trends and spatial distribution of NH_3 concentration. Continuous monitoring systems with a high temporal resolution can not only be used for trend analysis, but can also provide information about source contributions.

While investment, personnel and running costs of continuous NH_3 monitoring devices can be rather high, passive sampler systems provide a more cost-effective way for setting up a monitoring network. It is, however, recommended to combine passive samplers with a limited number of continuous devices for calibration purposes. For smaller Member States, these can be shared between neighbouring countries.

Costs for additional sampling points are provided based on the number provided by the respective Member State and for typical cost estimates in general (see Annex 4 for details). The costs differ depending on the sampling method chosen. While typical costs for continuous systems are about 50 000 € (median of the costs provided by Member States), the costs for setting up a site for passive systems are 250 €.

Regarding running costs of ammonia monitoring the replies from the Member States showed a large variability, ranging from 6 000 € to 25 000 € per sampling point for continuous monitoring (Table 33). For diffusive sampling these costs are around 30 € per sampler, so the total running costs depends on the number of samplers used by the Member States. Member States not providing specific numbers stated in general that running costs are roughly equal compared to monitoring of other, already regulated pollutants. The variability of costs results from the different QA/QC steps undertaken by the Member State. Therefore future running costs will depend on the requirements of a standard, the forthcoming reference method and possible level of cooperation between Member States.

Table 33: Running costs for ammonia monitoring

Source: Member States

Member State	Annual running cost estimate
AT	Diffuse: 30 € per sampler
CZ	Continuous: 11 000 €
DE	Higher
ES	Diffuse: 70 € - 100 € per sampler
FI	62 000 € (filter) - 30 000 € (MARGA)
FR	Continuous: 5 000 €
HR	Continuous: 4 000 €
HU	Continuous: 15 000 €
IE	Continuous: 23 000 €
IT	Continuous: 2 500 to 6 400 € Diffuse: 32 € per sampler

LU	Continuous: 6 000 €
NL	Continuous: 20 000 €
RO	Continuous: 400 € - 4 000 €

The guidance document on site selection lists two main approaches: a grid based approach and an approach based on biogeographical regions and pollution levels. Monitoring sites are to be established for each relevant ecosystem (cropland, grassland, heathland and shrub, wetlands, forests and woodlands) within each grid and/or biogeographical region/pollution level, as well as for more pristine areas within the Member States. Furthermore, a risk-based approach and a cost-effective approach were reflected in the guidance document[229].

According to the guidance document, the risk-based approach is aiming at monitoring at locations where effects of ammonia are likely to be present. For the locations of the monitoring sites, areas with a high sensitivity to ammonia pressure are to be selected. For this, Member States can look for sites with exceedance of critical loads. Such critical loads show the overall risk of potential impacts. It should be noted that there are critical loads for eutrophication and acidification, which are not only considering (deposition of) ammonia but also nitrogen oxides and sulphur dioxide. For a more ammonia focussed approach, the earlier mentioned critical levels can be considered. The priority is to have more monitoring sites in areas with (sensitive) relevant ecosystems. In the case of NH_3 this is interpretated as areas where the critical level for ammonia of 3 µg $NH_3.m^{-3}$ is exceeded. In addition, Member States will have a minimum of one site per relevant ecoysystem in cleaner areas.

Based on the characteristics of NH_3, its emission sources and guiding principles provided in the NEC ecossystem monitoring site guidance,, the following general recommendations are provided.

Recommendations:

- Monitoring obligation at specified site types (rural background in/near nature areas, in addition urban/suburban areas/traffic), the number of which depends on the amount of ammonia emission in areas within Member States and the distance to Natura 2000 areas, population and/or area of the Member States;
- To align with the site selection guidance provided for the EU NEC Directive (Directive 2016/2284), different approaches can be used focussing on e.g. representativeness and/or is risk-based;
- For calibration purposes (small) neighbouring countries could share continuous monitoring sites;
- A low-cost method for the determination of the concentration of ammonia using diffusive samplers is defined in CEN guideline EN 17346[230] and in VDI 3869-4[231];

[229] Ecologic Institute (2022).

[230] https://www.en-standard.eu/csn-en-17346-ambient-air-standard-method-for-the-determination-of-the-concentration-of-ammonia-using-diffusive-samplers/ (last viewed on 2 August 2022)

[231] https://www.vdi.de/en/home/vdi-standards/details/vdi-3869-blatt-4-measurement-of-ammonia-in-ambient-air-sampling-with-diffusive-samplers-photometric-or-ion-chromatographic-analysis (last viewed on 2 August 2022)

- Review of monitoring obligations after 3 years. Information about measured ammonia levels, in combination with their (modelled) spatial distribution and sources available by that time should enable the design of a long-term monitoring stategy.

For providing an actual number of sampling points per Member State a more detailed definition of criteria is required. The recent 2022 NEC Directive reporting by Member States regarding the siting and list of parameters for monitoring of air pollution impacts on ecosystems may be helpful in further defining the criteria.

From 23 available Member State reports twelve Member States reported monitoring of ammonia in the context of NEC Directive Art. 9. The number of NH_3 monitoring sites ranges from 1 (Luxemburg) to more than 20 (Belgium, Spain and Austria). It should be noted that some of the Member States that are known to have NH_3 monitoring networks (e.g. Netherlands, Denmark, Germany) have not (fully) reported at this moment (early August).

A starting point can furthermore be existing NH_3 monitoring networks in countries such as the Netherlands, Austria, or other Member States with well-developed ammonia monitoring strategies.

4.5. Methane

Methane (CH_4) is mainly known for its impact on climate change (about 25 times stronger greenhouse gas compared to CO_2); however, CH_4, is also a precursor for ozone (but not listed in Annex X of Directive 2008/50/EC). Furthermore, Member States mentioned monitoring of CH_4 being part of the EMEP monitoring strategy, GAW (Global Atmosphere Watch Programme) or ICOS (Integrated Carbon Observation Network)[232].

CH_4 emissions are known to originate from agricultural sources (about 55% in EU27 in 2020), mostly related to raising cattle. However, emissions from non-agriculture sources like waste (27%) and energy production and/or supply (12%) are also known to contribute to the overall antropogenic methane emissions[233].

The following table provides an overview of characteristics of CH_4, including the current status of monitoring, modelling and reporting, as well the costs. Furthermore, it provides information about the status of standardisation and considerations for QA/QC.

CH_4	Criteria, characteristics
Objective	Formation of tropospheric ozone formation, greenhouse gas, climate change, impact on human health and ecosystems.
Main sources	Agriculture, waste and energy production/supply
Number of existing stations	54

[232] www.icos-cp.eu (last viewed on 2 August 2022)

[233] EEA (2021).

Types of existing stations	Mainly rural background locations, some urban background and urban traffic stations
Monitoring methods	Gas chromatograph equipped with flame ionization detector (FID). Online CH_4 analyzers based on spectroscopic technologies (e.g. Cavity Ring-Down Spectroscopy, CRDS) are available since 2005.
Time coverage	Continuous monitoring (same as PM monitoring)
Time resolution	Hour (same as recommended in the EMEP Monitoring Strategy)
Status of modelling	Modelling of methane has been done in the recent past e.g. by means of inverse modelling. This methodology aims at estimating the methane emissions by means of available measurements.
QA/QC considerations	Different data quality objectives were named by Member States, ranging from ~ 20% to 2 ppb, or a precision of < 1 ppb and reproducibility of < 0.5 ppb. One Member State named the WMO intercomparibility goal[234] of ± 2 ppb.
Reporting	EMEP, EEA, UNFCCC, GAW
Additional investment costs per station	20 000 – 150 000 €
Running costs per year (if available)	5 000 – 40 000 €
Further considerations	Follow recommendations of existing networks like ICOS or GAW (measuring method and associated QA/QC SOP).

