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French agency for food, environmental
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Investigate, evaluate, protect

Particulate matter in ambient air

Health effects according to components, sources and particle size

Impact on air pollution of the technologies and composition of the motor vehicle fleet operating in France

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Amended summary report and recommandations
from the collective expert appraisal

August 2019 - Scientific Edition

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The Director General

Maisons-Alfort, 8 July 2019

OPINION[1] of the French Agency for Food, Environmental and Occupational Health & Safety

on the state of knowledge on particulate matter in ambient air (health effects according to chemical components, road traffic emissions)

On 30 June 2014, ANSES received a formal request from the Directorate General for Health (DGS), the Directorate General for Energy and Climate (DGEC) and the Directorate General for Risk Prevention (DGPR) to conduct a scientific expert appraisal on particulate matter (PM) in ambient air. Its purpose was to assess the health effects of ambient air particulate matter according to its components, sources and particle size, and to determine the impact on air pollution of the technologies and composition of the motor vehicle fleet operating in France.

1. BACKGROUND AND PURPOSE OF THE REQUEST

1.1. Background

Ambient air pollution can be described as the presence in outdoor air of gases and particulate matter that have harmful effects on human health and the environment. The issue of particulate matter (PM) in ambient air is a matter of concern in several parts of France that have high levels of PM concentrations in comparison to the air quality standards and objectives designed to protect human health. This situation has led to several warnings from the European Commission since 2009 (formal notice, reasoned opinion, referral to the European Court of Justice) for non-compliance with the regulatory air quality standards set for PM_{10}[2] in order to protect human health. Furthermore, ambient air particulate matter represents a public health issue. The impact of exposure to ambient air $PM_{2.5}$[3] due to human activity has been estimated at 48,000 premature

[1] This opinion cancels and replaces the 21 June 2019 opinion (see appendix 8)
[2] PM_{10}: mass concentration of particles with an aerodynamic diameter less than 10 µm per unit volume of air.
[3] $PM_{2.5}$: mass concentration of particles with an aerodynamic diameter less than 2.5 µm per unit volume of air.

deaths per year in France. This is exacerbated in urban areas with more than 100,000 inhabitants, where the results show an average loss of 15 months of life expectancy at 30 years of age due to this $PM_{2.5}$ exposure (Pascal *et al*., 2016). The health and non-health costs of $PM_{2.5}$ pollution have been estimated at €75 billion per year at least (Senate Committee of Inquiry, 2015)[4]. Concentrations[5] of particulate matter in ambient air have decreased over the years, but they still exceed the annual quality guidelines recommended by the World Health Organisation for $PM_{2.5}$ (WHO Europe, 2006).

The health effects of outdoor ambient air particulate matter are already well documented. Cardiovascular and respiratory effects from short- and long-term exposure to particulate pollution have been demonstrated over the past few decades. More recently, effects have been identified on other target organs such as the brain, and on certain functions such as reproduction. In October 2013, the International Agency for Research on Cancer (IARC) classified outdoor air pollution as a whole and the airborne particles making up this air pollution as carcinogenic to humans (Group 1) (IARC, 2016)

Uncertainty remains regarding the health effects associated with ambient particulate matter according to its composition, which has probably changed over the past 20 years. The US Environmental Protection Agency (US EPA) concluded in 2009 that "*many constituents of PM_2 can be linked with multiple health effects, and the evidence is not yet sufficient to allow differentiation of those constituents or sources that are more closely related to specific health outcomes*" (US EPA, 2009). This conclusion was shared and upheld by the WHO in 2013 in its report "Review of evidence on health aspects of air pollution – REVIHAAP Project" (WHO Europe, 2013). Since 2013, several scientific studies have been published on the subject, including major epidemiological studies conducted in Europe.

Fine particulate matter comes from a multitude of sources and from transformation processes in the atmosphere. The emissions can result from natural phenomena (desert sand, sea salt, volcanic eruptions, forest fires, etc.) or human activities (industry, transport, agriculture, heating, etc.). Road transport and heating in the residential and service sectors are important sources of organic aerosols in the atmosphere, through the combustion of fossil fuels and biomass. Besides particulate matter, road transport is also a major source of nitrogen oxides (NOx), especially nitrogen dioxide (NO_2).

Primary particulate matter from road transport is mainly emitted by those diesel vehicles that are not fitted with particulate filters. The level of emissions is highly dependent on vehicle age and technology, with older vehicles making a major contribution to road traffic particulate emissions. However, too little is still known about certain emissions (non-exhaust, the cold start phase, motorized two-wheelers, etc.). Similarly, the formation of secondary aerosols from road traffic emissions and their contribution to particulate pollution is relatively unclear, but is increasingly being studied.

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[4] Includes the tangible health cost "*[…] mainly measured through health expenditure reimbursed by health insurance in order to cover diseases attributable to air pollution, whether in the form of hospitalisation, primary care or the payment of daily benefits and disability pensions*", the intangible health cost "*[...] known as the social or socio-economic cost, associated with mortality and morbidity due to air pollution ([…] this cost, associated with a loss of well-being, has no direct impact on the general government finances […])*", and the non-health cost, i.e. "*[…] negative impacts in terms of reduced agricultural yields, loss of biodiversity or building degradation and erosion, as well as costs associated with controlling air pollution, such as expenditure on prevention and research activities carried out by the authorities or health agencies.*" (Senate Committee of Inquiry, 2015).

[5] Pollutant concentrations characterise the quality of the breathed air and are measured at different points in France: in cities, near emission sources (road traffic, industries) and in areas remote from these sources (urban background and rural areas).

Road traffic is the most widely documented source of particulate air pollution, both in terms of emissions and effects. The identified health effects include cardiovascular and respiratory effects associated with short- and long-term exposure. In 2012, IARC classified exhaust emissions from diesel engines as carcinogenic to humans (Group 1) and exhaust emissions from gasoline engines as possibly carcinogenic to humans (Group 2B) (IARC, 2014). IARC also determined that there was "sufficient" evidence in experimental animals for the carcinogenicity of whole diesel engine exhaust emissions, but also for exhaust particulate matter and the organic fraction of exhaust particulate matter.

Several studies have demonstrated that populations living near roads with heavy traffic have poorer health (HEI, 2010; ORS IdF, 2012). For example, the Aphekom project conducted in 10 European cities estimated that living close to major traffic routes induced 15-30% of new childhood asthma cases and similar or higher proportions of chronic obstructive pulmonary disease (COPD) and coronary heart disease in adults over 65 years of age (InVS, 2012).

The wish to reduce vehicle engine emissions and their impact on air quality has led to a continuous process of regulatory change, improvements in the composition of fuels and vehicle powertrains, and the development of new pollution control technologies, in the last 20 years or more in France and Europe. However, the actual and comparative effectiveness of these different technologies remains difficult to establish because it can vary according to numerous aspects (traffic conditions, vehicle use, local topographical and climate conditions, etc.). **This context raises questions about the potential environmental and health impact of future technological choices for the French road vehicle fleet.**

1.2. Purpose of the request

In a letter of 30 June 2014, the Directorate General of Health (DGS), Directorate General of Energy and Climate (DGEC) and Directorate General of Risk Prevention (DGPR) made a formal request to ANSES to answer several questions grouped into two separate parts.

- Regarding the first part on the health effects of ambient particulate matter, the following questions were asked:

1. *"Is there an expert report compiling all the existing data/studies combining concentrations, physico-chemical composition and sources of ambient air particulate matter in France?*

   If necessary, carry out this compilation, from a national and regional perspective, if possible assessing the aerosol's temporal and spatial variability, in order to estimate for the concentrations and physico-chemical composition of ambient air particulate matter in France the respective contributions of the different sources (traffic, heating, industry, agriculture, imports, natural, etc.) and their trends over recent years.

2. *Are there any conclusive data on toxicity differences according to particle composition and/or sources?*

   If so, what conclusions can be drawn about the toxicity of particulate matter according to composition and/or sources?"

- Under the second part on road traffic emissions, ANSES was asked to:

1. *"analyse the retrospective and prospective evolution of the particulate emissions from the French vehicle fleet on the road and in actual traffic conditions, according to different scenarios;*
2. *And identify the differentiated impacts of pollution-control technologies on particulate emissions from the "road traffic" source.*

This information could be compared to the emission data available concerning other sources of particulate matter."

As part of this formal request, ANSES was also asked "*its opinion as to the transposition of the conclusions issued by the International Agency for Research on Cancer (IARC) in 2012 on diesel engine exhaust emissions, to the emissions from diesel-powered road vehicles in France*". In response to this specific point, the Agency produced a scientific and technical support note, published on its website in April 2017 (ANSES, 2017).

In autumn 2014 at the initiative of the French Environment and Energy Management Agency (ADEME), a study ("SOURCES" project) was launched involving the National Institute for Industrial Environment and Risks (INERIS)/Central Laboratory for Air Quality Monitoring (LCSQA) and the Institute for Geosciences and Environmental Research (IGE, formerly the Laboratory of Glaciology and Geophysics of the Environment, LGGE). Its primary objective was to summarise the scientific studies seeking to identify and quantify sources of fine particulate matter (PM_{10} and $PM_{2.5}$) in ambient air in France (ADEME, 2018; LCSQA/INERIS/IGE, 2017a and 2017b). In this context, the scope of the formal request had to be redefined in consultation with the three ministerial directorates (DGPR, DGEC and DGS), in order to avoid any duplication of work. The questions put to ANSES were therefore officially finalised in May 2015: Question 1 of the first part mentioned above was excluded from the expert appraisal to be conducted[6].

2. ORGANISATION OF THE EXPERT APPRAISAL

The expert appraisal was carried out in accordance with French Standard NF X 50-110 "Quality in Expert Appraisals – General Requirements of Competence for Expert Appraisals (May 2003)".

The expert appraisal falls within the sphere of competence of the Expert Committee (CES) on "Assessment of the risks related to air environments". ANSES entrusted the expert appraisal to a dedicated working group (WG), which was set up in September 2015 after a public call for applications. It met from September 2015 to December 2018, 25 times in plenary sessions and 32 times in sub-groups (face-to-face or telephone meetings). Two external expert rapporteurs were also mandated to contribute to specific tasks of the WG's work (i.e. to analyse epidemiological studies and establish lines of evidence). The methodological and scientific aspects of the WG's work were presented to and discussed before the CES between 26 November 2015 and 17 January 2019. It was adopted by the CES in several stages at its meetings of 13 September 2018, 18 December 2018 and 17 January 2019.

This work is described in a summary report (ANSES, 2019c) and two foundation reports (ANSES, 2019a and 2019b) devoted respectively to the two parts of the formal request (see p.3).

ANSES analyses interests declared by experts before they are appointed and throughout their work in order to prevent risks of conflicts of interest in relation to the points addressed in expert appraisals.

[6] It should be noted that ANSES was able to monitor the work carried out as part of the "SOURCES" project and reference it in this expert appraisal.

3. ANALYSIS, CONCLUSIONS AND RECOMMENDATIONS OF THE WG AND THE CES

3.1. Part on the health effects of ambient air particulate matter: method and analysis

A procedure for assessing the weight of evidence in the literature was developed and implemented in order to respond to the question, so as to obtain a level of evidence for an adverse health effect of several components and sources of ambient air particulate matter. This level of evidence for an adverse health effect reflects the confidence placed in an association (or lack thereof) between an exposure of interest and a health category of interest based on a set of publications known as a body of evidence. A health category of interest, such as "cardiovascular health", includes several different health outcomes (impaired heart rate, heart attack and coronary events, cardiovascular hospitalisations, etc.). The underlined terms are defined in more detail in the glossary in Appendix 1.

The purpose of assessing this level of evidence for an adverse health effect was therefore to be able to conclude from the analysis of the scientific literature whether the observed association between a given component (or source) of ambient air particulate matter and a health category of interest was highly, moderately, or faintly plausible.

It can also be concluded that a component has no effect on health, or that the level of evidence available in the literature is inadequate to be able to reach any conclusion.

The exercise was essentially reproduced for as many particulate components, sources and health outcomes as had been described/documented in the scientific literature analysed, in order to then reach a conclusion, after compilation, for each component (or source) and for different health categories of interest that represent "families of health effects".

To conduct this analysis, the Working Group adapted the method proposed by the Office of Health Assessment and Translation as part of the National Toxicology Program (OHAT NTP, 2015). The assessment process consisted of seven steps (Figure 1) that are briefly described below. It also included a critical analysis of the approach that explains its limitations and uncertainties.

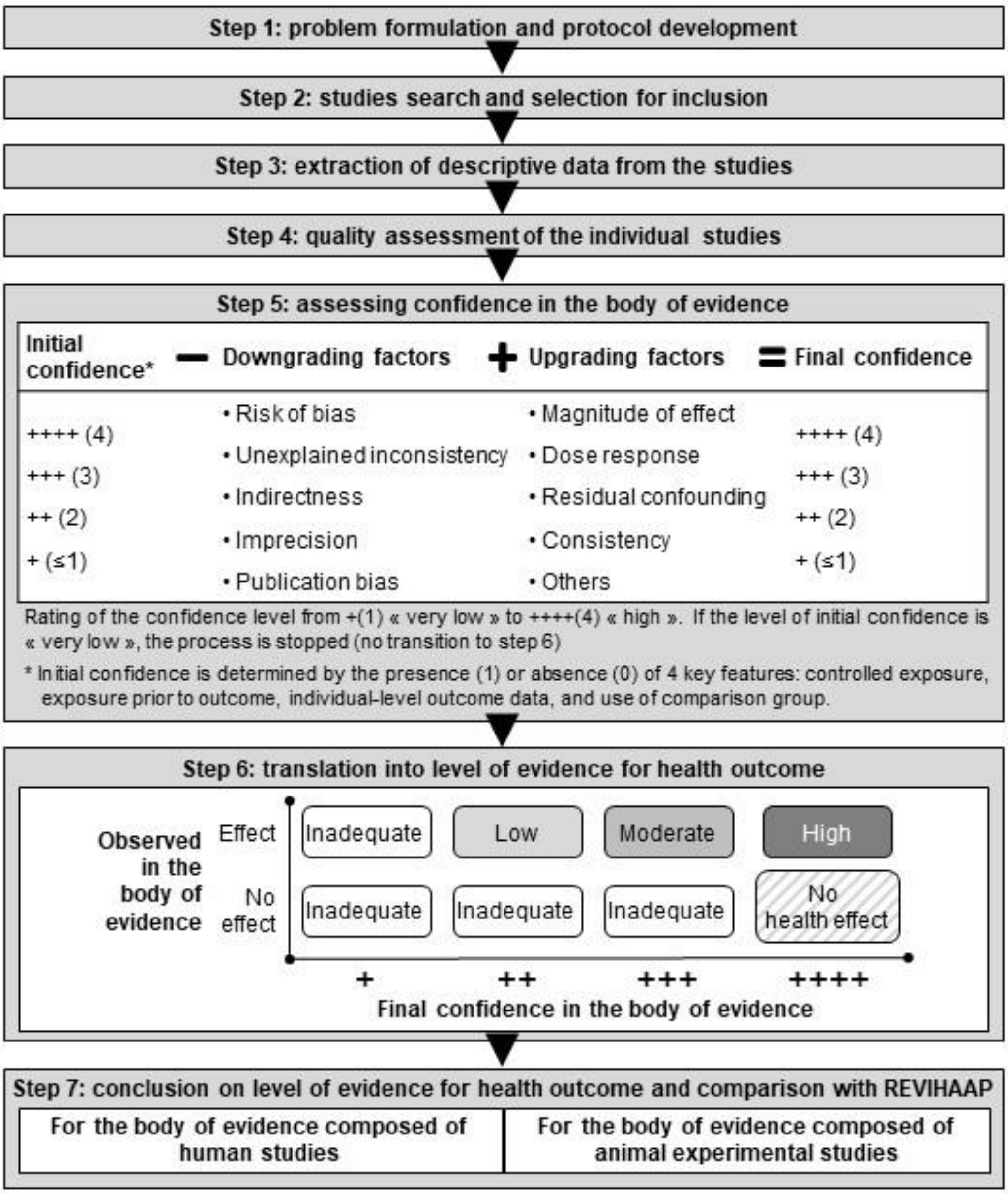

Figure 1: Process of the OHAT approach adapted by the Working Group

Step 1: Formulation of the scope of the problem

The question to be investigated was formulated by the WG as follows:

- What are the human health effects of ambient air particulate matter according to its components, sources and particle size?

After an initial literature search, and due to the amount of literature available, the WG experts selected the WHO Europe's REVIHAAP consensus review, published in 2013, as the starting point for the literature to be investigated in this work. Thus, only studies published after REVIHAAP and up to February 2016[7] were included in the assessment of the weight of evidence.

The target population was the general population, including sub-populations that are more vulnerable and sensitive to air pollution.

Targeted exposures were concentrations of particulate matter in ambient air categorised by components, particle size and sources (listed in Appendix 1). Publications investigating PM_{10} and $PM_{2.5}$ without chemical speciation or source apportionment were not included. The targeted comparators were no exposure or lower exposure levels. Adverse health outcomes (clinical and subclinical) documented in the reviewed literature (listed in Appendices 2 and 3) were grouped into ten broad health categories: respiratory health, cardiovascular health, all-cause mortality, all-cause hospitalisations, neurological health, perinatal health, reproductive health, lung cancer, other cancers, and diabetes (including metabolic disorders). The timings of exposure considered were short-term (one to several days in humans) and long-term (one to several years in humans).

The targeted health outcomes were adverse health events (clinical and subclinical) documented in the analysed litterature, and then grouped into ten broad health categories: respiratory health, cardiovascular health, all-cause mortality, all-cause hospitalisations, neurological health, perinatal health, reproductive health, lung cancer, other cancers, and diabetes (including metabolic disorders). Studies were included regardless of their geographical location.

Step 2: Study search and selection

A literature search with the PubMed and Scopus search engines, as well as among the literature known to WG experts, identified 4,677 references published after REVIHAAP and up to February 2016. After an initial screening (titles and abstracts, double reading by the WG coordinators), 244 references were selected as being eligible in view of the previously-defined scope. After assessing the full text (double reading by WG members), 160 publications were finally selected: 127 studies in humans (observational, clinical or semi-experimental) and 33 animal experimental studies (single, (sub)acute or (sub)chronic exposure).

Step 3: Extraction of descriptive data from the studies

All the publications were read by one or two WG members (two members for the human studies, one member for the animal experimental studies) in order to collect descriptive (qualitative) data. These individual descriptions followed the grid format suggested by OHAT and summarised information related to subjects (human, animal), methods used (follow-up time, study design, health outcomes and categories, exposure measurement or estimation, etc.) and results.

[7] The most recent publication date for the analysed studies was set at February 2016 due to the large number of studies over this period and the time needed to analyse them as part of the procedure for assessing the weight of evidence, with regard to the work schedule. Studies published from February 2016 to August 2018 were described in order to highlight the latest research trends and their possible future directions.

Step 4: Quality assessment of the individual studies

The risk of bias was assessed in each of the 160 studies using an adapted version of the rating tool proposed by OHAT that applies to both human and animal experimental studies. The tool includes 15 questions related to potential sources of bias, divided into several broad categories (selection, attrition, interpretation, confounding, detection and others). The four response options represent a gradient of the plausibility of the risk of bias: low risk, probably low risk, probably high risk and high risk.

The risks of bias in each study were independently assessed and then discussed by two WG members to obtain a final rating. Any discrepancies in ratings were discussed, in some cases by all WG members, in order to reach a consensus.

Regardless of the risk of bias risk rating, an initial confidence level was calculated for each study by adding together the answers to four questions (1 if yes, 0 if no) reflecting important features of study design: Was the exposure controlled? Did the exposure occur prior to the health outcome? Were the health outcome data individual? Was a comparison group used?

Step 5: Rating of the confidence level for the bodies of evidence

The publications were grouped into corpora of studies (bodies of evidence) within a set of lines of evidence, according to the components/sources, exposure timings, health categories and health outcomes examined in each one. A line of evidence therefore brought together integrated information of the same type. A total of 724 lines of evidence were obtained from 127 human study publications, and 314 lines of evidence were obtained from the 33 animal experimental study publications. The final confidence level of the body of evidence in each of the lines of evidence was assessed on the basis of 10 factors proposed by OHAT (see Figure 1 Step 5).

The body of evidence's final confidence level corresponded to the initial confidence level of the publications (from 1 to 4, see Step 4) minus the factors decreasing confidence (from 0 to 5) and plus the factors increasing confidence (from 0 to 5), according to the principle shown in Figure 1, Step 5. Each line of evidence was independently assessed by one WG member and then discussed with the entire group. Final decisions (to increase or decrease the level of confidence) were taken after reaching a consensus.

Lastly, in each line of evidence, on the basis of the results provided by the body of evidence, a decision was taken by the WG on the direction of the effect of the component/source of interest on a health outcome of interest (i.e. the presence or absence of an adverse health effect) for a given timing of exposure.

Step 6: Translation into a level of evidence for an adverse health effect

The final confidence level of the body of evidence and the direction of the health effect were then merged to obtain a level of evidence for an adverse health effect of a component/source of interest on a health outcome, for a given timing of exposure, according to the principle and wording presented in Figure 1, Step 6. For example, a "high" level of evidence for an adverse effect reflects "high" confidence in the body of evidence (i.e. final confidence level at 4) regarding the effect of exposure on a health outcome of interest.

The levels of evidence defined for each component/source, timing of exposure (e.g. short-term) and each health outcome (e.g. cardiovascular mortality, cardiovascular hospitalisations, blood pressure, etc.) were merged into an overall level of evidence for an adverse effect on the corresponding health category (e.g. cardiovascular health). The same wording was considered: "high", "moderate", "low", "inadequate", and "no health effect". For human studies, the WG developed a decision tree to standardise as far as possible this merging process for the definition of the level of evidence for an effect for each component/source, each timing of exposure, and each health category. This decision tree included the levels of evidence for all health outcomes of the category (previously obtained), the relevance of these outcomes (clinical or subclinical), the number of publications in the bodies of evidence, and the possible risks of bias or indirectness identified in Step 5. For animal experimental studies, an identical decision tree was used without distinguishing between (sub)acute and (sub)chronic exposure timings. When the body of evidence included only single exposure studies (mechanistic studies), the level of evidence for this health category was systematically rated as "inadequate".