The main focus of CH_4 monitoring should be on rural background stations, which is currently mostly done by 8 Member States. However, also urban background and urban traffic stations are used. When the focus is mainly on determining general trends in emissions for climate research, local sources of methane are preferably not taken into account. A good example of a running network on the monitoring of CH_4 is the ICOS. The ICOS network includes stations in 14 European countries. Each of the current 39 monitoring stations in these countries measures greenhouse gas concentrations (such as carbon dioxide and CH_4) in the atmosphere, as well as meteorological parameters.

The greenhouse gas measurements in the ICOS network are usually taken on top of tall towers, in mountainous terrain or in remote environments. These stations are usually not influenced much by local phenomena but are rather exposed to atmospheric transport and processes covering larger areas. Thus, integral information on regional sources and sinks of greenhouse gases can be retrieved. Consequently, the selection of stations allows to cover large parts of the European continent with a limited number of stations.

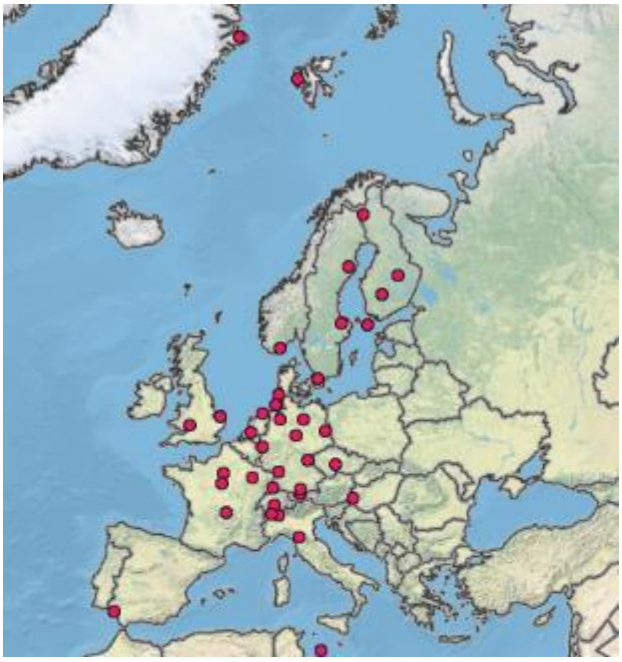
[234] WMO provides the following data quality objectives (WMO (2009)):

(i) The repeatability of CH_4 measurements should be ≤ 2.0 ppb, and the reproducibility ≤ 3.0 ppb.

(ii) The combined standard uncertainty for an ambient CH_4 measurement calculated using reproducibility (± 3 ppb), uncertainty in high-level standards (±1 ppb), and ability of a lab to propagate high-level standards to working standards (± 2 ppb) should be no larger than ± 3.7 ppb. Using optimized modern analytical methods should give uncertainties on order ± 2.2 ppb at the 66% confidence level.

(iii) The uncertainties defined above will determine the network or interlaboratory comparability of GAW CH_4 measurements.

The current ICOS network has a limited coverage in the Mediterranean region and in Eastern Europe, which is also mirrored in the responses from the Member States (see Figure below). A wider coverage in these regions is advised.



Investment, personnel and running costs of continuous methane monitoring devices can be rather high (up to € 150,000). However, especially for smaller Member States, these costs can be shared between neighbouring countries since monitoring sites are not necessary for individual Member States.

Recommendations:

- Monitoring obligation at specified site types (focus on rural background, in addition urban/suburban areas/traffic), the number per (combination of) Member State(s) depends on the general methane distribution in Member States;
- Align with the ICOS Atmosphere network in order to expand the methane network to a European coverage in an efficient way;
- For calibration purposes (small) neighbouring countries could share continuous monitoring sites;
- Review of monitoring obligations after 3 years. Information about measured methane levels, in combination with their (modelled) spatial distribution and sources available by that time should enable the design of a long-term monitoring stategy.

4.6. Monitoring of the oxidative potential of PM, 1,3-Butadiene, Formaldehyde, Mn, V

4.6.1. Oxidative potential of PM

The oxidative potential of PM has been suggested to be one of the many possible drivers of the acute health effects of PM, even though the link remains uncertain (section 1.6.9). Oxidative potential of PM is generally linked to fine particulate. So, as a starting point, the PM fraction to be measured could be $PM_{2.5}$ or PM_{10} (which generally is mainly constituted of $PM_{2.5}$).

Several analytical methods for measuring the oxidative potential are available; however, there is currently no common or standardised method[235].

Therefore, at this stage it seems premature to recommend a detailed number of sites and a specific analytical method. It is thus recommended that europe-wide monitoring at urban background stations is undertaken in a coordinated way within research projects in close cooperation with the health community[236]. Intensive monitoring campaigns similar to those undertaken by EMEP could be a possible approach. It is recommended that analysis is undertaken in selected, well experienced laboratories[237].

4.6.2. 1,3-Butadiene, formaldehyde

The main sources of 1,3-butadiene are chemical industries (section 1.6.5). Sources of formaldehyde are in addition power plants, incincerators, and atmospheric formation via the oxidation of various VOC species. Both 1,3-butadiene and formaldehyde are currently recommended to be monitored as ozone precursor substances according to Annex X of Directive 2008/50/EC; at least at one sampling point in each Member State. CEN standardisation work is in progress and will be available at mid-term. Working Group 7 under AQUILA prepared recommendations for monitoring of these and further precursors for both ozone and secondary organic aerosol[238]. AQUILA's recommendations are aimed to feed into the revision of the AAQDs.

The following recommendations for monitoring of 1,3-butadiene and formaldehyde are provided:

- Monitoring should be undertaken together with further ozone precursors in-line with recommendations by AQUILA to fulfill objectives such as trend analysis of precursors, efficiency of emission reduction strategies and consistency of emission inventories, source attribution, and to support the understanding of ozone formation. In general, these objectives thus require both urban and rural background stations[239].
- In addition, human health related monitoring of 1,3-butadiene should be undertaken at locations relevant for exposure near specific industrial plants. Emissions of 1,3-butadiene are not reported under the European Pollutant Release and Transfer Register (E-PRTR). Thus there is no information readily available which industrial

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[235] Janssen, et al. (2014).

[236] AQUILA (2021a).

[237] LCSQA (2020c).

[238] AQUILA (2021b).

[239] AQUILA (2021b).

facilities[240] in Europe emit 1,3-butadiene. Therefore, emission data has to be gathered on Member State level.

4.6.3. Manganese, Vanadium

The anthropogenic sources of manganese (Mn) and vanadium (V) are mainly industrial. Natural sources are soil particles (see section 1.6.7, 1.6.8), for V in addition marine aerosols and volcanic emissions. Both Mn and V are markers for non-exhaust emissions of traffic.

Selected metals are currently measured according to Directive 2004/107/EC on PM_{10} samples. Mn and V can easily be covered by the reference methods prescribed by this Directive. On-line methods have been developed in recent years, which however require substantial investment costs (i.e. automated X-ray fluorescence).

It is thus recommended to extend the list of metals already monitored to include Mn and V as well[241]. As for the other heavy metals it is recommended to monitor Mn and V near specific industrial plants, at traffic-orientated sites and at urban background locations for exposure assessments; and at rural background sites to get information on background levels.

[240] 1,3-butadiene is mentioned in several Best Available Techniques (BAT) Reference Documents, such as for the "Production of Large Volume Organic Chemicals", or the "Production of Polymers", https://eippcb.jrc.ec.europa.eu/reference/ (last viewed on 2 August 2022) However, in these documents there is no reference to specific industrial facilities.

[241] AQUILA (2021a).

Table 34: Overview characteristics and current status of the monitoring and modelling of oxidative potential of PM, 1,3-butadiene, formaldehyde, Manganese, Vanadium

Source: this study, Member States

Criteria, characteristics	Ox. potential of PM	1,3-Butadiene	Formaldehyde	Manganese	Vanadium
Objective	Impact on human health	Impact on human health, ozone precursor	Impact on human health, ozone precursor	Impact on human health; marker of non-exhaust traffic emissions	Impact on human health; marker of non-exhaust traffic emissions
Main sources	Traffic emissions, biomass burning, secondary organic aerosol. Various further sources can contribute[242]	Manufacture of rubbers, resins, latex-styrene-butadiene and neoprene emulsions, automobile engine exhaust, cigarette smoke, combustion of plastics and rubber	Power plants, manufacturing facilities (e.g. manufacture of composite wood products), incinerators and automobile exhaust emissions. Forest fires and other natural sources of combustion. Formation by oxidation of VOC	Industrial sources (production of ferro-alloys, foundries, combustion of fossil fuels). Entrainment of soil particles	Industrial emissions (ferrous alloys and steels, non-ferrous alloys production) and fuel combustion (oil refineries, power plants). Entrainment of soil particles, marine aerosols and volcanic emissions. Vanadium pentoxide is the major commercial product of vanadium.
Number of existing stations	Around 15 for campaigns	Around 20 active stations in 2020 (EEA, EBAS database)	7 active stations in 2020	Around 70 active stations	Around 30 active stations
Types of existing stations	Urban, rural background	Mainly rural and urban background	Rural, urban background	Mainly rural and urban background, a few urban traffic	Rural and urban background
Monitoring methods	Filter + assays	Gas chromatography	Active sampling, analyses with high performance liquid chromatography (HPLC)	Chemical analysis of PM filter samples (as for As, Cd, Ni, Pb see Annex V Directive 2004/107/EC, Annex I of Directive 2015/1480/EU and	Chemical analysis of PM filter samples (as for As, Cd, Ni, Pb see Annex V Directive 2004/107/EC, Annex I of Directive 2015/1480/EU and

[242] LCSQA (2020c).

				Annex VI of Directive 2008/50/EC)	Annex VI of Directive 2008/50/EC)
Time coverage	Campaigns	Continuous monitoring	Continuous monitoring	Continuous monitoring	Continuous monitoring
Time resolution	Daily average	1-hour or 24-h mean	24-h mean	24-h mean	24-h mean
Status of modelling	In principle possible, summarised in[243]	Different methods are named in literature; dependent on availability of emission data[244]	Chemical transport models routinely model formaldehyde	Same as for other heavy metals	Same as for other heavy metals
QA/QC considerations	Interlaboratory comparison of tests, harmonized test protocols, see[245]	As for other VOC named in Annex X of Directive 2008/50/EC, see also[246]	As for other VOC named in Annex X of Directive 2008/50/EC, see also[247]	As for As, Cd, Ni, Pb see Annex V Directive 2004/107/EC, Annex I of Directive 2015/1480/EU and Annex VI of Directive 2008/50/EC	As for As, Cd, Ni, Pb see Annex V Directive 2004/107/EC, Annex I of Directive 2015/1480/EU and Annex VI of Directive 2008/50/EC
Reporting	Studies should be made publicly available	Some MS report data to EEA. It is recommended that all data is reported.	Some MS report data to EEA It is recommended that all data is reported.	Some MS report data to EEA It is recommended that all data is reported.	Some MS report data to EEA It is recommended that all data is reported.
Additional investment costs per sampling point	15 000 € to 20 000 € according to CNR in Italy	NA	NA	irrelevant	irrelevant
Running costs per year (if available)	Unit cost of sample for three combined tests are around 30 € to 40 €[248] IT-CNR: significantly higher running costs)	NA	NA	irrelevant	irrelevant

[243] LCSQA (2020c).

[244] Czader, Rappenglück (2015); Luecken, Hutzell, Gipson (2006); Hystad, et al. (2011).

[245] LCSQA (2020c).

[246] AQUILA (2021b).

[247] AQUILA (2021b).

[248] LCSQA (2020c).

5. Abbreviations

AAQDs	Ambient Air Quality Directives
AASQA	Associations agréées de surveillance de la qualité de l'air
ACTRIS	Aerosol, Clouds and Trace Gases Research Infrastructure
ANSES	L'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail
AQUILA	European Network of National Air Quality Reference Laboratories
ATP	Adenosine triphosphate
BC	Black Carbon
CAS RN	Chemical Abstracts Service Registry Number
CH_4	Methane
COVID-19	Coronavirus disease 2019
CRDS	Cavity Ring-Down Spectroscopy
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EBAS	EMEP and AMAP databases
EC	Elemental Carbon
ECD	Electron Capture Detector
ECHA	European Chemicals Agency
EEA	European Environment Agency
EIONET	European Environment Information and Observation Network
EMEP	Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe
FID	Flame Ionization Detector
GAW	Global Atmosphere Watch
GC	Gas Chromatograph
HPLC	High Performance Liquid Chromatography
ICOS	Integrated Carbon Observation System
JRC	Joint Research Centre
LCSQA	Laboratoire Central de Surveillance de la Qualité de l'Air
LDSA	Lung Deposited Surface Area
LNT	Lean NO_x Trap
Mn	Manganese
MS	Member State(s)
N_2O	Nitrous Oxide
NA	Not Available, Not Applicable

NATA	National Air Toxics Assessment
NFP	National Focal Point
NH_3	Ammonia
OC	Organic Carbon
PAH	Polycyclic Aromatic Hydrocarbon
PAMS	Photochemical Assessment Monitoring Stations
PM	Particulate Matter
PNC	Particle Number Concentrations
PNSD	Particle Number Size Distribution
PUF	Polyurethane Foam
SCR	Selective Catalytic Reduction
SMPS	Scanning Mobility Particle Sizer
TSP	Total Suspended Particulates
UFP	Ultrafine Particles
US-EPA	United States Environmental Protection Agency
V	Vanadium
VOC	Volatile Organic Compound
VTR	Valeurs Toxicologiques de Référence
WHO	World Health Organization
WMO	World Meteorological Organization

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Annex 1: Detailed information on available data

EEA database

Table 35: 1,3-Butadiene details

Source: EEA database

*

Member State	Years	Station types									Number stations	Median [µg/m³]
		RB	RI	RT	SB	SI	ST	UB	UI	UT		
Belgium	Since 2008*	8			4	2		6		1	21	0.09 (2020)
France	Since 2014*				1			2			3	0.11 (2020)
Germany	2012-2017*											0.11 (2017)
Lithuania	2009-2021*							1			1	0.003 (2021)
Netherlands	2009-2020*	1						1			2	0.14 (2020)
Poland	2010-2020	1									1	0.32 (2020)
Spain	2010-2020	4			1			1		1	7	0.52 (2020)
Sweden	2005							1			1	0.19