Step 7: Conclusion on the level of evidence for an adverse health effect

The evidence for health effects obtained from studies published after REVIHAAP (in 2013) and up to February 2016 (examined by this process for assessing the weight of evidence) was summarised to enable a comparison with the knowledge base provided by the WHO's REVIHAAP review. These two contributions were compared and contrasted in order to reach a conclusion about the weight of all the evidence for health effects from human and animal studies, and to highlight trends such as the confirmation of previously reported health effects or the identification of new evidence.

3.2. Part on the impact on air pollution of the technologies and composition of the motor vehicle fleet operating in France: methodology and analysis

Simulations were performed to assess the impact of several scenarios of technological developments in the vehicle fleet on traffic emissions and air quality in the Île-de-France region and in metropolitan France as a whole.

To answer the question about the differentiated impact of technologies on road-traffic particulate emissions, an approach involving the simulation of pollutant emissions and concentrations in the Île-de-France region[8] and in metropolitan France as a whole was therefore developed and implemented, considering different scenarios of changes in the composition of the vehicle fleet (Figure 2).

[8] The Île-de-France region was chosen because of the availability of tools and data at a fine territorial scale, and due to traffic's contribution to a major pollution issue in this region, while the analysis on the national scale enabled greater representativeness as well as an analysis according to places and contexts.

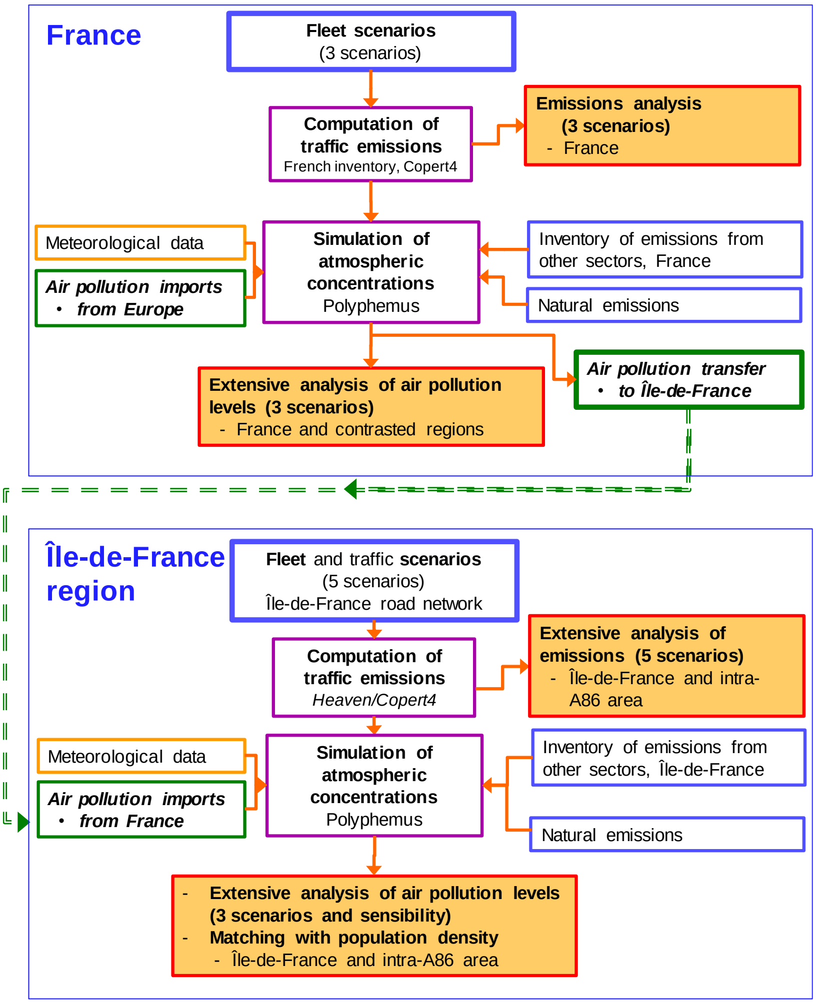

Figure 2: Diagram of the pollutant emission and concentration simulation process for France (top) and Île-de-France (bottom)

This approach combined existing tools: Airparif's Heaven modelling platform and CITEPA's national inventory for calculating traffic pollutant emissions in Île-de-France and France (European COPERT4 methodology); the Polyphemus atmospheric concentration simulation platform for the regional scale. It also used numerous types of data: traffic modelled throughout the Île-de-France region, meteorological data, Île-de-France/France/European inventories of pollutant emissions from the various activity sectors, etc. Overall, the approach took emissions of both anthropogenic and natural pollutants into account, as well as imported emissions from larger scales (Europe to France, France to Île-de-France, see Figure 2). It integrated most known physico-chemical interactions between pollutants (corresponding to calculation codes integrated in the modelling platforms used and mentioned above).

The scenarios of technological developments in vehicle fleet composition were derived from the current fleet compositions (Île-de-France and national, baseline situation, 2014 – for which detailed data on fleet, traffic and emission inventories were available).

A model was used to simulate vehicle renewal and fleet development by 2025 (André *et al.*, 2016) according to the following assumptions:

- **DPF scenario or S1**: Generalisation of the diesel particulate filter (the various current technologies) and concomitant changes to emission regulations (Euro standards) by this date. This scenario constituted near steady development ("business as usual"), without any change in the balance between engine types (gasoline, diesel, electric), or between vehicle categories and vehicle sizes.

- **S1-elec. 2W scenario**: A variant of this first scenario was considered in order to study the sensitivity of the simulation results to volatile organic compounds (VOCs). This variant consisted in cancelling the exhaust emissions from motorised two-wheeled vehicles, which are high VOC emitters (motorised two-wheeled vehicles were then all assumed to be electric).

- **Gasoline scenario or S2**: A large decline in diesel engines in favour of gasoline engines for light-duty vehicles, obtained by assuming a continuous decrease in sales of light-duty diesel vehicles (from 60% in 2014 to 5% in 2025), with the same regulatory changes as for the DPF scenario.

In addition to the baseline situation (2014), these scenarios were simulated in terms of pollutant emissions and concentrations in the Île-de-France region (fine resolution) and throughout France.

Two other scenarios were simulated solely for emissions in the Île-de-France region due to the complexity of the simulations and calculation times:

- **Alternative Technologies scenario**: in addition to the steady development in the DPF (or S1) scenario, strong promotion of electric vehicles on the urban road network alone, for all vehicle categories (40% of cars and 60% of light-duty commercial vehicles sold in 2025 are expected to be electric, all Euro 3 and earlier trucks and buses, and all two-wheeled vehicles of less than 250 cm^3 are replaced by electric vehicles), while the fleet from the DPF (or S1) scenario operates in the rest of the region (rural road network and motorways).

- **Ambition Air scenario**: 20-25% reduction in traffic and a similar fleet composition to that of the Alternative Technologies scenario in the highly urbanised intra-A86 area, while the fleet from the DPF (or S1) scenario operates in the rest of the region, with no reduction in traffic.

Several assumptions and input data were kept invariant for all the scenarios, to specifically analyse the impact related to the technological options for the vehicle fleets. These invariants included weather conditions, populations and their geographical distribution, emissions from activity sectors other than traffic, traffic volumes (except for the "Ambition Air" scenario) and traffic conditions.

The simulation results were compiled by combining statistics on changes in pollutant concentration (average values, exceedances of thresholds such as the WHO’s ambient air quality guideline for $PM_{2.5}$) and regional analysis. The interpretation of the results was based on a detailed "phenomenological" description allowing a better interpretation and understanding of the mechanisms that can lead to an improvement or degradation in air pollution and of the issues at stake.

This simulation work was supplemented by a documentary analysis of the historical trend in pollutant emissions and concentrations in France and Île-de-France.

The pollutants considered in the simulations were:

- at source emission: particulates in mass and size classes (PM_{10}, $PM_{2.5}$, $PM_{1.0}$)[9], particle number (PN) and according to their type (black carbon – BC[10], organic matter - OM), gaseous pollutants (nitrogen oxides - NOx, nitrogen dioxide - NO_2, ammonia - NH_3, volatile organic compounds - VOCs, carbon monoxide - CO) involved in the formation of secondary aerosols and ozone (O_3), as well as CO_2 because of the climate change issue;

- in the atmosphere (in concentrations): particulate pollutants broken down by mass and size classes ($PM_{2.5}$, PM_{10}), particle number (PN) and according to their type (BC, organic and inorganic fractions of PM_{10}), as well as the gaseous pollutants NO_2 and O_3.

A critical analysis was also conducted, justifying the methodological choices and assumptions while identifying their limitations, and suggesting more extensive studies. The literature provided partial insight into the uncertainties, while an analysis of emission factors illustrated the sensitivity of the simulations, such as the sensitivity of the formation of the secondary aerosols analysed with regard to the scheme for determining semi-volatile organic compounds (SVOCs).

In the end, the work presented here constitutes a rather unique experiment through its use of complementary skills, resources and data to simulate atmospheric pollutant emissions and concentrations under different scenarios. The approaches and tools developed provide a framework that can be used for further work investigating the impact of scenarios of changes in traffic and other emission sources on air pollution and health.

[9] PM_{10}, $PM_{2.5}$, $PM_{1.0}$: mass of particles with a median aerodynamic diameter less than 10 µm, 2.5 µm and 1 µm respectively.
[10] Black carbon is a carbon component (C) that is usually measured in the $PM_{2.5}$ fraction. It is produced by incomplete combustion of fossil fuels and biomass.

3.1. Conclusions of the WG and the CES

3.1.1. Conclusions on the health effects of particulate matter according to its composition, particle size and sources (first part of the expert appraisal)

a) Preamble

In response to the first part of the formal request, the evidence reported in the WHO Europe REVIHAAP review (published in 2013) and the levels of evidence for an adverse health effect obtained from the human studies published since then have been summarised in table form in Appendix 4 for components and in Appendix 5 for sources of particulate matter in ambient air.
The general conclusions presented below result from a comparison of the conclusions of the REVIHAAP review (the knowledge base representing the starting point) with the health evidence derived from studies published since REVIHAAP and up to February 2016 (human studies and animal experimental studies). Evidence accumulated since REVIHAAP refers to the levels of evidence for an adverse health effect obtained from studies published since REVIHAAP and up to February 2016:

- If the levels of evidence are moderate or high, this accumulated evidence confirms the health effect of a component or source when REVIHAAP already mentioned the specific effect of this component or source in 2013.
- Evidence is considered new and substantiates the health effect of a component or source when REVIHAAP did not mention a specific effect.
- If the levels of evidence are inadequate or low, the accumulated evidence does not allow a firm conclusion to be drawn about an adverse health effect, or only suggests such an effect; it reflects an emerging literature that does not show any associations, or a literature with an insufficient level of confidence[11] to draw any conclusion despite the observed associations.
- Non-existent evidence refers to an absence of studies published since REVIHAAP among those selected and assessed as part of this work.
- Lastly, evidence of no health effect corresponds to literature with a high level of confidence and showing no association between a component or source and health.

The general conclusions specifically address the health effects of outdoor ambient air particulate matter by components and sources of particulate matter. These conclusions do not call into question the evidence provided by other bodies of evidence investigating the harmfulness of substances or the health effects of particulate matter (such as silica, polycyclic aromatic hydrocarbons (PAHs), diesel engine exhaust particles, gasoline engine exhaust particles, particulate matter from specific industrial sources and particulate matter from biomass combustion). Lastly, these conclusions do not call into question the evidence provided by the literature on the adverse health effects of $PM_{2.5}$ and PM_{10} without chemical speciation or source apportionment.

[11] Level of confidence of the body of evidence defined from the rating tool proposed by OHAT, Step 6 Figure 1.

b) Conclusions by components of particulate matter in ambient air

➢ ***Ultrafine particles (<100 nm) and coarse particles ($PM_{2.5-10}$)***

In 2013, REVIHAAP concluded that the health effect of coarse particles was only suggestive and that evidence was still limited for ultrafine particles. The evidence accumulated since REVIHAAP is moderate and confirms the health effects of these fractions based on broad corpora of human studies, with a high level of confidence, examining many health categories. For ultrafine particles, the evidence accumulated since REVIHAAP from animal experimental studies underpins this conclusion. The highest levels of evidence for an adverse health effect in humans were obtained for respiratory health (coarse particles), cardiovascular health (ultrafine particles), and all-cause mortality (coarse particles). Lastly, the levels of new evidence accumulated since REVIHAAP are low and only suggest an effect of long-term exposure to ultrafine particles on neurological health (impaired development of children's cognitive performance), due to the body of evidence being limited to a single publication.

➢ ***Carbonaceous materials***

In 2013, REVIHAAP concluded that there was sufficient evidence for an adverse health effect of black carbon and increasing evidence for organic carbon. The levels of evidence accumulated since REVIHAAP are high and confirm the health effect of these components on the basis of broad corpora of human studies, with a high level of confidence and examining many health categories. Underpinning these results, the levels of evidence accumulated since REVIHAAP from animal experimental studies are low to moderate. The highest levels of evidence for an adverse health effect in humans were obtained for respiratory health, cardiovascular health, all-cause mortality and all-cause hospitalisations, both over the short and long term. Lastly, levels of new evidence accumulated since REVIHAAP are low and suggest a long-term effect of black carbon in ambient air particulate matter on neurological health (impaired development of children's cognitive performance) and perinatal health (low birth weight), two health categories not mentioned by REVIHAAP.

In 2013, REVIHAAP did not examine the health effects of polycyclic aromatic hydrocarbons (PAHs) in ambient particulate matter and secondary organic aerosols (SOAs) as a source factor[12]. In the case of SOAs as a source factor, levels of new evidence accumulated since REVIHAAP are inadequate and do not allow a firm conclusion to be drawn about a health effect, due to an emerging literature that is still limited in size and does not show any associations. Moreover, the heterogeneity of the source factors defined in the publications may make it difficult to interpret and compare the results. In the case of PAHs, levels of new evidence accumulated since REVIHAAP are low and do not allow a firm conclusion to be drawn about a health effect, due to the insufficient level of confidence in the body of evidence. Moreover, the great diversity of PAHs in ambient air makes it difficult to compare the results. However, PAHs can be associated with black carbon and are included in organic carbon measurements in ambient air, for which the levels of accumulated evidence are both high. In addition, there is an extensive literature, not assessed here, on the harmfulness of some PAHs (exposure classified as carcinogenic by IARC).

➢ ***Secondary inorganic aerosols***

In 2013, REVIHAAP reported associations between sulphate and nitrate – tracer elements of secondary inorganic aerosols (SIAs) in ambient air – and adverse health outcomes, but did not reach a conclusion regarding a level of evidence due to the lack of evidence on the direct and causal nature of the associations. The levels of evidence accumulated since REVIHAAP are high and confirm the health effects of sulphate-rich and nitrate-rich particulate matter based on broad corpora of human studies, with a high level of confidence and examining many health categories. Based on animal experimental studies, the levels of evidence accumulated since REVIHAAP are

[12] A factor (group of correlated components) derived by a statistical method of categorising components, often representing emission sources; for example, positive matrix factorisation or principal component analysis.

low regarding the effects of nitrate in diesel and gasoline engine exhaust on cardiovascular health – effects on atherosclerosis lesions and on complete blood count. The highest levels of evidence for an adverse health effect in humans are obtained for respiratory health, cardiovascular health and all-cause mortality. In addition, levels of new evidence accumulated since REVIHAAP are moderate and suggest an effect of sulphate-rich and nitrate-rich particulate matter on perinatal health (low birth weight), a health category not mentioned by REVIHAAP. Although the assessment carried out for this work takes many causality criteria into account, it is possible that the levels of evidence obtained reflects the ability of sulphates and nitrates to modulate the toxicity of particulate matter as a whole or the potential health effect of its common source (combustion), rather than their intrinsic toxicity.
In 2013, REVIHAAP did not mention the effects of other secondary inorganic aerosols, such as ammonium, or SIAs as a source factor. In the case of SIAs as a source factor,levels of new evidence accumulated since REVIHAAP are low and do not allow a firm conclusion to be drawn about an adverse health effect, due to an emerging literature that is limited in size and does not lead to a sufficient level of confidence. Moreover, the heterogeneity of the source factors defined in the publications makes the comparison of the results difficult. In the case of ammonium, levels of new evidence accumulated since REVIHAAP are low and do not allow a firm conclusion to be drawn about an adverse health effect, as the body of evidence do not lead to a sufficient level of confidence. However, ammonium concentrations are generally correlated with those of sulphate and nitrate levels, for which the levels of accumulated evidence are high.

➢ ***Transition metals***

In 2013, REVIHAAP reported associations between certain metals (nickel, zinc, vanadium; in mixtures) and health. Levels of new evidence accumulated since REVIHAAP, from moderate to high for these components, support the health effects of nickel, zinc, vanadium and iron based on broad corpora of human studies, with a high level of confidence and examining many health categories. The highest levels of evidence for an adverse health effect are obtained for cardiovascular health, respiratory health (nickel and vanadium) and all-cause mortality (iron). However, it is difficult to distinguish between the individual effects of transition metals because of their strongly correlated measured concentrations, related to their common sources: brake and tyre wear (iron, zinc and copper) and industry or combustion (nickel, vanadium and iron). The health evidence obtained for the metals, considered individually in the present work, may therefore fully reflect the health effect of their common sources or of mixtures of metals.

➢ ***Other chemical components of ambient air particulate matter***

The weight of evidence approach was not implemented for components or elements (metallic, inorganic or mineral) of ambient particulate matter, which have been historically considered less often associated with health outcomes in epidemiological studies. Nevertheless, studies published since REVIHAAP, described during the work, report associations between health (respiratory and cardiovascular) and exposure to calcium, potassium, magnesium, manganese, lead and chloride. Some of these components may be associated with sources (potassium: biomass-combustion tracer), with phenomena (calcium: abrasion and airborne dust related to construction sites, gravel pits and soil tillage or erosion), or with other components assessed individually.

➢ ***Silica***

The REVIHAAP review did not mention the health effects of silica in outdoor ambient air. The levels of new evidence accumulated since REVIHAAP are moderate and substantiate the health effects of silica in ambient air particulate matter, particularly on respiratory health and all-cause mortality, based on a broad body of evidence of human studies, with a high level of confidence and examining many health categories. There is also an extensive literature, not assessed here, on the harmfulness of crystalline silica (exposure classified as carcinogenic by IARC).

➢ ***Endotoxins***

The REVIHAAP review did not mention the potential health effects of endotoxins in outdoor ambient air. Levels of new evidence accumulated since REVIHAAP are moderate and substantiate the health effects of endotoxins in ambient particulate matter, particularly on cardiovascular health, based on a body of evidence that is limited but leads to a high level of confidence. The lack of standardisation in endotoxin measurement and analysis protocols, as well as the diversity of components to which they may be attached, call for caution in interpreting these conclusions. However, there is an extensive literature, not assessed here, examining the harmfulness of exposure to high concentrations of endotoxins in workers handling organic matter, such as sewer workers, waste-sorting and treatment plant workers and farmers.

➢ ***Oxidative potential of particulate matter***

The oxidative potential of particulate matter is not a component in itself. It is an indicator measured by acellular tests, quantifying the intrinsic ability of particulate matter to generate reactive oxygen species[13]. The oxidative potential of particulate matter has been put forward in recent years as a metric, other than the mass or chemical composition of atmospheric particles, for assessing their health effects.

In 2013, REVIHAAP only mentioned oxidative stress as a potential mechanism of the health effect of particulate matter. Levels of new evidence accumulated since REVIHAAP are low and only suggest an adverse effect of the oxidative potential of particulate matter on respiratory and cardiovascular health, as the literature is still emerging (limited body of evidence) and does not lead to a sufficient level of confidence to enable a firm conclusion to be drawn. Based on animal experimental studies, the levels of evidence accumulated since REVIHAAP are low for respiratory and cardiovascular health effects (respiratory inflammatory infiltration and systemic inflammation) of oxidative stress induced by inhalation of ambient air particulate matter in mice. It should be noted that measurement of the oxidative potential of particulate matter is still recent and there are several non-standardised measurement methods, each sensitive to molecules or families of chemical species that may differ. This may partly explain the limitations of size and confidence in the body of evidence.

c) Conclusions by sources of particulate matter in ambient air

➢ ***Road traffic***

In 2013, the REVIHAAP review concluded that there was sufficient evidence of the health effects of black carbon (mainly emitted by diesel vehicles in most urban environments) and likely associations between health and $PM_{2.5}$ emissions from road traffic and road dust (including crustal material). Levels of new evidence accumulated since REVIHAAP, from high to moderate depending on the type of emissions (e.g. traffic-related black carbon, traffic-related $PM_{2.5}$ emissions and road dust/crustal material), confirm the health effect of the "road traffic" source as a whole on the basis of corpora of human studies that lead to a high level of confidence and examine many health categories. However, the bodies of evidence for road traffic-related black carbon, diesel engine exhaust particulate matter and gasoline engine exhaust particulate matter were limited. Underpinning these results, the levels of evidence accumulated since REVIHAAP from animal experimental studies are low to moderate for the respiratory health effects (ultrastructural damage, respiratory function, lung remodelling) and the cardiovascular health effects (vascular function, coagulation, atherosclerosis lesions) of road traffic-related $PM_{2.5}$ emissions and diesel engine exhaust particulate matter. The highest levels of evidence for an adverse health effect in humans are obtained for road traffic-related black carbon (on respiratory health, cardiovascular health and all-cause mortality) and road dust (on respiratory health), based on broad bodies of

[13] *The ability of particulate matter to generate ROSs contributes, along with other molecular and cellular pathways, to the induction of oxidative stress in lung target cells. Oxidative stress is a mechanism of particle toxicity. The ability of particulate matter to generate ROSs is also related to the composition and surface of the particulate matter.*

evidence. Levels of new evidence accumulated since REVIHAAP are moderate and suggest an adverse effect of long-term exposure to $PM_{2.5}$ emissions from road traffic on neurological health and perinatal health, two health categories not mentioned in REVIHAAP. The conclusions for the "road traffic" source are consistent with the evidence obtained for some individual components, such as black carbon, organic carbon and some metals. Independently of the body of evidence analysed here on the effects of particulate matter in ambient air from road traffic, there is an extensive literature on the harmfulness of diesel engine exhaust and diesel particulate matter (exposure classified as carcinogenic by IARC) and gasoline engine exhaust (exposure classified as probably carcinogenic by IARC).