some years missing

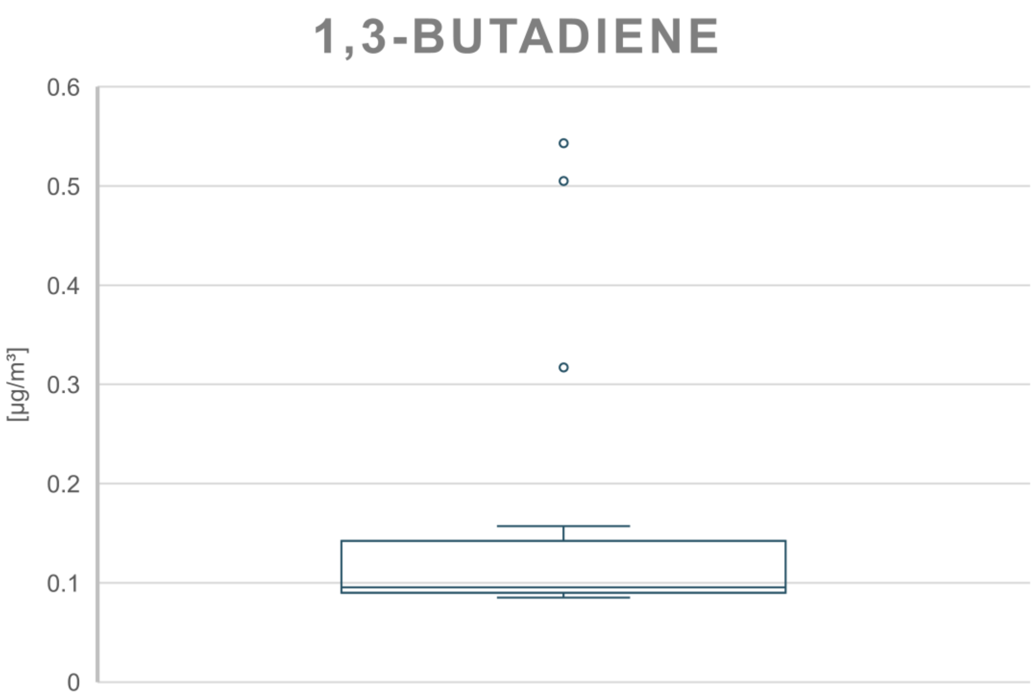


Figure 1: Box plot 1,3-Butadiene concentrations in 2020.

Table 36: Black Carbon details

Source: EEA database

Member State	Years	Station types									Number stations	Median [µg/m³]
		RB	RI	RT	SB	SI	ST	UB	UI	UT		

Belgium	2013-2020	3	3		3	6	1	7		5	28	0.8 (2020)
Finland	2011-2016*	5									5	0.1 (2016)
Netherlands	2016-2020	5	1	1	1			9	2	10	29	0.7 (2020)
Sweden	2013-2020	3						3		4	10	0.4 (2020)

* some years missing

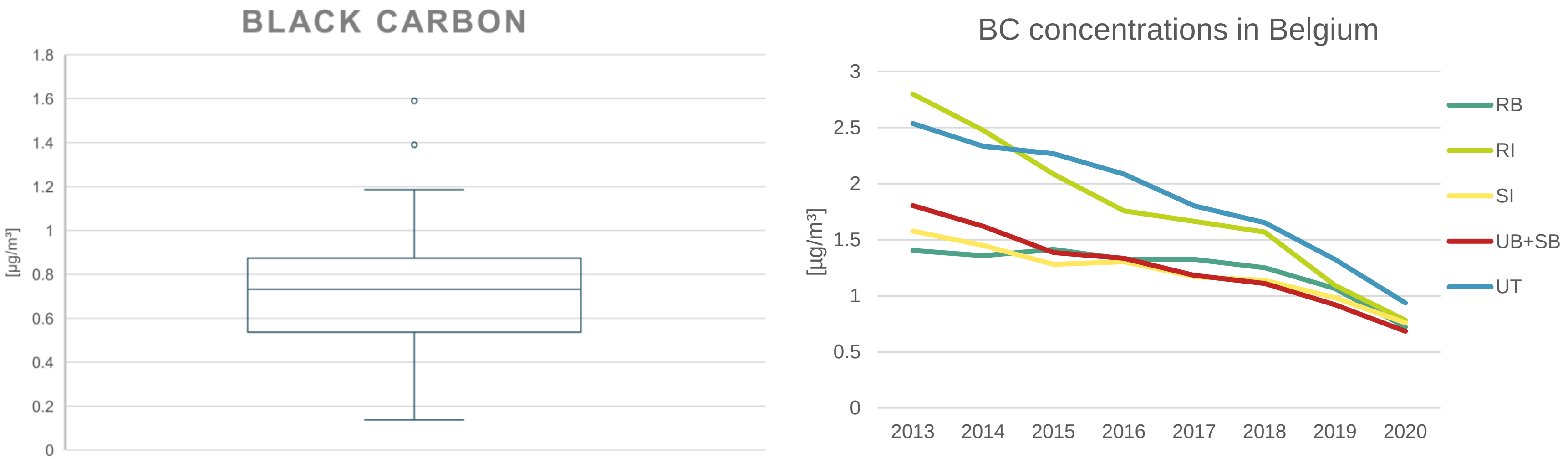


Figure 2: Box plot BC concentrations in 2020 (all available data); trend BC in Belgium (average of station types)

Table 37: Methane details

Source: EEA database

Member State	Years	Station types									Number stations	Median [µg/m³]
		RB	RI	RT	SB	SI	ST	UB	UI	UT		
Germany	2011-2020*	4			1			2			7	1382 (2020)
Italy	1999-2012*		4		2	5		2	3	8	26	1213 (2012)
Netherlands	2001-2010	1									1	1406 (2010)
Spain	1997-2001					1		2		4	7	1495 (2001)

* some years missing

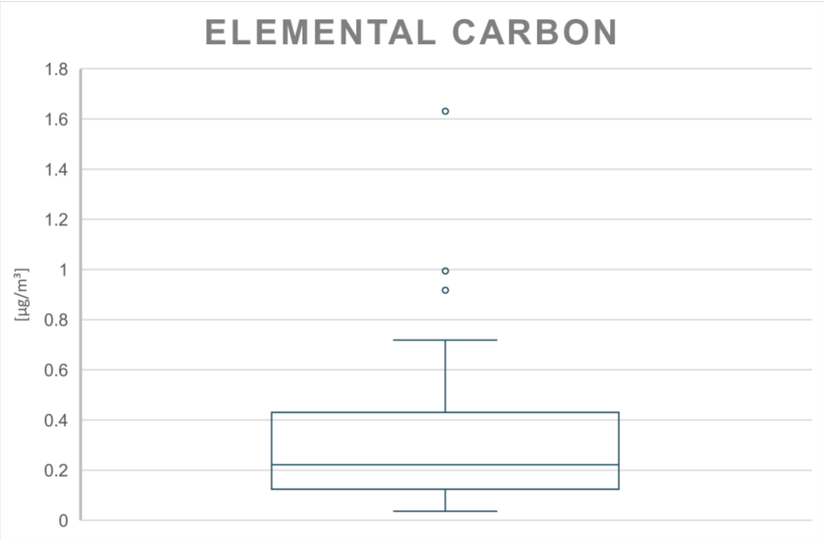
Table 38: Elemental Carbon details

Source: EEA database

Member State	Years	Station types									Number stations	Median [µg/m³]
		RB	RI	RT	SB	SI	ST	UB	UI	UT		
Austria	2013-2019	1									1	0.54 (2019)
Belgium	2017-2020	1						2			3	0.42 (2020)
Croatia	2015-2020	1						2			3	0.54 (2020)
Cyprus	2011-2020	1									1	0.23 (2020)

Denmark	2012-2020*	1								1	2	0.47 (2020)
Finland	2017-2020	3									3	0.11 (2020)
France	2019-2020	2									2	0.11 (2020)
Germany	2008-2020*	8			2			5		17	32	0.15 (2020)
Hungary	2019-2020	1									1	0.45 (2020)
Ireland	2011-2020*	1									1	0.19 (2020)
Lithuania	2009-2019	1									1	0.20 (2019)
Malta	2016-2020*	1									1	0.26 (2020)
Netherlands	2011-2019	2									2	0.38 (2019)
Poland	2011-2020	5									5	0.53 (2020)
Portugal	2016	1						1			2	0.72 (2016)
Slovenia	2013-2020	1						2		1	4	0.22 (2020)
Spain	2016-2020	5									5	0.20 (2020)
Sweden	2016-2020	4									4	0.06 (2020)