- ***Combustion of coal and petroleum products***

In 2013, REVIHAAP reported strong evidence of the health effects of coal combustion, based notably on evidence of an adverse effect of sulphate-rich particulate matter. Only mitigated associations were reported regarding the combustion of petroleum products. The evidence accumulated since REVIHAAP confirms the health effects of ambient particulate matter from these sources based on broad corpora of human studies, leading to a high level of confidence and examining several health outcomes. The levels of evidence range from high for coal combustion to moderate for petroleum-product combustion. These conclusions are consistent with the health evidence obtained for some components assessed individually: sulphate (coal combustion tracer), nickel and vanadium (petroleum-product combustion tracers). In addition, there is an extensive literature, not assessed here, on the harmfulness of emissions from coal combustion, particularly for household combustion (cooking and heating) in developing countries (exposure classified as carcinogenic by IARC).

- ***Biomass combustion***

In 2013, REVIHAAP reported a likely association between particulate emissions from biomass combustion and health, based mainly on publications investigating the occurrence of health events during forest fire episodes. The levels of evidence accumulated since REVIHAAP is inadequate and do not allow a firm conclusion to be drawn about an adverse health effect of outdoor particulate matter from biomass combustion, due to the limited body of evidence reporting inconclusive results. The body of evidence is likely to be limited due to the selection criteria used, favouring the inclusion of publications using statistical methods for source apportionment. Nevertheless, many associations between health and potassium, a tracer of biomass combustion, have been reported in the studies published since REVIHAAP. In addition, there is an extensive literature, not assessed here, on the harmfulness of emissions from biomass combustion, particularly for household combustion (cooking and heating) in developing countries (exposure classified as carcinogenic by IARC).

- ***Industry***

In 2013, REVIHAAP reported associations between the "industry" source category and health, but did not reach a firm conclusion about a level of evidence due to the heterogeneity of this source category, which may include a dominant source, a mixture of sources, or various combustion sources. The levels of evidence accumulated since REVIHAAP, from inadequate to low depending on the type of industry, do not allow a firm conclusion to be drawn about an adverse health effect of particulate matter emissions from industrial sources, due to a corpus of studies leading to an insufficient level of confidence or inconclusive results. In addition, the heterogeneity of definitions of the "industry" source in the various publications assessed makes the interpretation and comparison of the results difficult. Nevertheless, the potential health effects of this source category are consistent with the evidence obtained for the combustion of coal, the combustion of petroleum products and some individually-assessed metals (nickel and vanadium). In addition, there is an extensive literature, not assessed here, on the adverse effects on human health of environmental contamination by industrial sites (e.g. WHO Europe, 2014).

➢ ***Hazardous waste sites***

In 2013, REVIHAAP mentioned two publications that did not report any clear association between residential proximity to hazardous waste storage sites and perinatal health. The evidence accumulated since REVIHAAP is inadequate and does not allow a firm conclusion to be drawn about an adverse health effect for this source category, due to a body of evidence consisting of a single publication reporting inconclusive results for many health outcomes. The body of evidence assessed is likely to be limited due to the selection criteria used, favouring publications using statistical methods for source apportionment.

➢ ***Agriculture***

In 2013, REVIHAAP did not mention the health effects of outdoor ambient air particulate matter from agriculture. New evidence accumulated since REVIHAAP is non-existent (no human studies) or inadequate (in animal experimental studies), which does not allow any conclusion to be drawn about a health effect of ambient air particulate matter from this source category. The body of evidence is likely to be limited due to the selection criteria used, favouring publications using statistical methods for source apportionment (and in such publications, the application of these methods did not identify an agricultural source). In addition, there is an extensive literature, not assessed here, examining the health effects of occupational exposure to pesticides.

➢ ***Desert dust***

In 2013, REVIHAAP reported an increase in the number of adverse health events during air pollution episodes due to desert dust. The levels of evidence accumulated since REVIHAAP are moderate and confirm the health effect of desert dust, particularly on the respiratory health of children, based on a body of evidence that is limited but leads to a high level of confidence.

➢ ***Sea salt and sea spray***

In 2013, REVIHAAP reported mitigated associations between sea salt and sea spray and health, and even suggested that there was no health effect. The evidence accumulated since REVIHAAP does not allow a firm conclusion to be drawn that sea salt and sea spray have an adverse health effect, which could support the evidence of no health effect, based on broad corpora of human studies.

3.1.2. Conclusions on the impact on air pollution of the technologies and composition of the motor vehicle fleet operating in France (second part of the expert appraisal)

Important note: *Any comparison of this work with public policy impact assessments (implementation of restricted traffic zones*[14]*, announcement of restrictions or bans on combustion-engine vehicles, etc.) should be avoided. This is because the scenarios simulated in this expert appraisal compare different technological assumptions (or even traffic reductions) in a constant context. They do not take into account demographic changes, changes in mobility behaviour, changes in emissions other than those from vehicle traffic, or changes in the economic context. They enable a study of air pollution's sensitivity to different technological developments in the motor vehicle fleet, and are not a prospective study of air pollution in relation to public policies.*

In response to this second part on emissions from the "road traffic" source, the impacts of prospective scenarios varying in the technological composition of the motor vehicle fleet (engine types, pollution-control systems) are summarised in table form in Appendix 6 (impact on emissions in T/year) and Appendix 7 (impact on atmospheric concentrations in µg/m^3), for the main particulate and gaseous pollutants.

[14] The terms "Low Emission Zones" are now used, including in the context of the future French law governing mobility ("loi d'orientation des mobilités").

The conclusions are presented below, distinguishing between:

- firstly, results derived purely from the simulations and their analysis;
- secondly, results placed into perspective in a more general context where the developments and challenges are not limited to the impact of vehicle technologies on air pollution (*text in italics*). These associated conclusions or recommendations are therefore based on an elicitation of the experts' statements by self-analysis in regard to the scenarios studied and the knowledge of their limits.

➢ *Relative importance of traffic and of the different vehicle categories regarding pollutant emission in ambient air*

Road traffic is the main emitter of certain pollutants such as black carbon (BC), organic matter (OM) and nitrogen oxides (NOx) in urban areas. It also produces a significant proportion of $PM_{2.5}$ and PM_{10} and their precursor gases and is therefore a fairly strong contributor to urban air pollution. Passenger cars are predominant within the road traffic environment, but each of the other vehicle categories can play a major role regarding certain pollutants.

➢ *Reduction in simulated emissions with the various scenarios*

The simulation of pollutant emissions and ambient air concentrations in the Île-de-France region and France by 2025 and according to the "near steady development" scenario (Scenario S1), shows that traffic emissions decrease sharply (-30% to -60%), due to changes in emissions regulations (Euro standards), improvements in pollution-control technologies – particularly the near-generalisation of particulate filters on diesel vehicles – and the gradual renewal of the fleet.
The S2 scenario that promotes gasoline engines (56% light-duty vehicle traffic compared to 27% in the baseline situation and the DPF scenario (S1)) would result in an accelerated renewal of the vehicle fleet and further reductions in particulate matter and NOx emissions, but also a smaller reduction in VOC and NH_3 emissions.

➢ *Reduction in simulated atmospheric concentrations with the various scenarios*

In a constant context (demographics, road traffic, emissions from sectors other than transport), these reductions in simulated traffic emissions by the technological development scenarios are reflected in:

- a decrease in annual average concentrations (large for BC and NO_2);
- a decrease in the number of high-concentration episodes (except for ozone O_3 in urban areas), but still without achieving compliance with the WHO annual guidance values for $PM_{2.5}$;
- a possible but limited increase in O_3 concentration in urban areas.

In an actual changing context (including probable variations in other parameters), however, this improvement in air quality would be mitigated by an increase in traffic and other polluting activities in urban or suburban areas, related to urbanisation, if new types of mobility are not promoted (car-sharing, car-pooling, active modes of transport, etc.), in addition to the strengthening of public transport networks. Conversely, it could be amplified by a reduction in emissions from other activity sectors (heating, industry, etc.) that also undergo technical improvements and by various local measures or policies in favour of air quality. It could also be amplified by a decrease in imported pollution when the global context is favourable to a reduction in anthropogenic emissions. These various aspects, as well as climate and demographic changes, have not been considered in this framework and should be studied.

If they are not accompanied by traffic changes, therefore, technology developments may not be enough to achieve a sustainable improvement in air quality in urban agglomerations.

It should be noted that the more limited improvements observed for $PM_{2.5}$ and PM_{10} concentrations are related to:

- the high contribution of other sectors (combustion for heating and agriculture in Île-de-France). Coordinated air quality policies should therefore be promoted;
- traffic emissions being maintained by abrasion (tyres, brakes, road surface). These could be reduced thanks to improved braking systems and regulatory changes;
- the increase in oxidant concentrations in urban areas that promote the formation of secondary particles.

➢ ***Technological scenarios and other levers for reducing air pollution from road traffic***

Between the "steady development" with generalisation of the particulate filter (Scenario S1) and the scenario marking a shift from light-duty diesel vehicles to gasoline vehicles (Scenario S2), the differences would ultimately be quite limited compared to those observed between 2014 and 2025.

A small (and therefore uncertain) benefit would be observed with the gasoline scenario (S2) with respect to pollution by particulate matter and NO_2 concentrations, for various reasons:

- firstly, for particulate matter, this benefit is partly due to a greater decrease in precursor gases, including NO_2, despite an increase in urban O_3 concentrations;
- secondly, part of the benefit of the gasoline scenario (S2) compared to the DPF scenario (S1) is related to the accelerated fleet renewal (which results in a lower proportion of light-duty diesel vehicles without a DPF and a higher proportion of recent Euro 5 and 6 vehicles). This accelerated fleet renewal is due to the significant shift in the breakdown between gasoline and diesel vehicles over a relatively short period.

Regardless of the technological options, the "accelerated" renewal of the fleet (through various incentives, restrictive measures, etc.) therefore appears as a potential lever for improving air quality in addition to the technological improvements in vehicles and to regulatory changes. However, the side effects of renewal must be considered (additional economic and environmental costs of vehicle construction and destruction, increased use of recent vehicles, possible inequities in incentives and scarcity of used vehicles, etc.).

Nevertheless, the emission simulations with the "Alternative Technologies" and "Ambition Air" scenarios reveal above all the potential of promoting non-polluting (electric) engine types. Even more, they reveal the potential of an ambitious reduction in traffic in dense areas, contributing to a further reduction in emissions and anticipating a reduction in human exposure and local pollution.

Technological options, as well as accelerated fleet renewal, must therefore be compared with other measures such as traffic control (low-emission zones, urban tolls, etc.), the promotion of public transport, active modes of transport, car-sharing, car-pooling and freight logistics (e-commerce, last mile delivery, urban logistics platforms), which offer benefits for air quality by potentially reducing the contribution of road traffic. However, the real effectiveness of these different measures remains to be assessed.

The guidelines and measures designed to improve air quality in France in the areas of road transport and mobility (national plan to reduce air pollutant emissions, National Conference on Mobility) and the guidelines for the development of "sustainable transport systems" (international work by the OECD, UNECE, WHO-Europe) could provide an interesting framework for analysis.

Measures to improve air quality can bring co-benefits such as reduced noise pollution or commuting time. More generally, measures specific to mobility should be part of the *broader governance of towns and cities, integrating urban planning, transport, health, air and environmental quality, and quality of life.*

However, objectively assessing the effectiveness of the measures remains very complex and insufficiently documented, and requires going beyond the strict framework of air pollution. Thus, electric or hydrogen engines, etc., which can be effective solutions for reducing local pollution and greenhouse gas emissions under certain conditions, must be assessed taking multiple implications into account (availability and sources of energy, materials, induced environmental impacts, etc.). "All-electric" transport by 2025 or even 2040 would then probably seem rather unrealistic.

➢ ***Changes in the issues***

This work has shown the importance of traffic in urban air pollution. Several changes can be anticipated and are discussed below.

Urbanisation and development of suburban areas (even without urban expansion) contribute to increased mobility needs and car dependency. Traffic control and the promotion of public transport, active modes of transport and car-pooling for commuters seem essential to contain the resulting increases in emissions.

Developing urban logistics based on light-duty commercial vehicles (at the expense of heavy vehicles) could significantly increase urban traffic and pollutant emissions. However, their already high contribution to pollutant emissions should be reduced by bringing regulations forward (requirements closer to those of cars) and by the relatively rapid renewal of the professional vehicle fleet. Fewer diesel engines and a shift towards natural gas for vehicles are also expected. Lastly, due to the significant transfer of used light-duty commercial vehicles to the car fleet, incentive policies on light-duty commercial vehicles may prove to be strategic in terms of the overall development of the fleet.

Motorised two-wheeler traffic is already increasing considerably in some congested urban agglomerations. Its high contribution to VOC emissions is expected to decrease with regulatory changes and the promotion of electric motorised two-wheeled vehicles.

The decrease in actual road traffic emissions is generally lower than expected with regulatory changes, thus lessening the improvement in air quality. Focusing on compliance with approval and control procedures, sparked by recent scandals, seems likely to limit this risk for the future. The dismantling or disabling of pollution-control systems, or their malfunctioning and the degradation of emissions as the vehicle ages, should also decrease through the sophistication of vehicle pollution-control technologies and the strengthening of the pollution component of roadworthiness tests. New techniques for measuring emissions (on-board portable emissions measurement systems – PEMS, in situ measurements) and for identifying vehicles and encouraging eco-driving (Crit'Air stickers, connected stickers) should also help to improve knowledge and control of traffic emissions.

New forms of mobility (car-sharing, car-pooling, autonomous vehicles) and freight logistics (e-commerce, last mile delivery, urban logistics platforms) are expected to impact traffic, vehicle fleets and pollutant emissions, although it is not yet possible to assess their extent.

Regarding exhaust emissions of particulate matter from the latest automotive technologies on the market, there is now very little difference between the quantities of black carbon emitted by a diesel vehicle and those emitted by a gasoline vehicle. Nevertheless, the question of the difference in emissions of precursor gases to organic (SVOCs) and inorganic (NO_2, NH_3, etc.) secondary aerosols is still unresolved.

Regarding non-exhaust emissions of particulate matter from automotive technologies, they could decrease as a result of improved technologies and regulatory changes, but they essentially remain related to traffic volumes and not to technologies. Substituting *combustion-engine vehicles by equivalent but heavier electric or hybrid engine vehicles would not guarantee a reduction in non-exhaust $PM_{2.5}$ and PM_{10} emissions because their greater weight would increase particulate matter emissions related to tyre-road contact and resuspension (Timmers et al., 2016).*

➢ ***Uncertainties and limitations***

The simulation work presented is characterised by uncertainties (emissions, recent pollution-control technologies, precursors of secondary particles, spatial and temporal distribution of traffic and other polluting sources, etc.). Prospective changes are by nature uncertain, due to the fragility of some of the assumptions in the scenarios, and fail to take many aspects into account (changes in population, behaviour and lifestyles, etc.). The results do not predict the extent of local sources of ambient air pollution. However, they do provide a framework for analysing air quality trends, while allowing identification of issues and comparison of different scenarios by explaining the mechanisms of pollution.

The availability of high-quality data and observations (mobility, traffic, knowledge of emissions, etc.) is fundamental in this process.

3.2. Recommendations of the WG and the CES

The following recommendations concern the two parts of the formal request respectively and are made according to two areas:

- Public policies;
- Research and assessment work to support decision-making.

3.2.1. Recommendations on the health effects of particulate matter in ambient air according to components, sources and particle size

1/ In terms of public policies:

i) For components of particulate matter in ambient air:

Considering the evidence of adverse health effects identified for the particulate components mentioned below, the WG and the CES recommend, as part of policies to monitor ambient air quality and reduce air pollutant emissions, that the following particulate components be given priority consideration:

- ultrafine particles (< 100 nm, number concentration),
- black carbon,
- and organic carbon.

Coarse particles ($PM_{2.5-10}$), for which there is evidence for health effects, are already indirectly taken into account in the currently regulated measurement of PM_{10} and $PM_{2.5}$. These recommendations do not call into question the relevance of measuring $PM_{2.5}$ and PM_{10} in the current surveillance system.

These recommendations on ultrafine particles and black carbon reinforce those made previously on the need to supplement and sustain the acquisition of data on these two indicators, as part of the Agency's work on emerging pollutants in ambient air (ANSES, 2018).

ii) Regarding the sources of particulate matter in ambient air:

Considering the evidence of adverse health effects identified for the sources mentioned below, the WG and the CES recommend that national and international efforts continue to reduce outdoor air pollution and/or the related population exposure:

- road traffic (including exhaust and non-exhaust emissions),
- coal combustion,
- combustion of petroleum products,
- biomass combustion,
- and desert dust.

Regarding particulate pollution from road traffic, the WG and the CES stress the importance of continuing efforts to reduce population exposure to black carbon, organic matter and ultrafine particles emitted into outdoor air, considering:

- firstly, the results of the collective expert appraisal showing strong evidence of adverse health effects associated with exposure to black carbon from road traffic particulate matter, organic carbon and ultrafine particles,

- and secondly, the results of the collective expert appraisal showing decreases in atmospheric emissions and concentrations of black carbon, organic matter and ultrafine particles from road traffic, obtained through changes in emissions regulations (Euro standards), improvements in pollution-control technologies – particularly the near-generalisation of particulate filters on diesel vehicles – and the gradual renewal of the fleet, based on simulations from 2014 to 2025.

Regarding particulate air pollution from industries, it was not possible to reach a firm conclusion about health effects of this source category due to the heterogeneity of the emission sources and the insufficient quality of the corpus of assessed studies. Nevertheless, the WG and the CES point out that this limitation does not call into question the evidence accumulated from other bodies of literature on the harmful effects on human health of environmental contamination by industrial sites (e.g. WHO Europe, 2014), nor does it challenge the monitoring and control of emissions from industrial sources.

Lastly, in the present work, it was not possible to assess the evidence of health effects of other sources due to a lack of data: agriculture, shipping, airport pollution, natural sources such as pollen and plant debris, wind erosion, volcanic eruptions and biogenic emissions of volatile organic compounds (precursors to secondary organic aerosols) from the vegetation.

2/ In terms of assessment work to support decision-making and research work

To allow for health risk assessments and health impact assessments of outdoor air pollution, the WG and the CES recommend deriving – or producing as necessary – exposure-risk functions for the following particulate pollutants, in order to include them in future assessments:

- ultrafine particles (< 100 nm, number concentration),
- black carbon,
- and organic carbon.

In terms of improving knowledge, the WG and the CES recommend pursuing research efforts on:

- the health effects of exposure to particulate matter in ambient air by including exposure metrics other than PM_{10} and $PM_{2.5}$ mass, in order to develop other reference indicators (exposure-risk functions, ambient air quality standards, etc.) for particulate pollution,

- a metrological definition of secondary organic aerosols with a view, if possible, to harmonising and standardising this exposure metric,
- the predictive nature of the oxidative potential of particulate matter in ambient air in terms of health effects, as well as the definition of this indicator, which is currently measured by various tests under acellular conditions, with a view, if possible, to harmonising and standardising this exposure metric,
- the health effects of endotoxins in outdoor air,
- the health effects of outdoor air pollution from some as yet poorly documented anthropogenic sources such as agriculture, shipping and airport pollution.

3.2.2. Recommendations on the impact on air pollution of the technologies and composition of the motor vehicle fleet operating in France

1/ In terms of public policies

The WG and the CES point out that several documents specify national guidelines and measures designed to improve air quality in the areas of road transport and mobility, such as the Ministerial Order of 10 May 2017 establishing the national plan to reduce emissions of air pollutants, as well as the summary of the thematic workshop on "Cleaner mobility" from the National Conference on Mobility in December 2017.

However, the WG and CES note that objective assessment of the effectiveness of these measures remains very complex and insufficiently documented, and requires assessment methods to be defined, including the definition of prospective scenarios. Moreover, the enforcement of several of these measures by local authorities requires calls for projects to be implemented and sustained (for example, calls for projects on "segregated public transport lanes" and "public transport and sustainable mobility").

In view of the very focused analysis carried out as part of this expert appraisal and the current lack of information and of methods for assessing the actual effectiveness of the various air quality improvement measures, the WG and the CES stress the need to:

- enhance cross-sectoral coordination of air quality policies considering the contributions of different industry sectors[15] to ambient air pollution, especially particulate pollution;
- consider the issue of air pollution by road traffic in its entirety rather than think in terms of technological options and their impact on pollutant emissions alone;
- consider both local pollution and greenhouse gases;
- give joint consideration to technological and regulatory changes, the promotion of alternative technologies (electromobility) and the renewal of the motor vehicle fleet (all vehicle categories including motorised two-wheeled vehicles and light-duty commercial vehicles), but also and above all to the reduction in traffic being offset by greater use of public transport and active modes of transport in densely populated areas, as potential levers for reducing air pollution, local pollution and population exposure;

[15] Depending on the region, the dominant contributions to particulate pollution may come from the residential and service sectors, industry, road transport or agriculture.

- take into account the pollutants contributing to particulate pollution as a whole in the development of public policies for air quality, given the high dependence of particulate concentrations on precursor gases (NO_2 and organic components);

- use concentrations of black carbon and nitrogen dioxide (NO_2) and particle number concentrations (PNCs) as exposure indicators in impact assessments and monitoring studies of air pollution generated by road traffic.

2/ In terms of assessment work to support decision-making and research work

In terms of simulation and assessment methods, the WG and the CES recommend:

- extending the simulation work to other particulate components (polycyclic aromatic hydrocarbons, metals), to more radical scenarios (e.g. 100% gasoline, targeted traffic reductions) or to additional scenarios, in order to observe the sensitivity of certain results (influence on ozone and secondary aerosols). Work on various specific improvements in assumptions or simulation input data would also be useful (ANSES, 2019b);

- developing and implementing tools to enable – in conjunction with the various existing air pollution simulation platforms – more local analyses and the specific study at higher spatial resolutions of local pollution induced by emission sources;

- developing methods for the comparative analysis of different air quality improvement measures – particularly those relating to road traffic – as well as the predictive assessment of the impact of public policies; these methods should include other activity sectors, road traffic and mobility, and take into account the changing context (e.g. climate, demography, energy, emerging technologies and services, behaviour, etc.), in the form of prospective scenarios (even simplified ones) to be developed;

- broadening the issues of assessing air pollution and reduction measures and policies, by integrating the most robust models and indicators on population exposure, exposure to local pollution and health effects.

In terms of knowledge acquisition, the WG and the CES recommend:

- experimentally characterising the emission factors of unregulated pollutants, secondary pollutant precursors and semi-volatile organic compounds for the various vehicle technologies, and investigating more specifically abrasion emissions (brakes, tyres, road surface) and resuspension of particulate matter;

- deploying observation campaigns (traffic) and surveys (mobility) in order to obtain reliable statistics as input data for simulations (fleet composition, speeds, traffic data and activity profiles of the various pollutant-emitting sectors, etc.) and gain a better understanding of behavioural changes.

4. AGENCY CONCLUSIONS AND RECOMMENDATIONS

The French Agency for Food, Environmental and Occupational Health & Safety endorses the conclusions and recommendations of the WG on "Particulate matter" and the CES on "Assessment of the risks related to air environments" presented above.

In its first part, the expert appraisal focused on characterizing the levels of evidence for the associations between different health outcomes and exposure to ambient air particles according to their components, sources and size, in order to answer several lingering questions on the health effects of particles according to their composition and sources. To this end, it relied on a methodology for conducting a literature-based assessment of the levels of evidence, following the recommendations of the opinion “Illustrations and updating of recommendations for assessing weight of evidence and analysing uncertainty at ANSES” (ANSES, 2017b) brought by its Scientific Council.
ANSES emphasizes that this work constitutes an update of knowledge on the health effects of particle components, based on a standardized review of the literature and an analysis of the weight of evidence, subsequent to the REVIHAAP review (Review of evidence on health aspects of air pollution) conducted in 2013 by the WHO Regional Office for Europe.
In view of the identified evidence of adverse health effects, and of trends observed in recent scientific literature, the Agency recommends, as part of its public policies to improve air quality, to prioritize targeting three currently unregulated particulate indicators: ultrafine particles (<100 nm, number concentration), black carbon and organic carbon[16]. To reduce the population's exposure to these pollutants in the ambient air, ANSES insists on the need to act on the main controllable sources of emissions that include: road traffic, coal combustion, petroleum product combustion and biomass combustion. ANSES also highlights the lack of available data on the health effects of outdoor ambient air pollution from certain anthropogenic sources such as agriculture, maritime transport and airport pollution.

In its second part, the expert appraisal studied scenarios of possible changes in the emissions and concentrations of particles and gases in ambient air, based on road traffic in Metropolitan France and Ile-de-France by 2025, whose main studied variable is the change in technological composition of the vehicle fleet, with a constant volume of traffic (except in one scenario). This original study relied on simulation calculations of ambient air emissions and concentrations, with 2014 as the baseline year. Any direct comparison of this work with public policy impact studies (establishment of restricted traffic zones, announcement of restriction or ban of combustion vehicles, etc.) is to be avoided as it is a study of the sensitivity of air pollution to different technological developments in the vehicle fleet, and it is not a prospective study of air pollution in relation to public policies. This work was supplemented by a documentary analysis of the historical trends in pollutant emissions and concentrations in France and Île-de-France.
In view of the simulation work carried out with regard to emissions from the "road traffic" source, ANSES notes a favourable change in ambient air quality, irrespective of the prospective scenarios involving changes in technologies and the composition of the vehicle fleet in France (engines, pollution control systems). Nevertheless, the Agency stresses that these evolutions alone are insufficient to improve air quality in agglomerations because they do not make it possible to avoid exceedances of WHO guideline values. Thus, the Agency insists on the need to jointly consider technological and regulatory developments, the promotion of alternative technologies (drastically

[16] These recommendations support, in particular, those established as part of ANSES's work published in 2018 on so-called "emerging" pollutants in ambient air. The Agency states that these recommendations do not call into question the relevance of measuring $PM_{2.5}$ and PM_{10} in current systems, in particular in the interest of a historical monitoring of particulate pollution.

reducing the emission of pollutants, including electromobility), the renewal of the fleet (all categories of vehicles including two-wheelers and light-duty commercial vehicles), but also and above all the reduction in traffic offset by the strengthening of public transportation, intermodality[17] and active modes of transportation[18] in densely populated areas.
The Agency specifies that a complementary analysis of the environmental impacts of the technological scenarios, other than air pollution induced by road traffic, as well as an analysis of the health impacts, are likely to complete the results obtained.
In addition, the Agency notes that the French draft law governing mobility ("projet de loi d'orientation des mobilités") includes new measures on air quality and mobility.

The nature of the work carried out by ANSES as part of this expert appraisal makes it a science-based contribution, intended for the public authorities and, more broadly, for all stakeholders. Given the very high level of overlap between the technical, environmental, health and societal aspects, the Agency considers it important that different bodies, such as the French National Council for Air, be able to take up this work, to complete the analysis and to discuss it.

Beyond this, our work can serve to support the public authorities in the context of the ongoing reflection in the European Commission on assessment of the two European directives on ambient air quality (Directives 2008/50/EC and 2004/107/EC). Both Directives establish air quality standards and requirements to ensure that Member States monitor and/or assess the air quality in their respective territories in a harmonized and comparable manner.
The Agency also plans to bring this work to the attention of the WHO Regional Office for Europe, in the context of their objectives for the revision of the WHO Air Quality Guidelines (including those related to particulate matter) published in 2005.

Dr Roger Genet

[17] Intermodality consists of using and combining different means of transportation during the same journey (automobile, public transportation, active modes of transportation, etc.).
[18] Active modes of transportation are driven by the physical action of their users (walking, cycling, etc.).

KEYWORDS

First part of the expert appraisal related to health effects of ambient air particulate matter

Outdoor air pollution, Particulate matter, Health effects, General population, Review, Black carbon, Organic carbon, Metal, Ultrafine particles, Coarse particles, Secondary aerosol, Biomass combustion, Coal combustion, Oil combustion, Desert dust, Road traffic

Second part of the expert appraisal related the impact on air pollution of the technologies and composition of the motor vehicle fleet

Particulate matter, atmospheric pollutants, emission, concentration, modelling, simulation, Polyphemus, COPERT, vehicle technology, motorisation, diesel, gasoline, particulate filter, scenario, prospective, vehicle fleet composition, road traffic, Île-de-France, France

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APPENDIX 1 - GLOSSARY

Level of evidence for an adverse health effect:

The terms “level of evidence” for an adverse health effect ("high", "moderate", "low", "inadequate", “no health effect”) are defined by the weight of evidence approach of the Working Group adapted from OHAT (Rooney et al, 2014), based on studies in humans on the one hand, and in experimental animals on the other, and published since 2013 until in February 2016. This terminology is derived from that used by IARC (in French) for the classification of the carcinogenicity of an agent, which defines "degrees of carcinogenicity evidence" based on studies in humans on the one hand, and in experimental animals on the other (IARC, 2013; https://www.cancer-environnement.fr/478-Classification-des- substances-cancerogenes.ce.aspx).

The levels of evidence for an adverse health effect are part of the hazard identification step of the overall risk assessment approach (National Research Council Committee 2009). Indeed, levels of evidence represent the more or less proven existence of an association (or absence of association) between exposure to particles of ambient air (according to the components and sources) and health outcomes. Thus, this makes possible to establish whether the hypothesis of a causal link is more or less plausible on the basis of the publications, evaluated as a whole, taking into account certain causal criteria introduced by Bradford Hill: magnitude of the association, consistency of observations in different populations, temporality of association, dose-response relationship, biological plausibility, existence of experimental evidence and specificity (Bradford Hill 1965).

The defined levels of evidence do not reflect the strength of the association nor the magnitude of the risk. Nor do they reflect the relative toxicity between ambient air particles of different composition or from different sources.

Exposure of interest:

The terms "exposure of interest" refer to categories of compounds and sources of ambient air particles (see table below) that are defined by the approach of the Working Group, consistently with those documented in the WHO’s reference review REVIHAAP (WHO Europe 2013). Compared to REVIHAAP, categories were added based on available data from the epidemiological and toxicological studies selected thereafter. The inclusion of a publication in a category was based primarily on the definition of the components or sources made by the authors of the study.

Components	*Sources*
Black carbon, elemental carbon, PM absorbance	Road traffic (black carbon)
Organic carbon	Road traffic ($PM_{2,5}$)
Polycyclic aromatic hydrocarbons (PAH)	Diesel engines
Secondary organic aerosols (SOA)	New diesel engine technologies*
Ultrafine particles (UFP) (<0,1 µm)	Gasoline engines
Carbon ultrafine particles (UFP) (<0,1 µm)	Brake dust
Coarse particles (2,5-10 µm)	Road dust or crustal material
Concentrated ambient particles (CAP)	Coal combustion
NH_4	Petroleum products combustion
NO_3/N	Industries
S/Sulphates	Metallurgy
Secondary inorganic aerosols (SIA)	Biomass combustion
Ni	Desert dust
Zn	Sea salts and sprays
Cu	Hazardous waste sites
V	Agriculture, rural environment
Si/SiO_2	
Fe	
Other chemical elements	
Endotoxins	
Oxidative potential	

** Including vehicles with diesel particulate wall-flow filters.*

Health category of interest:

The terms "health category of interest", for example "cardiovascular health", pool various health outcomes (impaired heart rate, infarction and coronary events, cardiovascular hospitalisations, etc.). Ten health categories of interest (see table below) are defined by the approach of the Working Group, consistently with those documented in the WHO's reference review REVIHAAP (WHO Europe 2013) and from the health outcomes documented in the epidemiological and toxicological studies subsequently included in the evaluation of the Working Group.

All-cause mortality (deaths) (except traumatic causes)
All-cause hospitalisations (except traumatic causes)
Cardiovascular health
Respiratory health[1]
Lung cancers
Cancers (other than lung cancers)
Neurological health
Reproductive health[2]
Perinatal health[3]
Diabetes/Metabolism disorders

1: Including asthma in children and related in utero exposure. 2: Corresponding in humans to disorders from preconception until the first 20 weeks of pregnancy. 3: Corresponding in humans to disorders after the first 20 weeks of pregnancy until the first month of life after birth.

Health outcome of interest:

The ten health categories of interest mentioned above pool 83 "health outcomes of interest", which correspond to categories of health effect indicators identified in the studies included in the evaluation of the Working Group: 55 health outcomes identified in the studies in humans (see table in Appendix 2) and 28 health outcomes identified in the animal experimental studies (see table in Appendix 3).

APPENDIX 2 – HEALTH EVENTS IDENTIFIED IN HUMAN STUDIES PUBLISHED AFTER REVIHAAP

Effect category	Health events	Severity*
All-cause mortality	All-cause mortality, life expectancy	Yes
All-cause hospitalisation	All-cause hospitalisation	Yes
Respiratory health	Mortality (all respiratory causes), hospitalisations (all respiratory causes), hospitalisations (all respiratory causes) in children, asthma (incidence, symptoms, hospitalisations) or wheezing, asthma (incidence, symptoms, hospitalisations) or wheezing in children, COPD and chronic bronchitis, rhinitis, rhinitis in children, respiratory infections and ENT, respiratory infections and ENT in children	Yes
	Allergic sensitisation in children, ventilatory function, ventilatory function in children, FeNO, FeNO in children, inflammation markers in exhaled breath condensate, inflammation markers in bronchoalveolar lavage, CC16	No
Cardiovascular health	Mortality (all cardiovascular causes), hospitalisations (all cardiovascular causes), heart attack and coronary events, stroke, (congestive) heart failure	Yes
	Blood pressure, blood pressure in children, impaired heart rate, carotid intima-media thickness, vascular function, systemic inflammation markers, coagulation markers, systemic oxidative stress markers, vascular endothelial impairment markers	No
Neurological health	Cognitive performance (memorisation, learning), cognitive performance (memorisation, learning) in children, depression, hyperactivity, autism in children	Yes
Perinatal health	Low birth weight, premature birth, pre-eclampsia, birth defects	Yes
	Skull circumference	No
Lung cancer	Lung cancer (mortality, incidence)	Yes
Other cancers	Colorectal cancer, other digestive cancers, haematological cancer, bladder cancer, breast cancer, brain cancer, indeterminate cancer, indeterminate cancer in children	Yes
Diabetes and metabolic disorders		Yes

** Health events regarded as severe correspond to the clinical events considered in the WHO-Europe pyramid of health effects associated with air pollution; subclinical (subtle) effects are regarded as non-severe (WHO Europe 2006). Abbreviations: COPD: chronic obstructive pulmonary disease; ENT: ear, nose and throat; FeNO: fraction of exhaled NO; CC16: club cell protein 16 concentration.*

APPENDIX 3 – HEALTH EVENTS IDENTIFIED IN ANIMAL EXPERIMENTAL STUDIES PUBLISHED AFTER REVIHAAP

Effect category	Health events	Severity/Predictivity*
Respiratory health	Pulmonary histology (e.g. remodelling, inflammatory infiltrates), respiratory function, pulmonary/thoracic elasticity and airway resistance, markers of impaired pulmonary antimicrobial defences, BAL cellularity (neutrophils, macrophages)	Yes
	BAL proteins (albumin; no other severe events), BAL enzymes (LDH, γ-GT, NAG; no other severe events)	No
Cardiovascular health	Atherosclerotic lesions, blood pressure, heart rate, heart function, vascular function, venous and peripheral vascular thrombosis	Yes
	Systemic inflammation markers (without other severe events), coagulation markers (without other severe events), systemic oxidative stress markers (without other severe events), haematocrit/haemoglobin (without other severe events)	No
Neurological health	Behaviour (sociability, exploration, anxiety, locomotion, etc.), cognitive performance (memorisation, learning, etc.)	Yes
	Neural inflammation markers (without other severe events), neural oxidative stress markers (without other severe events), other neural markers (growth factors and receptors) (without other severe events),	No
Perinatal health	Behavioural development (sociability, exploration, anxiety, locomotion, etc. in the offspring of exposed mothers)	Yes
	Development on other neural markers (growth factors and receptors in the offspring of exposed mothers) (without other severe events)	No
Lung cancer	Histopathology of lung cancer	Yes
Other cancers	Histopathology of cancer (other than lung)	Yes
Diabetes and metabolism disorders	Diabetes (with characteristics of human type-I diabetes)	Yes
	Lipid metabolism (without other severe events)	No

** The classification of effect severity/predictivity was defined by the Working Group by typically distinguishing between biological markers that are not very predictive of adverse health effects (e.g. modification of cytokines without severe events) and markers that are more predictive (e.g. neutrophils or AMLA macrophages) or functional. Abbreviations: BAL: bronchoalveolar lavage, LDH: lactate dehydrogenase, γ-GT: gamma-glutamyltransferase, NAG: N-acetylglucosamine.*

APPENDIX 4 – SUMMARY OF ACCUMULATED EVIDENCE AND LEVELS OF EVIDENCE FOR HEALTH EFFECTS OF EXPOSURE TO AMBIENT AIR PARTICULATE COMPONENTS FROM HUMAN STUDIES IN REVIHAAP AND SINCE REVIHAAP

Component		In REVIHAAP: Reported level of evidence	In REVIHAAP: Associations reported†	Since REVIHAAP and up to February 2016: Highest level of evidence for an adverse health effect[θ] (number of publications in the body of evidence)		Summary of the accumulated evidence: Evidence or associations reported in REVIHAAP │ Evidence for an adverse health effect since REVIHAAP
Ultrafine particles (<100 nm)		Evidence still limited	Yes	cardiovascular health	Moderate (14) (+Exp.*)	+ │ ↗
Coarse particles ($PM_{2.5-10}$)		Suggestive evidence	Yes	respiratory health, all-cause mortality	Moderate (44)	+ │ ↗
Carbonaceous materials	Black carbon, elemental carbon	Sufficient evidence	Yes	respiratory health, cardiovascular health, all-cause mortality	High (78) (+Exp.*)	+ │ ↗
	Organic carbon	Increasing information	Yes	respiratory health, cardiovascular health, all-cause hospitalisations	High (37) (+Exp.*)	+ │ ↗
	SOAs (source factor€)	Ø	Yes		Inadequate (7) (+Exp.*)	+ │ →
	PAHs	Ø	Ø	respiratory health	Low (4)	Ø │ →
Secondary inorganic aerosols	SIAs (source factor€)	Ø	Yes	respiratory health	Low (6)	+ │ →
	Sulphate	Ø	Yes	respiratory health	High (48)	+ │ ↗
	Nitrate	Ø	Yes	cardiovascular health	High (25) (+Exp.*)	+ │ ↗
	Ammonium	Ø	Ø	respiratory health, cardiovascular health, all-cause mortality	Low (14)	Ø │ →
Transition metals	Nickel	Ø	Yes§	respiratory health	High (34) (+Exp.*)	Ø │ ↑
	Zinc	Ø	Yes§	cardiovascular health	Moderate (31)	Ø │ ↑
	Copper	Ø	Yes§	cardiovascular health	Low (31)	Ø │ →
	Vanadium	Ø	Yes§	cardiovascular health	High (32)	Ø │ ↑
	Iron	Ø	Ø	cardiovascular health	High (31)	Ø │ ↑
Silica		Ø	Ø	respiratory health, all-cause mortality	Moderate (30)	Ø │ ↑
Endotoxins		Ø	Ø	cardiovascular health	Moderate (5)	Ø │ ↑
Oxidative potential		Ø	Ø	respiratory health, cardiovascular health	Low (6)	Ø │ →

In REVIHAAP:
+ : effect reported;
–: no effect reported;
Ø: not examined.

│**Since REVIHAAP**:
↑ : new evidence for an adverse health effect;
↗ : confirmation of the health effect;
→ : no new evidence for an adverse health effect (i.e. a "low" or "inadequate" level of evidence for an adverse effect);
↘ : evidence of no health effect;
Ø: no studies identified.

all-cause mortality, respiratory health, cardiovascular health, all-cause hospitalisations. θ The purpose of assessing the level of evidence for an adverse health effect is to conclude whether the observed association between a given component of ambient air particulate matter and a given health category (e.g. cardiovascular health) is highly, moderately or faintly plausible. It may also be concluded that a component has no effect on health, or that there is too little evidence available in the literature to be able to reach any conclusion. *Abbreviations: SIAs: secondary inorganic aerosols; SOAs: secondary organic aerosols; PAHs: polycyclic aromatic hydrocarbons. * The conclusions based on animal experimental studies support this evidence of effects. † Yes if association reported, no if no association reported, Ø if not reported. § The reported associations do not specifically concern this element and include other transition metals in mixtures. Defined according to a statistical method of allocating components into categories or sources (e.g. positive matrix factorisation).*

APPENDIX 5 – SUMMARY OF ACCUMULATED EVIDENCE AND LEVELS OF EVIDENCE FOR HEALTH EFFECTS OF EXPOSURE TO SOURCES OF AMBIENT AIR PARTICULATE MATTER FROM HUMAN STUDIES IN REVIHAAP AND SINCE REVIHAAP

		In REVIHAAP:		Since REVIHAAP and up to February 2016:	Accumulated evidence:	
Source category		**Reported level of evidence**	**Associations reported**†	**Highest level of evidence for an adverse health effect**θ (number of publications in the body of evidence)	**Evidence or associations reported in REVIHAAP│Evidence for an adverse health effect since REVIHAAP**	
Road traffic	Traffic-related $PM_{2.5}$	Probable association	Yes	Moderate (16) (+Exp.*)	+	↗
	Traffic-related black carbon	Sufficient evidence₸	Ø	High (4)	+	↗
	Diesel engine exhaust	Ø	Yes	Moderate (3) (+Exp.*)	+	↗
	Gasoline exhaust	Ø	Yes	Moderate (1)	+	↗
	Road dust, crustal material	Probable association	Yes	High (16)	+	↗
	Brake dust	Ø	Ø	Low (1) #	Ø	→
Combustion	Coal combustion	Solid evidence‡	Yes	High (7) (+Exp.*)	+	↗
	Combustion of petroleum products	Influence on health	Yes and no	Moderate (10)	+	↗
Industry	Industry	Ø	Yes	Low (5)	+	→
	Metallurgy	Ø	Yes	Inadequate (10) #	+	→
Biomass combustion		Probable association	Yes§	Inadequate (4) #	+	→
Desert dust		Ø	Yes	Moderate (3)	+	↗
Sea salt and sea spray		Suggestion of no effect	Yes and no	Low (9)	–	→
Hazardous waste site		Ø	No	Inadequate (1)	–	→
Rural environment and agriculture		Ø	Ø	Ø	Ø	Ø

In REVIHAAP:
+ : effect reported;
–: no effect reported;
Ø: not examined.