* some years missing



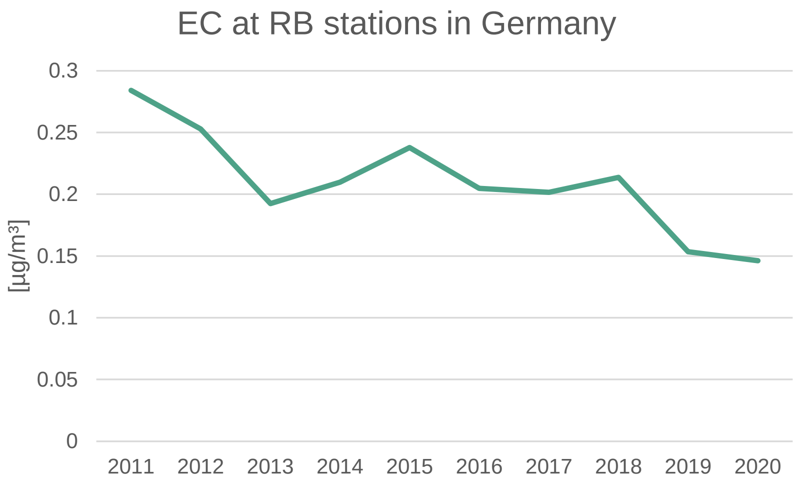


Figure 3: Box plot EC concentrations in 2020 (all available data). EC average concentrations at RB stations in Germany.

Table 39: Formaldehyde details

Source: EEA database

Member State	Years	Station types									Number stations	Median [µg/m³]
		RB	RI	RT	SB	SI	ST	UB	UI	UT		
France	2013-2020*							4		4	8	1.8 (2020)
Poland	2015-2020	1									1	1.6 (2020)
Romania	1999-2006				1				1	1	3	2.0 (2006)

Spain	2009-2020	2			2			2			6	1.5 (2020)

* some years missing

Table 40: Manganese aerosol and in PM_{10} details

Source: EEA database

Member State	Years	Station types									Number stations	Median [ng/m³]
		RB	RI	RT	SB	SI	ST	UB	UI	UT		
Cyprus	2009-2020	2									2	7.0 (2020)
Denmark	1993-2009	4						1		5	10	4.2 (2009)
France	2013-2020*							5	2	1	8	4.5 (2020)
Germany	2013-2020	8				1		12		1	22	6.2 (2020)
Italy	2006-2013*							2	2	2	6	75.4 (2013)
Spain	2017-2020*								1	3	4	11.3 (2020)
Sweden	2013-2020	46									46	3.6 (2020)

* some years missing

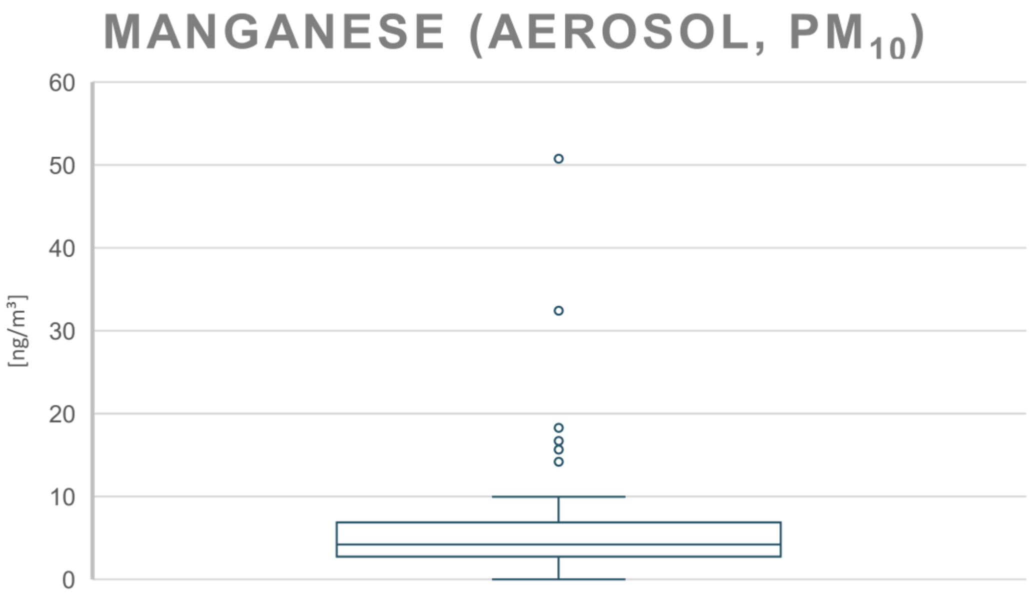


Figure 4: Box plot Mn concentrations in aerosol or PM_{10} in 2020.

Table 41: Ammonia details

Source: EEA database

Member State	Years	Station types									Number stations	Median [µg/m³]
		RB	RI	RT	SB	SI	ST	UB	UI	UT		
Bulgaria	1998-2020*							2		1	3	1.5 (2020)

Croatia	2006-2012*								1		1	18.9 (2012)
Germany	2011-2020	11								1	12	1.2 (2020)
Italy	1999-2014*		1			3			1		5	3.4 (2014)
Netherlands	1997-2015	10									10	7.6 (2015)
Romania	2001-2008				1			9	4	5	19	37.4 (2008)
Spain	2011-2020*	1			1	2		2		3	9	9.5 (2020)
Sweden	2013-2020	4									4	0.26 (2020)

* some years missing

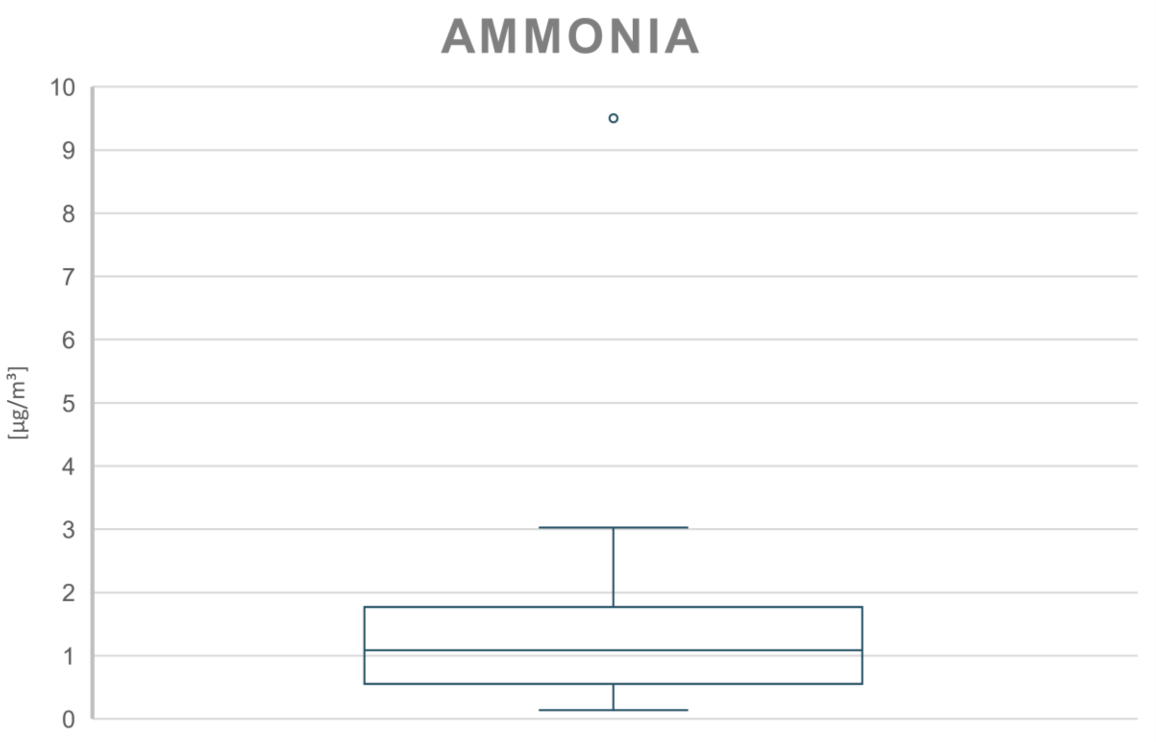


Figure 5: Box plot ammonia concentrations in 2020.