│**Since REVIHAAP**:
↑ : new evidence for an adverse health effect;
↗ : confirmation of the health effect;
→ : no new evidence for an adverse health effect (i.e. a "low" or "inadequate" level of evidence for an adverse effect);
↘ : evidence of no health effect;
Ø: not examined.

all-cause mortality, respiratory health, cardiovascular health, neurological health. θ The purpose of assessing the level of evidence for an adverse health effect is to conclude whether the observed association between a given source of ambient air particulate matter and a given health category (e.g. cardiovascular health) is highly, moderately or faintly plausible. It may also be concluded that a source has no effect on health, or that there is too little evidence available in the literature to be able to reach any conclusion. * *The conclusions based on animal experimental studies support this evidence of effects.* † *Yes if association reported, no if no association reported, Ø if not reported.* ₸ *This level of evidence is based on the accumulated evidence for black carbon.* ‡ *This level of evidence is based on the accumulated evidence for sulphate-enriched particles (chemical tracer of coal combustion).* § *In particular, associations between forest fires and health events.* # *Does not consider evidence for health effects that may have been observed for individual chemical components or tracers linked to this source.*

APPENDIX 6 – SUMMARY OF THE IMPACT OF THE SCENARIOS ON EMISSIONS OF PARTICULATE AND GASEOUS POLLUTANTS FROM ROAD TRAFFIC

		$PM_{2.5}$	PM_{10}	OM	PNC*	BC	NO_2	VOCs	NH_3	CO_2
Prospective scenarios compared to the baseline scenario (2014)	**DPF scenario (S1)** generalisation of the diesel particulate filter, "near steady development" until 2025	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓
	Gasoline scenario (S2) a decrease from 60% in 2014 to 5% in 2025 in sales of light-duty diesel vehicles in favour of gasoline	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓	↓
Change in average annual traffic emissions in the intra-A86 zone compared to the baseline scenario (T/year)**. ↓/↑: moderate decrease/increase: [8%; 15%]; ↓↓/↑↑: strong decrease/increase: [28%; 78%]										
Prospective scenarios compared to the DPF scenario (S1)	**Gasoline scenario (S2)** (mechanically, renewal of the fleet accentuated with the gasoline scenario (S2) compared to the DPF scenario (S1) involving a lower proportion of pre-Euro 5 vehicles in the Île-de-France fleet (8%) vs 21%)	↓	↓	↓	↓	↓	↓	↑	↑↑	=↗
	Alternative Technologies scenario urban: - change in the market to reach electric vehicle sales of 40% of passenger cars and 60% of light-duty commercial vehicles by 2025, and only 5% in diesel vehicles - Euro 3 and earlier trucks and buses, and motorised two-wheeled vehicles < 250 cm^3 all replaced by electric vehicles in 2025 outside urban areas: fleet for the DPF scenario (S1)	↓	↓	↓	↓	↓	↓	↓↓	=↘	↓
	Ambition Air scenario intra-A86 zone: - fleet for the Alternative Technologies scenario - traffic reduction (-25% passenger cars, -20% light-duty commercial vehicles and trucks) offset by +75% diesel and electric bus traffic, +50% motorised two-wheeled traffic (gasoline and electric) outside intra-A86 zone: fleet for the DPF scenario (S1)	↓	↓	↓	↓	↓	↓↓	↓	↓	↓↓
Change in average annual traffic emissions in the intra-A86 zone compared to the DPF scenario (T/year)**. =↘/=↗: equivalence or slight decrease/increase: [0%; 2%]; ↓/↑: moderate decrease/increase: [5%; 17%]; ↓↓/↑↑: strong decrease/increase: [21%; 24%]										

* PNC: particle number concentration

** The ranges presented include the variation values of all the pollutants to which they relate. In other words, these ranges do not refer to a specific pollutant.

APPENDIX 7 – SUMMARY OF THE IMPACT OF THE SCENARIOS ON CONCENTRATIONS OF PARTICULATE AND GASEOUS POLLUTANTS

		$PM_{2.5}$	Organic PM_{10}	Inorganic PM_{10}	PNC*	BC	NO_2	O_3 Urban	O_3 Non-urban
Prospective scenarios compared to the baseline scenario (2014)	**DPF scenario (S1)** generalisation of the diesel particulate filter, "near steady development" until 2025	↓	↓	↓	↓	↓↓	↓↓	↑	=↘
	Gasoline scenario (S2) a decrease from 60% in 2014 to 5% in 2025 in sales of light-duty diesel vehicles in favour of gasoline	↓	↓	↓	↓	↓↓	↓↓	↑	=↘

Change in annual average air concentration compared to the baseline scenario (µ/m³)**

- organic $PM_{2.5}$ and PM_{10}, inorganic PM_{10} and PNC: ↓ : moderate decrease: [3.3%; 6.2%] (variation in France and Île-de-France)
- BC and NO_2: ↓↓ : strong decrease: [30%; 47%] for BC and [19 µg/m³; 25 µg/m³] for NO_2 (maximum variation in Île-de-France on urban areas)
- O_3: =↘: equivalence or slight decrease: [4%]; ↑: moderate increase: [15%; 30%] (maximum variation on urban or rural areas in France and Île-de-France)

		$PM_{2.5}$	Organic PM_{10}	Inorganic PM_{10}	PNC*	BC	NO_2	O_3 Urban	O_3 Non-urban
Gasoline (S2) scenario compared to DPF (S1) scenario	**Gasoline scenario (S2)** (mechanically, renewal of the fleet accentuated with the gasoline scenario (S2) compared to the DPF scenario (S1): 8% vs 21% of pre-Euro 5 vehicles in the Île-de-France fleet)	=↘	=↘	=↘	=↘	↓	↓	=↗	=↘

Change in annual average atmospheric concentration compared to the DPF scenario (µ/m³)**

- organic $PM_{2.5}$ and PM_{10}, inorganic PM_{10} and PNC: =↘/=↗: equivalence or slight decrease: [0.4%; 1.2%] (variation in France and Île-de-France)
- BC and NO_2: ↓ : moderate decrease: [17%] for BC and [6 µg/m³] for NO_2 (maximum variation in Île-de-France on urban areas)
- O_3: =↘/=↗: equivalence or slight decrease/increase: [0.3%; 5%] (maximum variation on urban or rural areas in France and Île-de-France)

* PNC: particle number concentration

** The ranges presented include the variation values of all the pollutants to which they relate. In other words, these ranges do not refer to a specific pollutant. For $PM_{2.5,}$ organic PM_{10}, inorganic PM_{10} and PNC, there is no equivalence or slight decrease (=↘/=↗) nor any strong decrease/increase (↓↓/↑↑) for the comparison with the baseline scenario. For BC and NO_2, there is no equivalence or slight decrease (=↘/=↗) nor any moderate decrease/increase (↓/↑) for the comparison with the baseline scenario. For O_3, there is no strong (↓↓/↑↑) nor moderate (↓/↑) decrease/increase for the comparison with the DPF scenario.

APPENDIX 8 – FOLLOW-UP OF THE OPINION UPDATES

Date	**Version**	**Page**	**Description de la modification**
June 2019	01		First signed version of the ANSES opinion
July 2019	02	 12 18 26 27 27	Details given of: - the terms “black carbon" - the terms “restricted traffic zones" - the lack of data for certain sources of particulate matter - the existence of the French draft law governing mobility (“projet de loi d'orientation des mobilités”) Wording adjustment related to the communication on the work at the European level
January 2020*	03	22	Correction of an error in the English translation: - the expression “do question" has been replaced by “do not call into question"

* This correction of an error in the English translation does not require a change in the date of the Opinion, and has been made in order to be consistent with the original Opinion in French.

Investigate, evaluate, protect

State of knowledge on particulate matter in ambient air

Health effects according to components, sources and particle size

Impact on air pollution of the technologies and composition of the motor vehicle fleet operating in France

Request No 2014-SA-0156

SUMMARY REPORT AND RECOMMENDATIONS from the collective expert appraisal

Expert Committee on "Assessment of the risks related to air environments"

Working Group on "Particulate matter"

January 2019 amended report[1]

August 2019

[1] This report cancels and replaces the January 2019 report (see appendix)

Key words

Ambient air pollution, Particulate matter, Health effects, General population, Review, Black carbon, Organic carbon, Metal, Ultrafine particles, Coarse particles, Secondary aerosol, Biomass combustion, Coal combustion, Oil combustion, Desert dust, Road traffic, Emission, Concentration, Modelling, Simulation, Polyphemus, COPERT, Vehicle technology, Motorisation, Diesel, Gasoline, Particulate filter, Scenario, Prospective, Vehicle fleet, Île-de-France, France

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M. Dirk BOSTEELS – Director-General

Mrs Cécile FAVRE – Technology and Communications Manager

French Automobile Manufacturers' Association (CCFA) – 15 November 2016

M. Pierre MACAUDIERE: Master-expert clean-up systems and fuels (PSA Group)

Mrs Martine MEYER: Expert leader air quality and chemicals (Renault)

M. Nicolas LE BIGOT: Director of environmental and technical affairs (CCFA)

Chambre Syndicale Internationale de l'Automobile et du Motocycle (CSIAM) – 15 November 2016

M. Thierry ARCHAMBAULT: Deputy Chairman

M. Hassan KHAZZANI: Customer service manager (Triumph)

French Federation of vehicle equipment industries (FIEV) – 23 November 2016

M. Hugues BOUCHER: Engineer innovation and environment

France Nature Environnement association (FNE) – 1st December 2016

Mrs Anne LASSMAN-TRAPPIER

RESPIRE association – 1st December 2016

M. Sébastien VRAY

Association for the Prevention of Atmospheric Pollution (APPA) – 1st December 2016

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Comparison of six methods for assessment of the weight of evidence by the action team "weight of evidence" of the Working Group Methodology for Risk Assessment (meeting of the Working Group “Particulate matter” on 31 March 2016):

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Mrs Eve FEINBLATT – Coordination and scientific contribution for the action team "weight of evidence" of the Working Group Methodology for Risk Assessment – Department of information, communication and dialogue with civil society

Study of impact of the technologies and composition of the motor vehicle fleet operating in France on air pollution; research and development convention ANSES / Airparif / CEREA / CITEPA / IFSTTAR n°2016-CRD-04

Multi-site study of oxidative potential of atmospheric particulate matter in France, in relation with its chemistry and sources (ExPOSURE); research and development convention ANSES / CNRS (acting on behalf of the IGE laboratory, UMR 5001) n°2016-CRD-31

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Acronyms and abbreviations

Airparif: Air quality monitoring network in Île-de-France

ANSES: French Agency for Food, Environmental and Occupational Health & Safety

CEREA: The Research and Teaching Centre in Atmospheric Environment

CES: Expert Committee

CITEPA: the Interprofessional Technical Centre for Studies on Air Pollution

CO_2: carbon dioxide

COPD: chronic obstructive pulmonary disease

COPERT: COmputer Program to calculate Emissions from Road Transport

DPF: diesel particulate filter

IARC: the International Agency for Research on Cancer

IFSTTAR: the French Institute of Science and Technology for Transport, Development and Networks

LCVs: light-duty commercial vehicles

NH_3: ammonia

NMVOC: non-methane volatile organic compounds

NOx: nitrogen oxides

OHAT: the Office of Health Assessment and Translation

OM: organic matter

PAH: polycyclic aromatic hydrocarbons

PECOTS: Populations, Exposures, Comparators, Outcomes, Timings, Settings

PM: Particulate Matter

PM_{10}: Particulate Matter of less than or equal to 10 µm mass median aerodynamic diameter

$PM_{2.5}$: Particulate Matter of less than or equal to 2.5 µm mass median aerodynamic diameter

$PM_{2.5-10}$: Particulate Matter of a mass median aerodynamic diameter between 2.5 µm and 10 µm

PNC: Particle Number Concentration

REVIHAAP: Review of evidence on health aspects of air pollution

ROS: reactive oxygen species

SIA: Secondary Inorganic Aerosols

SOA: Secondary Organic Aerosols

US EPA: United States Environmental Protection Agency

VOC: volatile organic compounds

WG: working group

WHO: World Health Organization

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1 BACKGROUND AND PURPOSE OF THE REQUEST

1.1 Background

Ambient air pollution can be described as the presence in outdoor air of gases and particulate matter that have harmful effects on human health and the environment. The issue of particulate matter (PM) in ambient air is a matter of concern in several parts of France that have high levels of PM concentrations in comparison to the air quality standards and objectives designed to protect human health. This situation has led to several warnings from the European Commission since 2009 (formal notice, reasoned opinion, referral to the European Court of Justice) for non-compliance with the regulatory air quality standards set for PM_{10} in order to protect human health. Furthermore, ambient air particulate matter represents a public health issue. The impact of exposure to ambient air $PM_{2.5}$ due to human activity has been estimated at 48,000 premature deaths per year in France. This is exacerbated in urban areas with more than 100,000 inhabitants, where the results show an average loss of 15 months of life expectancy at 30 years of age due to this $PM_{2.5}$ exposure (SpFrance, 2016a). The health and non-health costs of $PM_{2.5}$ pollution have been estimated at €75 billion per year at least (Senate Committee of Inquiry, 2015)[2]. Concentrations[3] of particulate matter in ambient air have decreased over the years, but they still exceed the annual quality guidelines recommended by the World Health Organisation for $PM_{2.5}$ (WHO Europe, 2006).

The health effects of outdoor ambient air particulate matter are already well documented. Cardiovascular and respiratory effects from short- and long-term exposure to particulate pollution have been demonstrated over the past few decades. More recently, effects have been identified on other target organs such as the brain and certain functions such as reproduction. In October 2013, the International Agency for Research on Cancer (IARC) classified outdoor air pollution as a whole and the airborne particles making up this air pollution as carcinogenic to humans (Group 1) (IARC, 2016)

Uncertainty remains regarding the health effects associated with ambient particulate matter according to its composition, which has probably changed over the past 20 years. The US Environmental Protection Agency (US EPA) concluded in 2009 that "*many constituents of $PM_{2.5}$ can be linked with multiple health effects, and the evidence is not yet sufficient to allow differentiation of those constituents or sources that are more closely related*

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[2] Includes the tangible health cost "*[…] mainly measured through health expenditure reimbursed by health insurance in order to cover diseases attributable to air pollution, whether in the form of hospitalisation, primary care or the payment of daily benefits and disability pensions*", the intangible health cost "*[...] known as the social or socio-economic cost, associated with mortality and morbidity due to air pollution ([…] this cost, associated with a loss of well-being, has no direct impact on the general government finances […])*", and the non-health cost, i.e. "*[…] negative impacts in terms of reduced agricultural yields, loss of biodiversity or building degradation and erosion, as well as costs associated with controlling air pollution, such as expenditure on prevention and research activities carried out by the authorities or health agencies.*" (Senate Committee of Inquiry, 2015).

[3] Pollutant concentrations characterise the quality of the breathed air and are measured at different points in France: in cities, near emission sources (road traffic, industries) and in areas remote from these sources (urban background and rural areas).

to specific health outcomes" (US EPA, 2009). This conclusion was shared and upheld by the WHO in 2013 in its report "Review of evidence on health aspects of air pollution – REVIHAAP Project" (WHO Europe, 2013). Since 2013, several scientific studies have been published on the subject, including major epidemiological studies conducted in Europe.

Fine particulate matter comes from a multitude of sources and from transformation processes in the atmosphere. The emissions can result from natural phenomena (desert sand, sea salt, volcanic eruptions, forest fires, etc.) or human activities (industry, transport, agriculture, heating, etc.).

Road transport and heating in the residential and service sectors are important sources of organic aerosols in the atmosphere, through the combustion of fossil fuels and biomass. Besides particulate matter, road transport is also a major source of nitrogen oxides (NOx), and more specifically nitrogen dioxide (NO_2).

Primary particulate matter from road transport is mainly emitted by those diesel vehicles that are not fitted with particulate filters. The level of emissions is highly dependent on vehicle age and technology, with older vehicles making a major contribution to road traffic particulate emissions. However, too little is still known about certain emissions (non-exhaust, the cold start phase, motorized two-wheelers, etc.). Similarly, the formation of secondary aerosols from traffic emissions and their contribution to particulate pollution is relatively unclear, and is now being increasingly studied.

Road traffic is the most widely documented source of particulate air pollution, both in terms of emissions and effects. The identified health effects include cardiovascular and respiratory effects associated with short- and long-term exposure. In 2012, IARC classified exhaust emissions from diesel engines as carcinogenic to humans (Group 1) and exhaust emissions from gasoline engines as possibly carcinogenic to humans (Group 2B) (IARC, 2014). IARC also determined that there was "sufficient" evidence in experimental animals for the carcinogenicity of whole diesel engine exhaust emissions, but also for exhaust particulate matter and the organic fraction of exhaust particulate matter.

Several studies have demonstrated that populations living near roads with heavy traffic have poorer health (HEI, 2010; ORS IdF, 2012). For example, the Aphekom project conducted in 10 European cities estimated that living close to major traffic routes induced around 15-30% of new childhood asthma cases and similar or higher proportions of chronic obstructive pulmonary disease (COPD) and coronary heart disease in adults over 65 years of age (InVS, 2012).

The wish to reduce vehicle engine emissions and their impact on air quality has led to a continuous process of regulatory change, improvements in the composition of fuels and vehicle powertrains, and the development of new pollution control technologies, in the last 20 years or more in France and Europe. However, the actual and comparative effectiveness of these different technologies remains difficult to establish because it can vary according to numerous aspects (traffic conditions, vehicle use, local topographical and climate conditions, etc.). **This context raises questions about the potential environmental and health impact of future technological choices for the French road vehicle fleet.**

1.2 Purpose of the request

In a letter of 30 June 2014, the French Ministries of Health and the Environment formally asked ANSES to respond to the following requests:

1.2.1 Request concerning the health effects of ambient air particulate matter

Are there any conclusive data on toxicity differences according to particle composition and/or sources?

If so, what conclusions can be drawn about the toxicity of particulate matter according to composition and/or sources?

1.2.2 Request concerning road traffic emissions

Regarding the "road traffic" source, conduct an expert appraisal to:

1. analyse the retrospective and prospective evolution of the particulate emissions from the French vehicle fleet on the road and in actual traffic conditions, according to different scenarios;
2. identify the differentiated impacts of pollution-control technologies on particulate emissions from the "road traffic" source.

This information could be compared to the emission data available concerning other sources of particulate matter.

This report is a summary of the work by the working group (WG) on "Particulate matter" that has been detailed in two related foundation reports responding respectively to the two above-mentioned requests:

- ANSES (2019a) Health effects of ambient particulate matter according to components, sources and particle size. Collective expert appraisal report of the French Agency for Food, Environmental and Occupational Health & Safety [in French]: https://www.anses.fr/fr/system/files/AIR2014SA0156Ra-Sante.pdf
- ANSES (2019b) Impact on air pollution of the technologies and composition of the motor vehicle fleet operating in France. Collective expert appraisal report of the French Agency for Food, Environmental and Occupational Health & Safety [in French]: https://www.anses.fr/fr/system/files/AIR2014SA0156Ra-Emission.pdf

2 HEALTH EFFECTS OF AMBIENT AIR PARTICULATE MATTER – METHOD AND SUMMARY OF THE WG's WORK

2.1 METHOD

A procedure for assessing the weight of evidence in the literature was developed and implemented in order to respond to the question, so as to obtain a level of evidence for an adverse health effect of several components and sources of ambient air particulate matter. This level of evidence for an adverse health effect reflects the confidence placed in an association (or lack thereof) between an exposure of interest and a health outcome of interest based on a set of publications known as a body of evidence. To conduct this assessment, the WG adapted the method previously proposed by the Office of Health Assessment and Translation as part of the National Toxicology Program (OHAT NTP, 2015). The assessment process consisted of seven steps (Figure 1).

Step 1: Formulation of the scope of the problem

The question to be investigated was formulated by the WG on "Particulate Matter" as follows:

- What are the human health effects of ambient air particulate matter according to its components, sources and particle size?

After an initial literature search, and due to the amount of literature available, the WG experts selected the WHO Europe's REVIHAAP consensus review, published in 2013, as the starting point for structuring its work. Thus, only epidemiological studies (in humans) and experimental studies (in animals) published after REVIHAAP were included in the assessment of the weight of evidence. The eligibility criteria for these publications were defined with regard to the PECOTS method determining the scope of the assessment in terms of Populations, Exposures, Comparators, Outcomes (health events), Timings (exposure durations) and Settings (locations of interest). The target population was the general population, including sub-populations that are more vulnerable and sensitive to air pollution. Targeted exposures were concentrations of particulate matter in ambient air, categorised by components, particle size and sources. These categories were first defined in accordance with those documented in the REVIHAAP review; some categories were subsequently added based on new data available in the epidemiological and toxicological studies selected. Publications that considered PM_{10} and $PM_{2.5}$ without chemical speciation or source apportionment were not included. The targeted comparators were no exposure or lower exposure levels. The targeted outcomes were adverse health events (clinical and subclinical), grouped into ten broad health categories: respiratory health, cardiovascular health, all-cause mortality, all-cause hospitalisations, neurological health, perinatal health, reproductive health, lung cancer, other cancers, and diabetes (including metabolic disorders). The timings of exposure were short-term (one to several days in humans) and long-term (one to several years in humans). The setting of interest was France, but studies were included regardless of their geographical location.

Step 2: Study search and selection

A literature search with the PubMed and Scopus search engines, as well as among the literature known by WG experts, identified 4,677 references published after REVIHAAP and up to February 2016. After an initial screening (titles and abstracts, double reading by the WG coordinators), 244 references were selected as being eligible. After assessing the full text (double reading by WG members), 160 publications were finally selected: 127 studies in humans (observational, clinical, or semi-experimental) and 33 animal experimental studies (single, (sub)acute, or (sub)chronic exposure).

Step 3: Extraction of descriptive data from the studies

All the publications were read by one or two WG members (two members for the epidemiological part, one member for the toxicological part) in order to collect descriptive qualitative data. These individual descriptions followed the grid format suggested by OHAT and summarised information related to subjects (human, animal), methods used (follow-up time, study design, health outcomes and categories, exposure measurement or estimation, etc.) and results.

Step 4: Quality assessment of the individual studies

The risk of bias was assessed in each of the 161 studies using an adapted version of the rating tool proposed by OHAT that applies to both human and animal experimental studies. The tool that was developed includes 15 questions related to potential sources of bias, divided into several broad categories (selection, attrition, interpretation, confounding, detection and others). The four response options represent a gradient of the plausibility of the risk of bias: ++ if the risk is low, + if the risk is probably low, – if the risk is probably high, – – if the risk is high. A fifth option (NR: not reported) applies when the risk cannot be determined from the publication data and is deemed comparable to a probably high risk of bias. The last option (NA: not applicable) applies when the question is not applicable to the study design. The risk of bias in each study was independently assessed and then discussed by two WG members to obtain a final rating. Any discrepancies were discussed, in some cases by all WG members, in order to reach a consensus. As recommended by OHAT, several questions were considered as key elements that could have a major impact on the overall quality of the study. The four key elements for human studies focused on confounding variables, adjustment for other exposures (e.g. multi-pollutant model taking the total mass of $PM_{2.5}$ into account), exposure characterisation, and outcome assessment. For animal experimental studies, the two key elements were exposure characterisation and outcome assessment.

Lastly, an initial confidence level was derived for each study by adding the answers to four questions (1 if yes, 0 if no) reflecting important features of study design: Was the exposure controlled? Did the exposure occur prior to the health outcome? Were the health outcome data individual? Was a comparison group used?

Step 5: Rating of the confidence level for the bodies of evidence

The publications were grouped into corpora of studies (also called bodies of evidence) within a set of lines of evidence, according to the components/sources, exposure timings, health categories and health outcomes examined in each one. A line of evidence therefore brought together integrated information of the same type. A total of 724 lines of evidence were obtained from the 127 human study publications, and 314 lines of evidence were obtained from the 33 animal experimental study publications. The final confidence level of the bodies of evidence in each of the lines was assessed on the basis of 10 factors proposed by OHAT: five of them increased confidence in the results and five others decreased confidence in the results. The final confidence level corresponded to the initial confidence level (from 1 to 4) minus the factors decreasing confidence (from 0 to 5) and plus the factors increasing confidence (from 0 to 5). The names of the factors and the calculation principle are given in Figure 1, Step 5. Each line of evidence was independently assessed by one WG member and then discussed with the entire group. Final decisions (to increase or decrease the level of confidence) were taken after reaching a consensus.

Lastly, in each line of evidence, on the basis of the results provided by the body of evidence, a decision was taken by the WG on the direction of the effect of the component/source of interest on a health outcome of interest (i.e. the presence or absence of an adverse health effect) for a given timing of exposure.

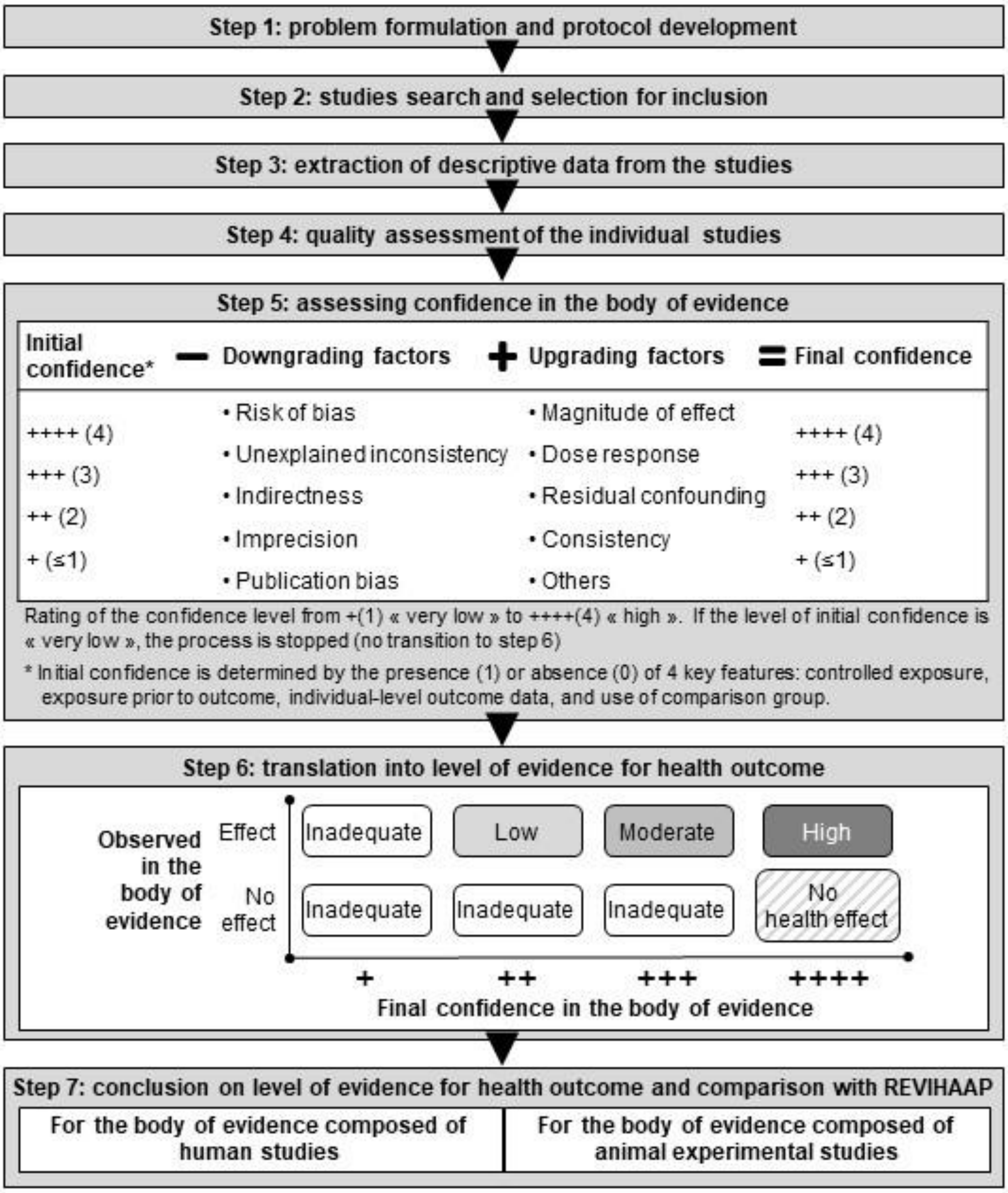


Figure 1: Process of the OHAT approach adapted by the Working Group

Step 6: Translation into a level of evidence for a health effect

The final confidence level of the body of evidence and the direction of the health effect were then merged to obtain a level of evidence for an adverse effect of a component/source of interest on a health outcome, for a given timing of exposure, according to the principle presented in Figure 1, Step 6. For example, a "high" level of evidence for an adverse effect reflects "high" confidence in the body of evidence (i.e. final confidence level at 4) regarding the effect of exposure on the health outcome; an "inadequate" level of evidence for an effect reflects "very low" confidence in the body of evidence with respect to an effect of the exposure on the health outcome OR "very low, low, moderate" confidence in the body of evidence that does not support the effect of the exposure on the health outcome.

The levels of evidence defined for each component/source, each timing of exposure (e.g. short-term) and each health outcome (e.g. cardiovascular mortality, cardiovascular hospitalisations, blood pressure, etc.) were merged into an overall level of evidence for an adverse effect on the corresponding health category (e.g. cardiovascular health). The same wording was considered: "high", "moderate", "low", "inadequate", and "no health effect". For human studies, the WG developed a decision tree to standardise as far as possible this merging process for the definition of the level of evidence for an effect for each component/source, each timing of exposure, and each health category. This decision tree included the levels of evidence for all health outcomes of the category (previously obtained), the relevance of these outcomes (clinical or subclinical), the number of publications in the bodies of evidence and the possible risks of bias or indirectness identified in the lines of evidence in Step 5. For animal experimental studies, an identical decision tree was used without distinguishing between (sub)acute and (sub)chronic exposure timings. When the body of evidence included only single exposure studies (mechanistic studies), the level of evidence for this health category was systematically rated as "inadequate".

Step 7: Conclusion on the level of evidence for a health effect

The evidence for health effects obtained from studies published after REVIHAAP (in 2013) and up to February 2016 (examined by this process for assessing the weight of evidence) was summarised to enable a comparison with the knowledge base provided by the WHO's REVIHAAP review. These two contributions were compared and contrasted in order to reach a conclusion about the weight of all the evidence for health effects from human and animal studies, and to highlight trends such as the confirmation of previously reported health effects or the identification of new evidence.

2.2 SUMMARY OF THE WG's WORK

The results presented here are a summarised version of the results obtained by the WG for all components and sources. The levels of evidence for a health effect obtained by component or source, timing of exposure, and specific health outcomes are not detailed here, nor is the process of establishing the level of evidence for an effect by health category. In the interest of brevity, conclusions on "inadequate" levels of evidence are not reported here. Similarly, health categories for which no publications were identified are not mentioned. Full details are available in the foundation report (ANSES, 2019a).

For the sake of clarity, these present results follow a predefined writing framework. First, a summary is presented of the levels of evidence or associations reported in REVIHAAP in 2013. Then, the levels of evidence obtained from human studies published after REVIHAAP and up to February 2016 are described and compared with the conclusions of REVIHAAP. Lastly, the same approach is applied for experimental animal studies published after REVIHAAP and up to February 2016. Summary tables incorporating main results are available (Table 1 and Table 2 for components and sources, respectively).

2.2.1 Health effects according to particle composition

1. CARBONACEOUS MATERIALS

1.1. Black carbon, elemental carbon

REVIHAAP concluded there was sufficient evidence for an association between black carbon in ambient particulate matter and cardiovascular health and premature mortality for both short- and long-term exposures. In humans, REVIHAAP concluded there was sufficient evidence of an association between short-term exposure and cardiopulmonary hospital admissions and between long-term exposure and cardiopulmonary mortality. Regarding toxicological studies, REVIHAAP reported an association between 24-hour exposure to ultrafine carbon particles and changes in heart rate and blood pressure.

The **human studies published after REVIHAAP** up to February 2016 **confirm REVIHAAP's conclusions** regarding the health effects (respiratory and cardiovascular) of black carbon, with a "high" level of evidence for short-term exposure and a "moderate" level of evidence for long-term exposure. The data also confirm REVIHAAP's conclusions regarding effects on premature mortality, with "moderate" and "high" levels of evidence for short- and long-term exposure, respectively. The data **provide new information** on the health effects of black carbon or elemental carbon on outcomes not mentioned in REVIHAAP, with a "high" level of evidence for an effect on all-cause hospitalisations, a "low" level of evidence for an effect on neurological health (impaired cognitive performance in children) and a "low" level of evidence for an effect on perinatal health (low birth weight).

The **toxicological studies published after REVIHAAP** up to February 2016 **confirm REVIHAAP's conclusions**, with a "moderate" level of evidence for an adverse effect of black carbon exposure on cardiovascular health (atherosclerotic lesions, heart rate, blood pressure). These data **also provide new information**, with a "moderate" level of evidence for an effect on respiratory health (lung inflammation).

1.2. Organic carbon

REVIHAAP concluded there was increasing information on the association between organic carbon in ambient air particulate matter and health (respiratory and cardiovascular). REVIHAAP noted it was difficult to distinguish the specific effects of the components of organic carbon (a complex mixture of primary and secondary organic aerosols), each of which can have major health effects. In humans, REVIHAAP reported associations between short- and long-term exposure to organic carbon in ambient air particulate matter and health (respiratory and cardiovascular).

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations** reported in REVIHAAP, with "high" levels of evidence for an adverse effect on respiratory and cardiovascular health of short-term exposure to organic carbon, as well as "moderate" levels of evidence for an adverse effect on respiratory and cardiovascular health of long-term exposure. These data **also provide new information compared to REVIHAAP** on the short-term effects of organic carbon exposure on all-cause hospitalisations ("high" level of evidence for an effect) and all-cause mortality ("moderate" level of evidence for an effect).

The **toxicological studies published after REVIHAAP** up to February 2016 provide **new information**, with a "moderate" level of evidence for an effect on cardiovascular health (systemic oxidative stress and heart rate variability) and a "low" level of evidence for an effect on respiratory health (decreased bronchoalveolar alkaline phosphatase).

1.3. Secondary organic aerosols

REVIHAAP concluded there was insufficient evidence to distinguish the toxicity of primary from secondary organic aerosols. In humans, REVIHAAP reported associations between short-term exposure to secondary organic aerosols and health (respiratory and cardiovascular).

The **human studies published after REVIHAAP** up to February 2016 provide "inadequate" levels of evidence for a health effect of secondary organic aerosols as defined by a statistical method for source apportionment, and thus do not provide new information compared to REVIHAAP.

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "moderate" level of evidence for an effect on respiratory health (inflammation and impaired respiratory function).

1.4. Polycyclic aromatic hydrocarbons (PAHs)

REVIHAAP did not examine the short- or long-term health effects of polycyclic aromatic hydrocarbons (PAHs) in ambient air particulate matter.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "low" level of evidence for an adverse effect on respiratory health of short-term exposure to PAHs from ambient particulate matter.

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "low" level of evidence for cardiovascular health effects (heart rate, atherosclerosis and increased haemoglobin levels).

2. ULTRAFINE PARTICLES

REVIHAAP concluded there was still limited evidence of health effects from exposure to ultrafine particles (in general, <0.1 µm in diameter), although the potential for such effects was considered to be large. In humans, REVIHAAP reported associations between short-term exposure to ultrafine particles and cardiovascular health and all-cause mortality, but limited associations with respiratory health. Regarding toxicological studies, REVIHAAP reported an association between acute exposure of rats to ultrafine particles and cardiovascular health (changes in heart rate and blood pressure).

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP**, with a "moderate" level of evidence for an adverse effect on cardiovascular health of short-term exposure to ultrafine particles. These data **also provide new information**, with a "low" level of evidence for an adverse effect on respiratory health over the short term, a "low" level of evidence for an adverse effect on cardiovascular health over the long term, and a "low" level of evidence for an adverse effect on neurological health over the long term (cognitive performance in children).

The **toxicological studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP**, with a "moderate" level of evidence for an adverse effect on cardiovascular health (heart rate, atherosclerosis). These data **also provide new information**, with a "moderate" level of evidence for an adverse effect on respiratory health (lung inflammation).

3. COARSE PARTICLES ($PM_{2.5-10}$)

REVIHAAP concluded there was suggestive evidence of a health effect from short-term exposure to coarse particles ($PM_{2.5-10}$), but insufficient evidence to conclude on a long-term health effect. In humans, REVIHAAP reported associations between short-term exposure to coarse particles and health (respiratory, cardiovascular, and all-cause mortality), as well as a suggested association between long-term exposure and ischemic stroke. Regarding toxicological studies, REVIHAAP reported the absence of an association between short-term exposure to coarse particles and lung inflammation and cytotoxicity.

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP** on the short-term health effects of coarse particles, with a "moderate" level of evidence of an adverse effect on respiratory health and a "low" level of evidence for cardiovascular health. These data **also provide new information** on the long-term health effects of coarse particles, with a "low" level of evidence of an adverse effect on respiratory health (in children) and a "moderate" level of evidence for an effect on premature mortality.

The **toxicological studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of coarse particles, and thus do not provide new information compared to REVIHAAP.

4. SECONDARY INORGANIC AEROSOLS

Regarding secondary inorganic aerosols in ambient particulate matter, REVIHAAP concluded the toxicological data provided little evidence of a harmful effect at current ambient concentrations (including ammonium, sulphate, and nitrate). However, REVIHAAP mentioned several epidemiological studies reporting associations between human health outcomes – mainly related to cardiovascular health – and sulphate and nitrate ambient levels. REVIHAAP did not rule out the possibility that these secondary inorganic compounds may influence the bioavailability of other components such as transition metals. Nor did it rule out the possibility that the cations associated with sulphates and nitrates (e.g. transition metals, acidity marked by hydrogen cations) or absorbed components (such as organic particles) may be the underlying cause of the strong associations observed between sulphate and health.

4.1. "Secondary inorganic aerosols" as a source factor

In humans, REVIHAAP reported associations between short-term exposure to "secondary sulphate" and "secondary nitrate" factors (as defined by a factor analysis) and mortality. Regarding the toxicological studies, REVIHAAP did not report any association.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** regarding the adverse effects of short-term exposure to secondary inorganic aerosols (as a factor) on respiratory health in children, with a "low" level of evidence.

No toxicological studies published after REVIHAAP up to February 2016 were identified regarding the health effects of secondary inorganic aerosols (as a factor).

4.2. Sulphates

In humans, REVIHAAP reported associations between short-term exposure to sulphate in ambient air particulate matter, as well as to secondary sulphate, and health (respiratory and cardiovascular). The review reported associations between long-term sulphate exposure and mortality. Regarding toxicological studies, REVIHAAP did not report any association.

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP** regarding the effects of sulphate in ambient air, with a "low" level of evidence for an adverse effect on respiratory health over the short term, a "moderate" level of evidence for an adverse effect on cardiovascular health over the short term and a "moderate" level of evidence for an adverse effect on all-cause mortality over the long term. The data **also provide new information compared to REVIHAAP** on the adverse health effects of long-term exposure to sulphate in ambient air particulate matter, with a "low" level of evidence for respiratory health in children, a "moderate" level of evidence for cardiovascular health, a "moderate" level of evidence for perinatal health (low birth weight) and a "low" level of evidence for an effect on lung cancers.

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the adverse effects of sulphate on cardiovascular health, with a "low" level of evidence (systemic oxidative stress and development of atherosclerotic lesions).

4.3. Nitrates and nitrogen derivatives

In humans, REVIHAAP reported associations between short-term exposure to nitrate and cardiorespiratory hospital admissions but no association for respiratory mortality. The review reported an association between long-term exposure to nitrate and all-cause mortality. Regarding toxicological studies, REVIHAAP did not report any association.

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP** regarding the short- and long-term health effects of nitrate in ambient particulate matter, with a "low" level of evidence for respiratory health, a "high" level of evidence for cardiovascular health and a "moderate" level of evidence for an effect on all-cause mortality. These data **also provide new information compared to REVIHAAP** on the effects of nitrate on all-cause hospitalisations ("moderate" level of evidence over the short term) and perinatal health ("moderate" level of evidence over the long term).

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information**, with a "low" level of evidence for the adverse effect of particulate nitrate in ambient air on cardiovascular health (complete blood count and development of atherosclerotic lesions).

4.4. Ammonium

In humans, REVIHAAP reported an association between short-term exposure to a mixture of nitrate and ammonium and cardiovascular health. Regarding toxicological studies, REVIHAAP did not report any association.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the health effects of particulate ammonium in ambient air, with "low" levels of evidence for an adverse effect on respiratory health over the short term, on cardiovascular health over the short term, and on all-cause mortality over the short and long term.

The **toxicological studies published after REVIHAAP** up to February 2016 provide an "inadequate" level of evidence for the health effects of ammonium, and thus do not provide new information compared to REVIHAAP.

5. TRANSITION METALS AND OTHER CHEMICAL ELEMENTS

In general, REVIHAAP noted it was not possible to make a comparison of the relative harmfulness of different metals because most studies included only certain metals (mainly zinc and nickel), often in mixtures, and the available results were very heterogeneous and inconclusive.

5.1. Nickel

REVIHAAP reported associations between nickel in ambient air particulate matter and cardiovascular health in both human and animal studies.

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP** regarding the adverse effects of short-term exposure to nickel in ambient particulate matter on cardiovascular health ("moderate" level of evidence). These data **also provide new information compared to REVIHAAP** with a "high" level of evidence for an adverse effect on respiratory health over the short term and a "low" level of evidence for an adverse effect on perinatal health over the long term.

The **toxicological studies published after REVIHAAP** up to February 2016 **confirm the association reported in REVIHAAP** with a "moderate" level of evidence for the effect of nickel on cardiovascular health (modification of vascular function related to aortic contraction).

5.2. Zinc

In humans, REVIHAAP reported an association between short-term exposure to a mixture of particles rich in zinc, copper and vanadium, and cardiovascular health. In the toxicological studies, REVIHAAP reported an association between exposure to dust rich in water-soluble zinc and copper and cardiovascular health (cardiac oxidative stress in rats).

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the respiratory health effects ("low" levels of evidence over both the short and long term) and cardiovascular health effects ("moderate" level of evidence over the short term) of zinc.

The **toxicological studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of zinc, and thus do not provide any new information compared to REVIHAAP.

5.3. Copper

In humans, REVIHAAP reported an association between short-term exposure to a mixture of particles rich in copper, zinc and vanadium, and cardiovascular health. Regarding the toxicological studies, REVIHAAP reported an association between intratracheal exposure to zinc-rich tyre dust and water-soluble copper-rich tyre dust and cardiovascular health (cardiac oxidative stress in rats).

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** with a "low" level of evidence for impaired cardiovascular health for long-term exposure to particulate copper in ambient air.

The **toxicological studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of copper, with no new information compared to REVIHAAP.

5.4. Vanadium

In humans, REVIHAAP reported an association between short-term exposure to a mixture of particles rich in vanadium, zinc and copper, and cardiovascular health. An association between vanadium alone (used as an indicator of emissions from the combustion of petroleum products) and cardiovascular health was reported. Regarding the toxicological studies, REVIHAAP did not report any association.

The **human studies published after REVIHAAP** up to February 2016 **confirm some of the associations reported in REVIHAAP** with regard to the cardiovascular health effects of particulate vanadium in ambient air, with a "high" level of evidence over the short term and a "low" level of evidence over the long term. These data **also provide new information compared to REVIHAAP** on the respiratory health effects of vanadium, with a "moderate" level of evidence over the short term and a "low" level of evidence over the long term (in children).

The **toxicological studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of vanadium, and thus do not provide any new information compared to REVIHAAP.

5.5. Iron

REVIHAAP did not mention the potential health effects of iron in ambient particulate matter.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the effects of particulate iron in ambient air on cardiovascular health ("high" level of evidence for an effect over the short term and "moderate" level of evidence for an effect over the long term) and all-cause mortality ("moderate" level of evidence for an effect over the short term).

The **toxicological studies published after REVIHAAP** up to February 2016 provide an "inadequate" level of evidence for the health effects of iron, and thus do not provide any new information compared to REVIHAAP.

5.6. Other elements

REVIHAAP did not mention any possible health effects of other elements contained in ambient air particulate matter, either in human studies or animal experiments.

No process for assessing the weight of evidence, based on studies published since REVIHAAP, was implemented for these other components (metallic, inorganic, or mineral)[4]. However, the number of publications showing statistically significant associations according to health categories and health outcomes has been reported for information purposes.

In human studies published since REVIHAAP up to February 2016, the elements for which the greatest number of studies shows significant associations were calcium, potassium, manganese and lead (for respiratory health); cadmium, manganese, potassium, calcium, arsenic and lead (for cardiovascular health); and potassium, manganese and titanium (for all-cause mortality).

The toxicological studies published since REVIHAAP up to February 2016 did not report any association between (sub-)acute or (sub-)chronic exposure to other elements contained in ambient particulate matter and health outcomes.

6. SILICA

REVIHAAP did not mention the potential health effects of silica in ambient air particulate matter, either in human studies or animal experiments.

[4] Given the large number of documented chemical elements in the literature, including metals, and in order to rationalise the review method, only elements for which associations with health were often observed in epidemiological studies have been included in the present assessment of the weight of the evidence (Eeftens et al. 2014).

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on respiratory health effects of silica exposure over the short and long term ("moderate" and “low” levels of evidence, respectively), on cardiovascular health effects over the short term ("low" level of evidence), and on all-cause mortality over the short and long term ("moderate" and “low” levels of evidence, respectively).

The **toxicological studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for the health effects of silica in ambient air particulate matter, and thus do not provide any new information compared to REVIHAAP.

7. ENDOTOXINS

REVIHAAP did not mention the potential health effects of endotoxins in ambient particulate matter.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the cardiovascular health effects of endotoxins in ambient particulate matter, with a "moderate" level of evidence for short-term exposure and a "low" level of evidence for long-term exposure.

The **toxicological studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of endotoxins in ambient particulate matter, and thus do not provide any new information compared to REVIHAAP.