Table 42: Vanadium aerosol and in PM_{10} details

Source: EEA database

Member State	Years	Station types									Number stations	Median [ng/m³]
		RB	RI	RT	SB	SI	ST	UB	UI	UT		

Cyprus	2009-2020	2									2	1.5 (2020)
Denmark	2002-2009	4						1		3	8	2.7 (2009)
France	2013-2020*							5	2	1	8	0.3 (2020)
Germany	2013-2020	8				1		12		1	22	0.4 (2020)
Sweden	2013-2020	5									5	0.4 (2020)

* some years missing

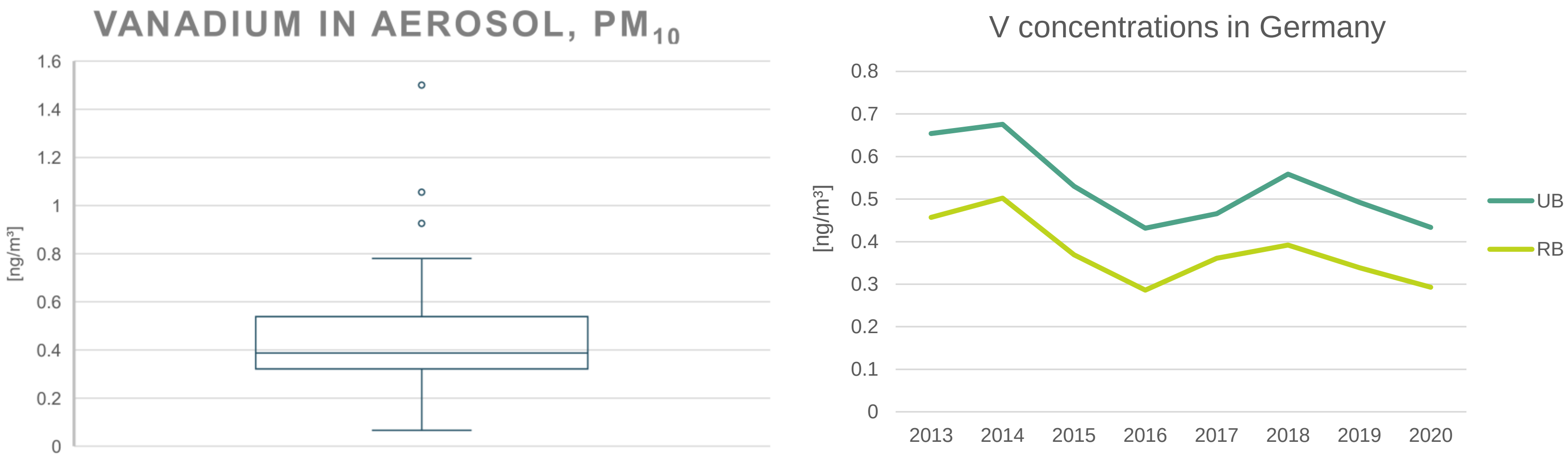


Figure 6: Box plot Vanadium in aerosol or PM_{10} concentrations in 2020. Average V concentrations in Germany.

EBAS database

Table 43: Datasets of additional pollutants in the EBAS database for 2020 and / or 2021

Source: EBAS database

MS	Code	Station Name	component	matrix	time resolu-tion
AT	AT0034G	Sonnblick	UFP	aerosol	0
BE	BE0014R	Koksijde	NH_3	air	4w
BE	BE0014R	Koksijde	Mn	pm10	2d
CY	CY0002R	Agia Marina Xyliatou / Cyprus Atmospheric Observat...	Mn	pm10	1d
CY	CY0002R	Agia Marina Xyliatou / Cyprus Atmospheric Observat...	V	pm10	1d
CZ	CZ0005R	Churanov	V	pm10	2d
CZ	CZ0003R	Kosetice (NOAK)	EC	pm25	4h
CZ	CZ0003R	Kosetice (NOAK)	V	pm10	2d
CZ	CZ0003R	Kosetice (NOAK)	V	pm25	2d
DE	DE0043G	Hohenpeissenberg	1-3 butadiene	air	12h
DE	DE0044R	Melpitz	EC	pm25	1d

DE	DE0044R	Melpitz	EC	pm10	1d
DE	DE0007R	Neuglobsow	NH_3	air	1w
DE	DE0007R	Neuglobsow	EC	pm25	6d
DE	DE0007R	Neuglobsow	Mn	pm10	1w
DE	DE0007R	Neuglobsow	V	pm10	1w
DE	DE0003R	Schauinsland	NH_3	air	1w
DE	DE0003R	Schauinsland	EC	pm25	6d
DE	DE0003R	Schauinsland	Mn	pm10	1w
DE	DE0003R	Schauinsland	V	pm10	1w
DE	DE0008R	Schmücke	NH_3	air	1w
DE	DE0008R	Schmücke	EC	pm25	6d
DE	DE0008R	Schmücke	Mn	pm10	1w
DE	DE0008R	Schmücke	V	pm10	1w
DE	DE0002R	Waldhof	NH_3	air	1w
DE	DE0002R	Waldhof	EC	pm25	6d
DE	DE0002R	Waldhof	Mn	pm10	1w

DE	DE0002R	Waldhof	V	pm10	1w
DE	DE0001R	Westerland	NH_3	air	1w
DE	DE0001R	Westerland	Mn	pm10	1w
DE	DE0001R	Westerland	V	pm10	1w
DE	DE0009R	Zingst	1-3 butadiene	air	84h
DE	DE0009R	Zingst	NH_3	air	1w
DE	DE0009R	Zingst	EC	pm25	6d
DE	DE0009R	Zingst	Mn	pm10	1w
DE	DE0009R	Zingst	V	pm10	1w
DK	DK0008R	Anholt	NH_3	air	1d
DK	DK0012R	Risoe	NH_3	air	1d
DK	DK0003R	Tange	NH_3	air	1d
DK	DK0031R	Ulborg	NH_3	air	1d
EE	EE0009R	Lahemaa	Formaldehyde	air	1d
ES	ES0009R	Campisabalos	NH_3	air	1w
ES	ES0100R	El Arenosillo	UFP	aerosol	0

ES	ES0014R	Els Torms	NH_3	air	1w
ES	ES0022R	Montsec	EC	pm10	4d
ES	ES1778R	Montseny	EC	pm1	4d
ES	ES1778R	Montseny	EC	pm10	4d
ES	ES1778R	Montseny	EC	pm25	4d
ES	ES0008R	Niembro	NH_3	air	1w
ES	ES0001R	San Pablo de los Montes	NH_3	air	1w
ES	ES0001R	San Pablo de los Montes	Formaldehyde	air	3d
ES	ES0007R	Víznar	NH_3	air	2w
FI	FI0050R	Hyytiälä	NH_3	air	1w
FI	FI0050R	Hyytiälä	Mn	pm10	1w
FI	FI0050R	Hyytiälä	V	pm10	1w
FI	FI0022R	Oulanka	NH_3	air	1w
FI	FI0036R	Pallas (Matorova)	NH_3	air	1d
FI	FI0036R	Pallas (Matorova)	Mn	pm10	1w
FI	FI0036R	Pallas (Matorova)	V	pm10	1w