8. OXIDATIVE POTENTIAL

REVIHAAP mentioned the role of oxidative stress in the mechanism of action of ambient particulate matter on health but did not report any associations between oxidative potential and health outcomes, either in human studies or animal experiments.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the effects of exposure to ambient particulate matter with a high oxidative potential on respiratory health ("low" levels of evidence for short- and long-term exposures) and cardiovascular health ("low" level of evidence for short-term exposures).

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "low" level of evidence for the effect of oxidative stress of ambient particulate matter on respiratory and cardiovascular health.

2.2.2 Health effects according to particle source

1. ROAD TRAFFIC

In general, REVIHAAP warned of the great heterogeneity of the "road traffic" source, which includes both combustion particles and dust (from road, brake and tyre wear). These simultaneous emissions, combined with the generation of gaseous pollutants and noise, make it difficult to estimate specific health effects. REVIHAAP concluded that most of the accumulated evidence focused on the harmful health effects of carbonaceous materials (including some of the compounds mentioned above) from road traffic.

1.1. Road traffic-related $PM_{2.5}$

REVIHAAP concluded that fine particles related to combustion sources, including road traffic, were probably associated with cardiovascular health. In humans, REVIHAAP reported associations between exposure to $PM_{2.5}$ from road traffic and respiratory and cardiovascular health, all-cause mortality, and perinatal health. Regarding the toxicological studies, REVIHAAP did not report a specific association.

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP** regarding the effects of exposure to $PM_{2.5}$ from road traffic, defined by a source-apportionment method, with a "low" level of evidence for short-term respiratory health effects, a "moderate" level of evidence for short-term cardiovascular health effects, and a "moderate" level of evidence for perinatal health effects. The data **also provide new information compared to REVIHAAP** on the health effects of long-term exposure to $PM_{2.5}$ from road traffic with a "low" level of evidence for adverse effects on cardiovascular health and a "moderate" level of evidence for neurological health (cognitive performance).

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "moderate" level of evidence for the effects of $PM_{2.5}$ from road traffic on respiratory health (respiratory function and lung inflammation) and a "low" level of evidence for cardiovascular health effects (vascular function not associated with systemic inflammation or oxidative stress).

1.2. Road traffic-related black carbon

REVIHAAP did not mention any specific association between traffic-related black carbon and health, either from human studies or animal experiments. However, REVIHAAP concluded that black carbon from diesel vehicle exhaust is harmful because of the evidence accumulated on the harmful health effects of black carbon.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the effects of short-term exposure to black carbon from road traffic, defined by a source-apportionment method, with a "high" level of evidence for respiratory health effects, a "high" level of evidence for cardiovascular health effects, and a "high" level of evidence for an adverse effect on all-cause mortality. These data **also provide new information compared to REVIHAAP** on the adverse effects of long-term exposure to black carbon from road traffic, with a "moderate" level of evidence for respiratory health effects, a "low" level of evidence for cardiovascular health effects and a "moderate" level of evidence for an adverse effect on all-cause mortality.

The **toxicological studies published after REVIHAAP and** up to February 2016 provide only an "inadequate" level of evidence for health effects (respiratory and cardiovascular) for this source category, and thus do not provide any new information compared to REVIHAAP.

1.3. Diesel engine exhaust particles (including new technologies)

In humans, REVIHAAP reported associations between short-term exposure to diesel emissions and health (respiratory and cardiovascular). REVIHAAP mentioned an association between gestational exposure and low birth weight. Regarding toxicological studies, REVIHAAP reported an association between sub-chronic exposure to particles from diluted diesel engine exhaust and the development of atherosclerotic plaques. REVIHAAP did not mention any association between the exhaust of new diesel engines and health, either from human studies or animal experiments.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the health effects of short-term exposure to diesel exhaust particles, defined by a source-apportionment method, with a "moderate" level of evidence for respiratory health effects (in children).

The **toxicological studies published after REVIHAAP** up to February 2016 **confirm the effects of** diesel exhaust particles on cardiovascular health reported by **REVIHAAP**, with a "moderate" level of evidence (atherosclerosis, coagulation). The data **also provide new information compared to REVIHAAP**, with a "moderate" level of evidence for the effects of diesel exhaust particles on respiratory health (lung inflammation, lung remodelling).

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the long-term effects of exhaust emissions from new diesel engines, with a "low" level of evidence for an adverse effect on respiratory health (impaired respiratory function).

1.4. Gasoline engine exhaust particles

In humans, REVIHAAP reported an association between gestational exposure to particles from gasoline combustion and low birth weight. In the same study population, associations were also reported with diesel combustion particles and geological particles.

The **human studies published since REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP** on the health effects of gasoline engine exhaust particles, with a "moderate" level of evidence for respiratory health effects (in children) for short-term exposure.

The **toxicological studies published since REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "low" level of evidence for the adverse effect of gasoline engine exhaust on cardiovascular health (complete blood count) and a "low" level of evidence for an adverse effect on respiratory health (pulmonary antimicrobial defences).

1.5. Road dust (including crustal material)

REVIHAAP concluded particles related to crustal sources (including road traffic) were probably associated with cardiovascular health. In humans, REVIHAAP reported associations between short-term exposure to road dust and health (respiratory and cardiovascular, and mortality). REVIHAAP reported associations between gestational exposure and perinatal health. Regarding toxicological studies, REVIHAAP reported an association between short-term exposure to road dust and respiratory health effects, but not with cardiovascular health.

The **human studies published after REVIHAAP** up to February 2016 **confirm REVIHAAP's conclusions** regarding the adverse effects of short-term exposure to road dust, with a "moderate" level of evidence for respiratory health effects, a "low" level of evidence for cardiovascular health effects, and a "high" level of evidence for an effect on all-cause mortality. The data **also provide new information compared to REVIHAAP** on the adverse effects of long-term exposure to road dust on respiratory health, with a "moderate" level of evidence.

The **toxicological studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of this source category, and thus do not provide any new information compared to REVIHAAP.

1.6. Brake dust

REVIHAAP did not specifically mention the association between brake dust exposure and health.

The **human studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "low" level of evidence for perinatal health effects of long-term exposure to particles resulting from brake wear, defined by a source-apportionment method.

No toxicological studies published after REVIHAAP up to February 2016 examining the relationship between this source category and health were identified.

2. COMBUSTION OF COAL AND PETROLEUM PRODUCTS

NB: Sulphate is considered a reliable indicator of hazardous compounds in ambient air particulate matter from coal combustion. Nickel and vanadium are tracers of heavy fuel oil combustion, and are often associated with secondary sulphate. These compounds were considered individually in the present assessment of the weight of evidence.

2.1. Coal combustion

REVIHAAP concluded there was evidence of the adverse health effects of sulphate-rich particles, emitted from coal combustion. In humans, REVIHAAP reported associations between exposure to particles from coal combustion and to selenium (indicator of coal combustion) and health. Regarding toxicological studies, REVIHAAP reported an association between inhalation of particles from simulated coal combustion emission and allergic response.

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP** regarding the health effects of short- and long-term exposure to particles from coal combustion. The data provide a "low" level of evidence for cardiovascular health effects of short-term exposure, a "moderate" level of evidence for cardiovascular health effects of long-term exposure, a "low" level of evidence for an effect on all-cause mortality of short-term exposure, and a "high" level of evidence for an adverse effect on all-cause mortality of long-term exposure. The data **also provide new information compared to REVIHAAP** on adverse effects of long-term exposure on respiratory health ("low" level of evidence) and on mortality from lung cancers ("moderate" level of evidence).

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "**moderate**" level of evidence for the effect of particles from coal combustion on **respiratory health** (lung inflammation).

2.2. Combustion of petroleum products

REVIHAAP mentioned the impact of the combustion of petroleum products on health through specific sources such as energy production and maritime transport. In humans, REVIHAAP noted that studies dealing with the combustion of petroleum products reported conflicting results, but nevertheless mentioned an association between short-term exposure to particles from fuel oil combustion and health (cardiovascular and all-cause mortality).

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP,** with a "low" level of evidence for an adverse effect on cardiovascular health of short-term exposure to particles from combustion of petroleum products, defined by a source-apportionment method. The data **also provide new information compared to REVIHAAP** on the health effects of long-term exposure, with a "low" level of evidence for an adverse effect on all-cause mortality and a "moderate" level of evidence for neurological health effects (children's cognitive performance).

No toxicological studies examining the relationship between this source category and health outcomes were identified among the corpus of studies published after REVIHAAP up to February 2016.

3. INDUSTRIES, METALLURGY

In general, REVIHAAP drew attention to the complexity of the source category "industry", which can refer to a very heterogeneous group of emission sources differing between publications.

3.1. Industry

In humans, REVIHAAP reported associations between particles from an "industrial" source and children's respiratory health; the review stated that no conclusions could yet be drawn about the long-term effects. Regarding toxicological studies, REVIHAAP reported an association between intranasal exposure to particles from "industrial combustion or incinerators" and respiratory allergies.

The **human studies published after REVIHAAP** up to February 2016 **confirm the associations reported in REVIHAAP**, with a "low" level of evidence for an adverse effect on respiratory health of short-term exposure to industrial particulate matter. The data **also provide new information compared to REVIHAAP** on the short-term cardiovascular health effects of industrial particulate matter ("low" level of evidence).

No toxicological studies published after REVIHAAP up to February 2016 examining the relationship between this source category and health were identified.

3.2. Metallurgy

In humans, REVIHAAP reported associations between short-term exposure to particles from a "metallurgy" source and health (respiratory, cardiovascular, and mortality). REVIHAAP also reported an association between residential proximity to a smelter (long-term exposure to nickel and copper) and cardiovascular mortality. Regarding toxicological studies, REVIHAAP reported that no information had been identified to support the importance of particles from industrial sources other than those from combustion processes.

The **human studies published after REVIHAAP** up to February 2016 provide an "inadequate" level of evidence for health effects of exposure to particulate matter from this source category, and thus do not provide any new information compared to REVIHAAP.

No toxicological studies examining the relationship between this source category and health outcomes were identified among the corpus of studies published after REVIHAAP up to February 2016.

4. BIOMASS COMBUSTION

NB: Potassium is often considered a reliable marker for biomass combustion. Potassium was examined in the present work but was not specifically included in the process of assessing the weight of the evidence.

REVIHAAP concluded exposure to particulate matter from biomass combustion, including residential wood combustion, was likely to have respiratory and cardiovascular health effects. In humans, REVIHAAP reported associations between short- and long-term exposure to particles from biomass combustion and health (respiratory, cardiovascular, and perinatal). Regarding toxicological studies, REVIHAAP reported a higher toxicity of particles collected during forest fires compared to particles collected without forest fires.

The **human studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of exposure to this source category, and thus do not provide any new information compared to REVIHAAP.

The **toxicological studies published after REVIHAAP** up to February 2016 **provide new information compared to REVIHAAP**, with a "low" level of evidence for the effect of particles from biomass combustion on cardiovascular health (complete blood count and coagulation).

5. DESERT DUST

REVIHAAP concluded that desert dust is linked to cardiovascular health, but could not conclude as to which components (crustal, anthropogenic, biological) are responsible for these effects. In humans, REVIHAAP reported associations between short-term exposure to particles during desert dust episodes and health (respiratory and cardiovascular). Regarding toxicological studies, REVIHAAP reported a weak association between intratracheal instillation of desert dust and lung inflammation.

The **human studies published after REVIHAAP** up to February 2016 **confirm the conclusions reported by REVIHAAP**, with a "moderate" level of evidence for an adverse effect on respiratory health (in children) related to short-term exposure.

No toxicological studies examining the relationship between this source category and health outcomes were identified among the corpus of studies published after REVIHAAP up to February 2016.

6. SEA SALT AND SEA SPRAY

REVIHAAP suggested that sea salt and sea spray have no effect on health at current concentrations. Nevertheless, in humans, REVIHAAP reported associations between short-term exposure to sea salt-related particles and to sodium in particles and health.

The **human studies published after REVIHAAP** up to February 2016 provide a "low" level of evidence for the effect of short-term exposure to sea salt or spray on respiratory health, which confirms some of the associations reported in REVIHAAP.

No toxicological studies examining the relationship between this source category and health outcomes were identified among the corpus of studies published after REVIHAAP up to February 2016.

7. HAZARDOUS WASTE SITES

In humans, REVIHAAP reported limited evidence of an association between exposure to particles from hazardous waste sites and perinatal health.

The **human studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of exposure to this source category, and thus do not provide any new information compared to REVIHAAP.

The **toxicological studies published after REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of exposure to this source category, and thus do not provide any new information compared to REVIHAAP.

8. RURAL ENVIRONMENT AND AGRICULTURE

8.1. Rural environment

REVIHAAP did not mention possible health effects of rural ambient air particulate matter, either in human or animal experimental studies.

No epidemiological studies published after REVIHAAP up to February 2016 examining the relationship between this source category and health were identified.

The **toxicological studies published since REVIHAAP** up to February 2016 provide only an "inadequate" level of evidence for health effects of exposure to this source category (respiratory and cardiovascular), and thus do not provide any new information compared to REVIHAAP.

8.2. Agriculture

NB: Agriculture is a major source of ammonium nitrate particles in ambient air. Ammonium was considered individually in the present assessment of the weight of the evidence.

REVIHAAP did not mention possible health effects of ambient particulate matter from agriculture, either in human or animal experimental studies.

No studies examining the relationship between this source category and health outcomes (epidemiological or toxicological) were identified among the corpus of studies published after REVIHAAP up to February 2016.

Table 1: Summary of accumulated evidence and levels of evidence for health effects of exposure to ambient air particulate components from human studies in REVIHAAP and since REVIHAAP

Compound		In REVIHAAP: Reported level of evidence	In REVIHAAP: Associations reported†	Since REVIHAAP and up to February 2016: Highest level of evidence for a health effect[θ] (number of publications in the corpus)		Summary of the accumulated evidence: Evidence or associations reported in REVIHAAP │ Evidence for a health effect since REVIHAAP
Ultrafine particles (<100 nm)		Evidence still limited	Yes	[cardiovascular health]	Moderate (14) (+Exp.*)	+ │↗
Coarse particles ($PM_{2.5-10}$)		Suggestive evidence	Yes	[respiratory health] [all-cause mortality]	Moderate (44)	+ │↗
Carbonaceous materials	Black carbon, elemental carbon	Sufficient evidence	Yes	[respiratory health] [cardiovascular health] [all-cause mortality]	High (78) (+Exp.*)	+ │↗
	Organic carbon	Increasing information	Yes	[respiratory health] [cardiovascular health] [all-cause hospitalisations]	High (37) (+Exp.*)	+ │↗
	SOAs (source factor€)	Ø	Yes		Inadequate (7) (+Exp.*)	+ │→
	PAHs	Ø	Ø	[respiratory health]	Low (4)	Ø │→
Secondary inorganic aerosols	SIAs (source factor€)	Ø	Yes	[respiratory health]	Low (6)	+ │→
	Sulphate	Ø	Yes	[respiratory health]	High (48)	+ │↗
	Nitrate	Ø	Yes	[cardiovascular health]	High (25) (+Exp.*)	+ │↗
	Ammonium	Ø	Ø	[respiratory health] [cardiovascular health] [all-cause mortality]	Low (14)	Ø │→
Transition metals	Nickel	Ø	Yes§	[respiratory health]	High (34) (+Exp.*)	Ø │↑
	Zinc	Ø	Yes§	[cardiovascular health]	Moderate (31)	Ø │↑
	Copper	Ø	Yes§	[cardiovascular health]	Low (31)	Ø │→
	Vanadium	Ø	Yes§	[cardiovascular health]	High (32)	Ø │↑
	Iron	Ø	Ø	[cardiovascular health]	High (31)	Ø │↑
Silica		Ø	Ø	[respiratory health] [all-cause mortality]	Moderate (30)	Ø │↑
Endotoxins		Ø	Ø	[cardiovascular health]	Moderate (5)	Ø │↑
Oxidative potential		Ø	Ø	[respiratory health] [cardiovascular health]	Low (6)	Ø │→

In REVIHAAP:
+: effect reported;
–: no effect reported;
Ø: not examined.

│**Since REVIHAAP**:
↑: new evidence for a health effect;
↗: confirmation of the health effect;
→: no new evidence for a health effect (i.e. a "low" or "inadequate" level of evidence);
↘: evidence of no health effect;
Ø: no studies identified.

[all-cause mortality] all-cause mortality [respiratory health] respiratory health [cardiovascular health] cardiovascular health [all-cause hospitalisations] all-cause hospitalisations. θ The purpose of assessing the level of evidence for a health effect is to conclude whether the observed association between a given component of ambient particulate matter and a given health category (e.g. cardiovascular health) is highly, moderately or faintly plausible. It may also be concluded that a component has no effect on health or that evidence available in the literature is inadequate to be able to reach any conclusion. *Abbreviations: SIAs: secondary inorganic aerosols; SOAs: secondary organic aerosols; PAHs: polycyclic aromatic hydrocarbons. * The conclusions based on animal experimental studies support this evidence of effects. † Yes if association reported, No if no association reported, Ø if not reported. § The reported associations do not specifically concern this element and include other transition metals in mixtures. € As defined by a statistical method of allocating components into categories or sources (e.g. positive matrix factorisation).*

Table 2: Summary of accumulated evidence and levels of evidence for health effects of exposure to source-related ambient air particulate matter from human studies in REVIHAAP and since REVIHAAP

Source category		In REVIHAAP: Reported level of evidence	In REVIHAAP: Associations reported†	Since REVIHAAP and up to February 2016: Highest level of evidence for a health effect[θ] (number of publications in the corpus)	Accumulated evidence: Evidence or associations reported in REVIHAAP	Accumulated evidence: Evidence for a health effect since REVIHAAP
Road traffic	Traffic-related $PM_{2.5}$	Probable association	Yes	Moderate (16) (+Exp.*)	+	↗
	Traffic-related black carbon	Sufficient evidence[₸]	Ø	High (4)	+	↗
	Diesel exhaust	Ø	Yes	Moderate (3) (+Exp.*)	+	↗
	Gasoline exhaust	Ø	Yes	Moderate (1)	+	↗
	Road dust, crustal material	Probable association	Yes	High (16)	+	↗
	Brake dust	Ø	Ø	Low (1) [#]	Ø	→
Combustion	Coal combustion	Solid evidence[‡]	Yes	High (7) (+Exp.*)	+	↗
	Combustion of petroleum products	Influence on health	Yes and no	Moderate (10)	+	↗
Industry	Industry	Ø	Yes	Low (5)	+	→
	Metallurgy	Ø	Yes	Inadequate (10) [#]	+	→
Biomass combustion		Probable association	Yes[§]	Inadequate (4) [#]	+	→
Desert dust		Ø	Yes	Moderate (3)	+	↗
Sea salt and sea spray		Suggestion of no effect	Yes and no	Low (9)	–	→
Hazardous waste site		Ø	No	Inadequate (1)	–	→
Rural environment and agriculture		Ø	Ø	Ø	Ø	Ø

In REVIHAAP:
+: effect reported;
–: no effect reported;
Ø: not examined.

│Since REVIHAAP:
↑: new evidence for a health effect;
↗: confirmation of the health effect;
→: no new evidence for a health effect (i.e. a "low" or "inadequate" level of evidence for an effect);
↘: evidence of no health effect;
Ø: not examined.

all-cause mortality, respiratory health, cardiovascular health, neurological health. θ The purpose of assessing the level of evidence for a health effect is to conclude whether the observed association between a given source of ambient particulate matter and a given health category (e.g. cardiovascular health) is highly, moderately or faintly plausible. It may also be concluded that a source has no effect on health or that there is too little evidence available in the literature to be able to reach any conclusion. ** The conclusions based on animal experimental studies support this evidence of effects. † Yes if association reported, No if no association reported, Ø if not reported. ₸ This level of evidence is based on the accumulated evidence for black carbon. ‡ This level of evidence is based on the accumulated evidence for sulphate-rich particles (chemical tracer of coal combustion). § In particular, associations between forest fires and health outcomes. # Does not consider evidence of health effects that may have been observed for individual chemical components or tracers.*

2.2.3 Discussion, limitations and uncertainties

Assessment of the weight of evidence from studies published after REVIHAAP

Definition of the levels of evidence for a health effect

The levels of evidence for a health effect ("high", "moderate", "low", or "inadequate") defined by the Working Group on the basis of studies published since REVIHAAP up to February 2016 are part of the hazard identification stage of the risk assessment process. These levels of evidence for a health effect of exposure to component and source-related particulate matter do not reflect the strength of the association, nor the relative toxicity between components or between sources. Nor do they reflect the probability of occurrence in the population or the magnitude of the risk. The levels of evidence for a health effect represent the more or less proven existence of an association (or absence of association) between exposure to ambient particulate matter (depending on its composition and source) and a health outcome. Thus, the levels of evidence enable the plausibility of an assumed causal relationship to be established based on the publications assessed as a whole, while taking account of certain causality criteria developed by Bradford Hill: strength of the association, consistency of the observations in different populations, temporality of the association, exposure-effect relationship, biological plausibility, existence of experimental evidence and specificity.

Interpretation of the levels of evidence for a health effect

The different ways exposure is measured and estimated in the various studies are a source of heterogeneity and variability in the results and conclusions per component and source category. This intrinsic variability calls for caution when formulating and interpreting the conclusions of the expert appraisal, especially for poorly documented categories of components and sources.

Correlation between components and sources

It cannot be excluded that the levels of evidence for a health effect obtained for a components or source actually reflect other components emitted or formed with it, particularly in observational studies (in which the exposure is not controlled). The level of evidence for a health effect obtained for a component of interest, considered individually in the approach, could therefore indicate the health effect of an emitting source or a mixture of highly correlated components, rather than the component's intrinsic toxicity. For example, the levels of evidence for a health effect for sulphate and nitrate in ambient particulate matter could reflect the ability of these components to modulate the toxicity of the particles as a whole or reflect the health effect of a source such as coal combustion (which emits sulphate). Similarly, it is difficult to identify the individual effects of transition metals because of the strongly correlated concentrations, related to their shared sources, for example brake and tyre wear (iron, zinc and copper) and industry or combustion of petroleum products (nickel, vanadium and iron). To limit the impact that this could have on the conclusions, the Working Group systematically took account of the corresponding risk of bias in the lines of evidence, regarding the absence of a multi-pollutant model or to the loss of an association after adjustment for other components.