FI	FI0009R	Utö	NH_3	air	1d
FI	FI0018R	Virolahti III	NH_3	air	1d
FI	FI0018R	Virolahti III	Mn	pm10	1w
FI	FI0018R	Virolahti III	V	pm10	1w
FR	FR0008R	Donon	EC	pm25	6d
FR	FR0028R	Kergoff	EC	pm25	6d
FR	FR0026R	La Réunion - Maïdo atmospheric observa-tory	UFP	aerosol	0
FR	FR0022R	Observatoire Perenne de l'Environnement	EC	pm25	6d
FR	FR0022R	Observatoire Perenne de l'Environnement	EC	pm10	6d
FR	FR0022R	Observatoire Perenne de l'Environnement	UFP	aerosol	0
FR	FR0013R	Peyrusse Vieille	1-3 butadiene	air	4d
FR	FR0013R	Peyrusse Vieille	EC	pm25	6d
FR	FR0013R	Peyrusse Vieille	Formaldehyde	air	84h
FR	FR0019R	Pic du Midi	EC	aerosol	1w
FR	FR0019R	Pic du Midi	UFP	aerosol	0
FR	FR0030R	Puy de Dôme	EC	aerosol	1w

FR	FR0030R	Puy de Dôme	UFP	aerosol	0
FR	FR0009R	Revin	EC	pm25	6d
FR	FR0023R	Saint-Nazaire-le-Désert	EC	pm25	6d
FR	FR0020R	SIRTA Atmospheric Research Observa-tory	EC	pm25	1d
FR	FR0025R	Verneuil	EC	pm25	6d
GR	GR0100B	DEM_Athens	EC	pm25	3h
HU	HU0002R	K-puszta	NH_3	air	1d
IE	IE0031R	Mace Head	UFP	aerosol	0
IT	IT0004R	Ispra	EC	pm25	1d
IT	IT0019R	Monte Martano	Mn	pm10	1w
IT	IT0019R	Monte Martano	V	pm10	1w
LV	LV0010R	Rucava	NH_3	air	1d
MT	MT0001R	Giordan Lighthouse	CH_4	air	1h
NL	NL0644R	Cabauw Wielsekade	EC	pm10	1d
NL	NL0091R	De Zilk	NH_3	air	1h
PL	PL0005R	Diabla Gora	NH_3	air	1d

PL	PL0005R	Diabla Gora	EC	pm25	1d
PL	PL0009R	Zielonka	EC	pm25	2d
SE	SE0005R	Bredkälen	NH_3	air	1d
SE	SE0005R	Bredkälen	Mn	aerosol	1mo
SE	SE0005R	Bredkälen	V	aerosol	1mo
SE	SE0020R	Hallahus	NH_3	air	1mo
SE	SE0020R	Hallahus	NH_3	air	1d
SE	SE0020R	Hallahus	Mn	aerosol	1mo
SE	SE0020R	Hallahus	V	aerosol	1mo
SE	SE0022R	Norunda Stenen	NH_3	air	1d
SE	SE0022R	Norunda Stenen	EC	pm10	3d
SE	SE0022R	Norunda Stenen	Mn	aerosol	1mo
SE	SE0022R	Norunda Stenen	V	aerosol	1mo
SE	SE0014R	Råö	NH_3	air	1d
SE	SE0014R	Råö	Mn	aerosol	1mo
SE	SE0014R	Råö	V	aerosol	1mo

SK	SK0006R	Starina	NH_3	air	1d

Annex 2: Israeli clean air values

Target values

The target value is defined in the Israeli Clean Air Law 5768-2008 as "*values whose exceedance constitutes potential danger or harm to the life, health and quality of life of human beings, to property and to the environment, including in soil, water, fauna and flora, and which should be striven to achieve as a target;* […] *the target values shall serve as a basis for setting the targets of the program*".[33]

Table 44: Israeli target values for ambient air

Source: Israeli Clean Air (Air Quality Values) Regulations (Temporary Provision)[249], 5771-2011

Pollutant	Maximum Average conc. in µg/m³	Given Time Interval
1,2 Dichloroethane	1.14	24 hours
	0.38	Year
Dichloromethane (Methylene Chloride)	72	24 hours
	24	Year
Toluene	3770	24 hours
	300	Year
Tetrachloroethylene	63	24 hours
	21	Year
Trichloroethylene	23	24 hours
	7	Year
Hydrogen Sulphide	2	Half an hour
	1	Year
Styrene	100	Half a year
	100	Year

[249] https://www.gov.il/he/Departments/General/air_quality_values, https://www.gov.il/BlobFolder/generalpage/air_quality_values/he/air_quality_air-quality-values.pdf (last viewed on 10.8.2022)

Formaldehyde	0.8	24 hours
	0.8	Year
1, 3 Butadiene	0.11	24 hours
	0.036	Year
Sulphate Salts (in Suspended Particu-late Matter)	25	24 hours
Vanadium (in Suspended Particulate Matter)	0.8	24 hours
	0.1	Year
Chromium (in Suspended Particulate Matter)	10	Hour
	1.2	Year
Mercury (in Suspended Particulate Matter)	1.8	Hour
	0.3	Year

Ambient values

According to the Israeli Clean Air Law 5768-2008, ambient values are those "*whose exceedance constitutes considerable or unreasonable air pollution, to be set on the basis of the target values and of updated scientific and technological knowledge, and in consideration of the practical possibility of preventing exceedance from the target values*".[33] Ambient values are thus in general higher than target values.

Table 45: Israeli ambient values for ambient air

Source: Israeli Clean Air (Air Quality Values) Regulations (Temporary Provision)[249], 5771-2011

Pollutant	Maximum Average Concentration in µg/m³	Given Time Interval
1,2 Dichloroethane	0.38	Year
Dichloromethane (Methylene Chloride)	24	Year
Toluene	3770	24 hours
	300	Year
Tetrachloroethylene	21	Year
Trichloroethylene	1000	24 hours

Hydrogen Sulphide	45	Half an hour
	15	24 hours
Styrene	100	Half an hour
Formaldehyde	100	Half an hour
Benzene	5	Year
Sulphate Salts (in Suspended Particulate Matter)	25	24 hours
Vanadium (in Suspended Particulate Matter)	1	24 hours
Chromium (in Suspended Particulate Matter)	1.2	Year

Annex 3 Request sent to Member States

Additional pollutants not covered in the Ambient AIR QUALITY Directives

Request to Member States for information

On behalf of DG ENV (Directorate General for Environment of the European Commission), a consortium led by IIASA (Institute for Applied System Analysis) together with Umweltbundesamt (Austria), EMISIA (spin-off company of the Aristotle University of Thessaloniki, Greece) and RIVM (National Institute for Public Health and the Environment, The Netherlands) has been recently awarded a contract to assess the monitoring of air pollutants not covered under the Ambient Air Quality Directives 2004/107/EC and 2008/50/EC, especially ultrafine particles (UFP), black carbon/elemental carbon (BC/EC), ammonia (NH_3) and methane (CH_4) in ambient air, as part of the on-going revision of EU air quality legislation. The work started on 15 January 2022 and should be finalised by September 2022. Next to these four pollutants, the consortium will collect and prioritize recommendations and current practice regarding monitoring of 4-6 additional pollutants in ambient air, which are relevant for human health or ecosystems or act as precursors for other pollutants. In detail, the work comprises the following tasks:

1. Provide an overview of current scientific recommendations for monitoring of other air pollutants not covered under EU Directives 2004/107/EC and 2008/50/EC
2. Collate comprehensive information on the monitoring of ultrafine particles, black carbon/elemental carbon, ammonia and methane (plus other relevant air pollutants) in all EU Member States
3. Assess the distance to meeting the good practice statements recently published by WHO for measuring ultrafine particles, and for measuring black carbon/elemental carbon in ambient air in all EU Member States
4. Provide recommendations (including estimates of the costs) on steps needed to meet WHO good practice statements and current scientific recommendations for other air pollutants not covered under the Ambient Air Quality Directives in all Member States

This request for information is part of Task 2 described above. Therefore, we want to discuss with all Member States individually the following questions related to UFP, BC/EC, NH_3, CH_4 and oxidative potential of particulate matter (PM); and would welcome your replies in written form. If you do not have the requested data and information, we would ask you to forward this questionnaire to those who can provide this information. If deemed necessary we would certainly welcome an online meeting to discuss the questions and your answers together with all related institutions.

Question	Answer				
Which of the selected additional pollutants (UFP, BC/EC, NH_3, CH_4) and oxidative potential of PM are being measured in your country?					
Number and location (geographic co-ordinates, address) of monitoring stations or sampling points for these pollutants (or link to website / reference where this information can be found)					
	UFP	BC/EC	NH_3	CH_4	Oxidative potential of PM
Number of sampling points					
Locations of these sampling points (geographic co-ordinates, address					
Start of monitoring (+end of monitoring, if appropriate)					
Permanent monitoring OR temporary monitoring campaign(s)?					
Institution(s) responsible for monitoring or sampling and chemical analysis, quality assurance, data analysis and reporting, incl. contact details					
Monitoring objectives for these additional pollutants (e.g. impact on human health or ecosystem, precursor, for source apportionment)					
Applied measurement, sampling and analytical methods, type of measuring device(s) used and data quality objective achieved					
	Method, type of device			Data quality objective (if available or any other information regarding uncertainty)	
UFP					
BC					
EC					
NH_3					

Question	Answer
CH_4	
Oxidative potential of PM	
Are information sources and communication channels of monitored data made available to the public and the scientific community?	
Are components of UFP or particle number size distribution being monitored?	
Are there thresholds used to distinguish between low, medium and high levels of concentrations?	
Is there an assessment of exposure and health impacts to air pollutant?	
Please specify costs for monitoring (in € per sampling point) of these additional pollutants[250]:	

		UFP	BC/EC	NH_3	CH_4	Oxidative potential of PM
Costs of purchase for equipment (per sampling point): Monitoring or sampling devices, calibration unit (if available), data collection equipment						
Running costs per year (if available; otherwise please indicate whether you	Consumables and spare parts, reference gases					

[250] It is assumed, that the monitoring equipment for the respective sampling point is installed in an existing monitoring stations, i.e. costs include only those that incur on top of the initial investment and running costs of the existing monitoring station

Question		Answer				
expect running costs to be “roughly equal”, “significantly higher” or “significantly lower” compared to monitoring of PM & compared to monitoring of gaseous pollutants (e.g. O_3, NO_2, SO_2, CO	personnel costs for calibration, repair and maintenance					
	laboratory analysis (relevant in case of sampling in the station, e.g. for EC and NH_3.					
	power consumption					
	personnel training					
Quality Assurance costs						
Costs of purchase for equipment (per sampling point): Equipment for primary standards and transfer standards						
Running costs per year (if available; otherwise please indicate whether you expect running costs to be “roughly equal”, “significantly higher” or “significantly lower” compared to monitoring of PM & compared to monitoring of gaseous pollutants (e.g. O_3, NO_2, SO_2, CO): reference materials, costs for intercomparison exercises and proficiency testing						
Running costs per year (if available; otherwise please indicate whether you expect running costs to be “roughly equal”, “significantly higher” or “significantly lower” compared to monitoring of PM & compared to monitoring of gaseous pollutants (e.g. O_3, NO_2, SO_2, CO): data handling, including validation and correction of monitoring data; statistical analysis; data reporting						
If detailed cost estimates are not available: global cost estimate						
Any additional information deemed useful						

WHO Good Practice Statements for UFP and BC/EC

The WHO published in September 2021 an update of global air quality guidelines[251] that includes so-called good practice statements for UFP and BC/EC (see below). Therefore, part of this study is to collect information to what degree Member States already apply practices similar or identical to these good practice statements. Therefore, we would like to ask you the following questions regarding monitoring of UFP and BC/EC, if appropriate:

Question	Answer
1. Are measurements "systematic"[252]? (both UFP and BC)	
2. In case of UFP:	
2.a Is the particle number concentration (PNC) monitored for a size range with a lower limit of ≤ 10 nm and no restriction on the upper limit?	
2.b Do you distinguish between high/low concentrations[253] to guide decisions on the priorities of UFP source emission control	
3. Are additional PM metrics simultaneously monitored?	
4. What is the time resolution of monitoring? (both UFP and BC)	
5. Are the measurements integrated into an existing regular monitoring network? (both UFP and BC)	
6. Do you utilise the monitoring results for exposure and health impact assessment? (both UFP and BC)	
7. In case of BC/EC:	
7.a Do you prepare emission inventories?	
7.b Do you undertake source apportionment studies?	
8. Any additional information deemed useful	

Summary of good practice statements

For UFP the WHO provide four good practice statements:

[251] https://apps.who.int/iris/handle/10665/345329 (last viewed on 2 August 2022)

[252] Measurements are considered „systematic" when covering different site types – traffic, urban background, rural background – representative for major parts of the country.

[253] According to WHO good practice statements, low PNC can be considered < 1000 particles/cm³ (24-hour mean). High PNC can be considered > 10 000 particles/cm³ (24-hour mean) or 20 000 particles/cm³ (1-hour).

Quantify ambient UFP in terms of particle number concentration (PNC) for a size range with a lower limit of ≤ 10 nm and no restriction on the upper limit.

Expand the common air quality monitoring strategy by integration of UFP monitoring into existing air quality monitoring. Include size-segregated real-time PNC measurements at selected air monitoring stations in addition to, and simultaneously with, other airborne pollutants and characteristics of PM.

Distinguish between low and high PNC to guide decisions on the priorities of UFP source emission control. Low PNC can be considered < 1000 particles/cm³ (24-hour mean). High PNC can be considered > 10 000 particles/cm³ (24-hour mean) or 20 000 particles/cm³ (1-hour).

Utilize emerging science and technology to advance approaches to the assessment of exposure to UFP for application in epidemiological studies and UFP management.

For BC/EC WHO provides the following good practice statements, which are relevant for this study:

3. *Make systematic measurements of black carbon and/or elemental carbon. Such measurements should not replace or reduce the existing monitoring of pollutants for which guidelines currently exist.*
4. *Undertake the production of emission inventories, exposure assessments and source apportionment for BC/EC.*

Contact

In case you have any question regarding this request, please do not hesitate to contact the project team:

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Annex 4: Replies from Member States

The detailed replies from Member States have been collected in a separate Excel document which can be found here:

https://circabc.europa.eu/ui/group/cd69a4b9-1a68-4d6c-9c48-77c0399f225d/library/fa682705-3e7b-4917-b5e7-3ac77117b5ac/details

Annex 5: Details of recommended number of stations per Member State

The detailed calculation of the number of sampling points per Member State can be found in the following Excel document which can be found here:

https://circabc.europa.eu/ui/group/cd69a4b9-1a68-4d6c-9c48-77c0399f225d/library/fa682705-3e7b-4917-b5e7-3ac77117b5ac/details

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