Some publications used more sophisticated analyses than a simple adjustment to study the risks associated with particulate component exposure independently of other components or of the total mass of particles. One example is the residual method in which the component of interest is regressed on the total mass in order to obtain an exposure indicator independent of this total mass – i.e. the model residuals. Although the results from these different methods (sophisticated or not) required specific interpretations, they were shown to be generally homogeneous and to not alter the conclusions regarding the existence (or not) of a health effect. No distinction was therefore made between the different methods when the Working Group assessed the lines of evidence.

The concentration of NO_2 is an important factor that can modify the health effects associated with ambient particulate matter. It is also a key indicator of traffic air pollution. In particular, it has been shown that high concentrations of NO_2 (absolute concentrations or concentrations relative to PM_{10}) are associated with higher short-term effects of PM_{10} (for an increment of 10 µg/m^3) on mortality (Katsouyanni et *al.*, 2001). However, few studies published after REVIHAAP up to February 2016 took NO_2 concentrations into account in their analyses of the health effects of particulate components or sources, particularly over the long term. Therefore, given the importance of NO_2 as an indicator of road traffic air pollution, the levels of evidence for a health effect of certain components or sources (themselves related to road traffic) should be interpreted with caution.

Metrological variability

The Working Group's conclusions should be interpreted with caution given the lack of standardisation in the measurement and analysis protocols for certain components or particle size fractions between studies. The same source may also be defined differently from one study to another. This heterogeneity limits the comparability of the expert appraisal results associated with the different components, but may also limit the comparability and interpretation of the conclusions for a given component, fraction or source. For example, some components or fractions may have significant physico-chemical variability from one geographical area to another (in particular, secondary organic aerosols, organic carbon and coarse particles). Moreover, some components (nitrate ions, ammonium, sulphates and transition metals) are relatively easy to analyse, while the sampling, analysis and extraction of others is more complex (e.g. polycyclic aromatic hydrocarbons). These considerations can therefore facilitate the measurement and investigation of components such as ions and transition metals and thus the occurrence of unintended (false positive) associations. Polycyclic aromatic hydrocarbons include a large number of species of varying toxicity; this complexity could introduce artificial variability into the results of studies and limit their comparability, as well as the interpretation of the conclusions of the expert appraisal for this component. Counts of ultrafine particles (<100 nm) may include different fractions (3 or 10 nm, for example) depending on the instrument used (SMPS, nanoSMPS, DMPS, etc.), which is a potentially major source of variability between studies investigating the measured number of particles, their chemical composition, or their state (for example, <10 nm particles that are possibly gaseous in the respiratory tract). Grouping black carbon, elemental carbon and PM absorbance together in the same category is also a source of heterogeneity that can limit the interpretation of the conclusions. However, this grouping is supported by an international desire to standardise measurements and the known correlations between the ambient levels of these three components.

Statistical methods for source apportionment

The sources or factors to which the particle concentrations have been assigned using statistical source-apportionment methods (mainly positive matrix factorisation – PMF) differ intrinsically from one study to another, in terms of the method used (definition based on measured data) and the geographical area (different components and levels). Some sources refer to a complex group of emission categories, whose type differs in each of the publications (e.g. the industrial source and combustion of petroleum products). The associations reported in the publications may therefore be difficult to compare and the corresponding levels of evidence for a health effect may be limited (in their definition and interpretation). Moreover, some sources may be highly interlinked and difficult to separate (e.g. several particulate sources related to road traffic), making it complicated to exclude their contribution in the levels of evidence for a health effect obtained for one of them. Overall, it should be noted that primary sources of particulate matter in ambient air are generally well captured by the PMF method (this is not necessarily the case for sources of secondary particles or aerosols). In addition, the results obtained by the PMF method are strongly influenced by the parameters entered by the user (sources of uncertainty), as well as by the authors' choice of interpretation. Some sources could therefore be classified in a certain category (e.g. sea salt and spray) despite being only vaguely defined (e.g. potential inclusion of road salt).

Limitations of the approach

The Working Group excluded the use of quantitative methods such as Bayesian inference and meta-analysis. Indeed, the studies assessed were published over a limited period of time and are thus not representative of the literature as a whole (since REVIHAAP in 2013 and up to February 2016) and had disparate protocols that cannot easily be combined. In addition, the WG did not have the resources to statistically process the large number of triplets (components/sources, timing of exposure, and health outcomes). However, the qualitative approach used based on the model proposed by OHAT enabled these different studies and protocols to be included using a standardised system for rating risk of bias and confidence levels according to predefined criteria. In addition, this approach enabled human studies and animal experimental studies to be assessed in a similar way, in order to obtain consistent and parallel levels of evidence for a health effect for each of the two bodies of evidence.

Study search and selection

The search strategy adopted targeted studies that examined different compositions, sources or sizes (ultrafine or coarse) of ambient air particulate matter to which the general population is exposed. This approach helped improve comparability and consistency between components and sources to answer the questions asked, but also had the effect of leaving out certain fields of literature (in particular, studies in the workplace). The WG believes that the components and sources mainly affected by this omission are polycyclic aromatic hydrocarbons (PAHs), endotoxins, diesel engine exhaust particles, gasoline engine exhaust particles, and particles from industrial sources.

The cut-off date for the search and analysis of publications was set at February 2016, due to the large number of studies over this period and the time needed to integrate them in the lines of evidence, with regard to the work schedule. Mechanistic studies published after REVIHAAP up to February 2016 on strictly *in vitro* or *in silico* assays were not included, due to insufficient resources within the Working Group and the non-directive nature and unsuitability of the OHAT tool at that time for these types of studies. However, the results of *in vitro* assays in support of those obtained *in vivo* were not excluded. For information purposes, studies published after February 2016 until 21 August 2018 corresponding to the WG's research criteria were identified (80 human studies selected from full-text analysis, 39 animal experimental studies selected from screening of title and abstract), to summarise the more recently documented components, sources and health outcomes.

The bodies of evidence were based on queries made with the PubMed and Scopus search engines, supplemented by studies known by the members of the WG or cited in the identified publications. Other potentially relevant databases, such as Embase, Toxline or Web of Science, were not searched, nor was the grey literature (outside bibliographic control systems). The search terms and equations used were based on rather broad concepts (the concept of particles, cross-referenced with that of composition, source and particle size) and did not target studies examining one component, source or particle size fraction (other than ultrafine and coarse particles) in particular, nor studies examining the toxicity of substances in their pure state. Nevertheless, this approach complied with the principles shared by the Cochrane Collaboration (Higgins and Green, 2011), the European Food Safety Authority (EFSA, 2010), the Office of Health Assessment and Translation as part of the National Toxicology Program (OHAT NTP, 2015) and ANSES (ANSES, 2017) which recommend using at least two databases. Lastly, the search strategy enabled a wide range of components and sources to be included while rationalising the query and selection method, to avoid multiple variants of the particle components and sources in the search equations and to reduce the background noise that this might generate in the obtained references.

Quality assessment of the individual studies

In order to assess the individual quality of the studies, on the basis of the tool proposed by OHAT, two members of the WG rated the risk of bias in the publications according to predefined guidelines, reflecting a standardisation effort. However, the Working Group did not develop a more detailed protocol, given the expected complexity of this process due to the heterogeneity of the study protocols, exposure indicators, effect indicators and statistical methods. Any discrepancies in ratings between the two assessors were resolved through discussions involving all members of the Working Group, in order to reach a consensus. Independent double reading by two trained assessors is in line with the recommendations of ANSES's Working Group on "Risk assessment methodology".

The quality of the human studies appeared to be relatively satisfactory, where risks of bias rated as high were found in fewer than 25% of studies. They concerned: exposure characterisation, other issues (e.g. statistical methods), confounding factors or modifying variables, and adjustment or control for other exposures (e.g. models adjusted for the total mass of $PM_{2.5}$). For the animal studies, certain risks of bias could not be assessed from the publication data (60-90% of studies) in particular those related to: randomisation of the administered dose, concealment of study group allocation, blinding for research personnel, and blinding of outcome assessment. For the animal studies, the risks of bias that were most frequently rated as high were those related to confounding factors or modifying variables and attrition or exclusion of data from the analysis. The seemingly less-satisfactory quality of animal studies could be explained by the literature search queries, which are probably less effective for animal studies, and by the relatively non-restrictive inclusion criteria allowing low-quality studies to be included.

Assessment of the levels of evidence for a health effect

Assessing the level of evidence for a health effect of each of the components/sources, timings of exposure and health outcomes consisted in upgrading or downgrading (increasing or decreasing, respectively) the confidence in each body of evidence according to predefined factors; and determining whether or not there was an effect on health, which implied having to assess the relative importance of the studies making up the body of evidence. In order to harmonise these decisions and make them as transparent as possible, the Working Group identified some general guidelines, examples of which are presented here. The decisions were taken after reaching a consensus among the Working Group members and were documented in the supplemental material associated with the foundation report (ANSES, 2019a).

The decision on whether or not there was an effect on health was largely based on the rule of the majority (i.e. a majority of publications in the body of evidence showing an effect led to the conclusion that there was an effect, and *vice versa*), although the quality of the publications was also taken into account, in particular, risks of bias and sample size. Following a precautionary principle, the WG members always favoured the decision of the presence of an effect in cases where the reported effects (although in the minority) came from good quality publications or where the body of evidence was composed of 3 or fewer publications.

The downgrading of the level of confidence in the bodies of evidence was mainly due to the risk of bias – considered high or probably high – in studies showing health effects, mostly related to the absence of multi-pollutant models, an association becoming null after adjustment for the total mass of particulate matter or for another component, or the limitations in the measurement or estimation of exposure. The upgrading of the confidence level due to the high magnitude of an effect estimate was based on a comparison of the magnitude of the effect estimate of interest with that of the total mass of particulate matter or of other components. In the lines of evidence for human studies, the upgrading of the confidence level due to the presence of residual confounding factors (i.e. confounding factors that, if they had been considered, may have reinforced the results already observed) was systematically applied in relation to the measurement or estimation of exposure. This decision was based on the assumption that classification errors related to the measurement or estimation of exposure are generally regarded as non-differential (although the exact nature of the bias may be unknown in each study), which biased the results towards the null association. Thus, associations already observed despite the presence of this bias may be further strengthened after taking the residual confounding factor into account (i.e. a *better* estimation or measurement of exposure, closer to the assumed actual exposure of individuals), thereby increasing the confidence level of the body of evidence (Sheppard et al. (2005) cited in EPA (2009)).

Assessment of the conclusions of REVIHAAP

The REVIHAAP review, which was selected by the Working Group as the knowledge base, provides a state of the art on the health effects of different fractions, metrics, chemical components and source types of ambient air particulate matter (WHO Europe, 2013). This review was not systematic and cannot therefore claim to provide the most exhaustive information. Some components and sources were not specifically assessed, such as polycyclic aromatic hydrocarbons, silica, endotoxins, oxidative potential, (individual) transition metals, brake dust, diesel engine exhaust particles, gasoline engine exhaust particles and ambient particulate matter in rural areas. Nevertheless, the conclusions of this review were considered robust by the Working Group as it is a consensus review involving a large number of leading authors, reviewing both human and animal studies, and covering aspects of composition, size and sources of ambient air particulate matter.

Other sources were not specifically assessed, either in the REVIHAAP review or in the present work, and include airport areas, natural sources such as pollen and plant debris, wind erosion, volcanic eruptions, and vegetal emissions of biogenic volatile organic compounds.

Comparison of the accumulated evidence (in REVIHAAP and since REVIHAAP)

The comparison of the evidence derived from studies published from 2013 to February 2016 with the information provided by REVIHAAP deviates from the systematic nature of the process for assessing the weight of the evidence. Conclusions formulated in the REVIHAAP review, due to their heterogeneous format, could not be systematically combined with the standardised conclusions drawn from the studies published subsequently. However, efforts have been made to ensure consistency using the same exposure indicators and health effect indicators, as well as a standardised format for writing the present report's results and conclusions.

3 HEALTH EFFECTS OF AMBIANT AIR PARTICULATE MATTER – CONCLUSIONS OF THE CES "Air" and the WG on "Particulate matter"

Preamble

The general conclusions presented here result from the comparison of the conclusions of WHO Europe's REVIHAAP review (published in 2013) with the evidence for a health effect derived from studies published since REVIHAAP up to February 2016 (human studies and animal experimental studies). Evidence accumulated since REVIHAAP refers to the levels of evidence for a health effect obtained from studies published since REVIHAAP up to February 2016:

- If the levels of evidence are moderate or high, this accumulated evidence confirms the health effect of a component or source when REVIHAAP already mentioned the effect of this component or source in 2013.
- Evidence is considered new and substantiates the health effect of a component or source when REVIHAAP did not mention a specific effect.
- If the levels of evidence are inadequate or low, the accumulated evidence does not allow a firm conclusion to be drawn about a health effect of a component or source, or only suggests such an effect. It reflects an emerging literature that does not show any associations, or literature with an insufficient level of confidence[5] to draw any conclusion despite observed associations.
- Non-existent evidence refers to an absence of studies published since REVIHAAP among those included and assessed as part of this work.
- Lastly, evidence of no health effect corresponds to literature with a high level of confidence and showing no association between a component or source and health.

The conclusions specifically address the health effects of outdoor ambient air particulate matter by components and sources of particulate matter. These conclusions do not call into question the evidence provided by other bodies of evidence investigating the harmfulness of substances or the health effects of particulate matter (such as silica, polycyclic aromatic hydrocarbons, diesel engine exhaust particles, gasoline engine exhaust particles, particulate matter from specific industrial sources and particulate matter from biomass combustion). Lastly, these conclusions do not call into question the evidence provided by the literature on the adverse health effects of $PM_{2.5}$ and PM_{10} without chemical speciation or source apportionment.

[5] Level of confidence body of evidence defined from the rating tool proposed by OHAT (see Section 2.1).

3.1 Conclusions by components of ambient particulate matter

Ultrafine particles (<100 nm) and coarse particles ($PM_{2.5-10}$)

In 2013, REVIHAAP concluded that the health effect of coarse particles was only suggestive and that evidence was still limited for ultrafine particles. The evidence accumulated since REVIHAAP is moderate and confirms the health effects of these fractions based on broad bodies of evidence of human studies, with a high level of confidence, examining many health categories. For ultrafine particles, the evidence accumulated since REVIHAAP from animal experimental studies underpins this conclusion. The highest levels of evidence for an adverse health effect in humans were obtained for respiratory health (coarse particles), cardiovascular health (ultrafine particles), and all-cause mortality (coarse particles). Lastly, the levels of new evidence accumulated since REVIHAAP are low and only suggest an effect of long-term exposure to ultrafine particles on neurological health (impaired development of children's cognitive performance), due to the body of evidence being limited to a single publication.

Carbonaceous materials

In 2013, REVIHAAP concluded that there was sufficient evidence for an adverse health effect of black carbon and increasing evidence for organic carbon. The levels of evidence accumulated since REVIHAAP are high and confirm the health effect of these components based on broad corpora of human studies, with a high level of confidence and examining many health categories. Underpinning these results, the levels of evidence accumulated since REVIHAAP from animal experimental studies are low to moderate. The highest levels of evidence for an adverse health effect in humans are obtained for respiratory health, cardiovascular health, all-cause mortality and all-cause hospitalisations, both over the short and long term. Lastly, levels of new evidence accumulated since REVIHAAP are low and suggest a long-term effect of black carbon in ambient particulate matter on neurological health (impaired development of children's cognitive performance) and perinatal health (low birth weight), two health categories not mentioned by REVIHAAP.

In 2013, REVIHAAP did not examine the health effects of polycyclic aromatic hydrocarbons (PAHs) in ambient particulate matter and secondary organic aerosols (SOAs) as a source factor[6]. In the case of SOAs as a source factor, levels of new evidence accumulated since REVIHAAP are inadequate and do not allow a firm conclusion to be drawn about a health effect, due to an emerging literature that is still limited in size and does not show associations. Moreover, the heterogeneity of the source factors defined in the publications may make it difficult to interpret and compare the results. In the case of PAHs, levels of new evidence accumulated since REVIHAAP are low and do not allow a firm conclusion to be drawn about a health effect, due to the insufficient level of confidence in the body of evidence. Moreover, the great diversity of PAHs in ambient air makes it difficult to compare the results. However, PAHs can be associated with black carbon and are included in organic carbon measurements in ambient air, for which the levels of accumulated evidence are both high. In addition, there is an extensive literature, not assessed here, on the harmfulness of some PAHs (exposure classified as carcinogenic by IARC).

[6] A factor (grouping of correlated compounds) obtained by a statistical method of categorising compounds, often representing emission sources; for example, positive matrix factorisation or principal component analysis.

Secondary inorganic aerosols

In 2013, REVIHAAP reported associations between sulphate and nitrate – tracer elements of secondary inorganic aerosols (SIAs) in ambient air – and adverse health outcomes, but did not reach a conclusion regarding a level of evidence due to the lack of evidence on the direct and causal nature of the associations. The levels of evidence accumulated since REVIHAAP are high and confirm the health effects of sulphate-rich and nitrate-rich particulate matter based on broad bodies of evidence of human studies with a high level of confidence, examining many health categories. Based on animal experimental studies, the levels of evidence accumulated since REVIHAAP from animal experimental studies are low regarding the effects of nitrate in diesel and gasoline engine exhaust on cardiovascular health – effects on atherosclerosis lesions and on complete blood count (erythrocytes/haemoglobin). The highest levels of evidence for an adverse health effect in humans are obtained for respiratory health, cardiovascular health and all-cause mortality. In addition, levels of new evidence accumulated since REVIHAAP are moderate and also suggest an effect of sulphate-rich and nitrate-rich particulate matter on perinatal health (low birth weight), a health category not mentioned by REVIHAAP. Although the assessment carried out for this work takes many causality criteria into account, it is possible that the levels of evidence obtained reflect the ability of these components (sulphates and nitrates) to modulate the toxicity of particulate matter as a whole or the potential health effect of a common source (combustion) rather than the intrinsic toxicity of these components.

In 2013, REVIHAAP did not mention the effects of other secondary inorganic aerosols, such as ammonium, or SIAs as a source factor. In the case of SIAs as a source factor, levels of new evidence accumulated since REVIHAAP are low and do not allow a firm conclusion to be drawn about an adverse health effect, due to an emerging literature that is limited in size and does not lead to a sufficient level of confidence. Moreover, the heterogeneity of the source factors defined in the publications makes the comparison of the results difficult. In the case of ammonium, levels of new evidence accumulated since REVIHAAP are low and do not allow a firm conclusion to be drawn about an adverse health effect, as the body of evidence do not lead to a sufficient level of confidence. However, ammonium concentrations are generally correlated with those of sulphate and nitrate, for which the levels of accumulated evidence are high.

Transition metals

In 2013, REVIHAAP reported associations between certain metals (nickel, zinc, vanadium; in mixtures) and health. Levels of new evidence accumulated since REVIHAAP, from moderate to high for these components, support the health effects of nickel, zinc, vanadium and iron based on broad bodies of evidence of human studies, with a high level of confidence and examining many health categories. The highest levels of evidence for an adverse health effect are obtained for cardiovascular health, respiratory health (nickel and vanadium only) and all-cause mortality (iron only). However, it is difficult to distinguish between the individual effects of transition metals because of their strongly correlated concentrations, related to their common sources: brake and tyre wear (iron, zinc and copper) and industry or combustion (nickel, vanadium and iron). The evidence obtained for the metals, considered individually in the present work, may therefore actually reflect the health effect of their common sources or of mixtures of metals.

Other chemical components of ambient air particulate matter

The weight of evidence approach was not implemented for components or elements (metallic, inorganic or mineral) of ambient particulate matter, which have been historically considered less often associated with health outcomes in epidemiological studies. Nevertheless, studies published since REVIHAAP, selected and described during the present work, reported associations between health (respiratory and cardiovascular) and exposure to calcium, potassium, magnesium, manganese, lead and chloride. Some of these components may be associated with sources (potassium: biomass-combustion tracer), with phenomena (calcium: abrasion and airborne dust related to construction sites, gravel pits and soil tillage or erosion), or with other components assessed individually.

Silica

The REVIHAAP review did not mention the health effects of silica in outdoor ambient air. Levels of new evidence accumulated since REVIHAAP are moderate and substantiate the health effects of silica in ambient particulate matter, particularly on respiratory health and all-cause mortality, based on a broad body of evidence of human studies, with a high level of confidence, examining many health categories. There is also an extensive literature, not assessed here, on the harmfulness of crystalline silica (exposure classified as carcinogenic by IARC).

Endotoxins

The REVIHAAP review did not mention the potential health effects of endotoxins in outdoor ambient air. Levels of new evidence accumulated since REVIHAAP are moderate and substantiate the health effects of endotoxins in ambient particulate matter, particularly on cardiovascular health, based on a body of evidence that is limited but leads to a high level of confidence. The lack of standardisation in endotoxin measurement and analysis protocols, as well as the diversity of components to which they may be attached, call for caution in interpreting these conclusions. However, there is an extensive literature, not assessed here, examining the harmfulness of exposure to high concentrations of endotoxins in workers handling organic matter, such as sewer workers, waste-sorting and treatment plant workers and farmers.

Oxidative potential of particulate matter

The oxidative potential of particulate matter is not a component in itself. It is an indicator, measured by acellular tests, quantifying the intrinsic ability of particulate matter to generate reactive oxygen species (ROSs)[7]. The oxidative potential of particulate matter has been put forward in recent years as a metric, other than the mass or chemical composition of atmospheric particles, for assessing their health effects.

In 2013, REVIHAAP only mentioned oxidative stress as a potential mechanism of the health effect of particulate matter. Levels of new evidence accumulated since REVIHAAP are low and only suggest an adverse effect of the oxidative potential of particulate matter (measured under acellular conditions) on respiratory and cardiovascular health, as the literature is still emerging (limited body of evidence) and does not lead to a sufficient level of confidence to enable a firm conclusion to be drawn. Based on animal experimental studies, the levels of evidence accumulated since REVIHAAP are low for respiratory and cardiovascular health effects (respiratory inflammatory infiltration and systemic inflammation) of oxidative stress induced by inhalation of ambient air particulate matter in mice. It should be noted that measurement of the oxidative potential of particulate matter is still recent and there are several non-standardised measurement methods, each sensitive to molecules or families of chemical species that may differ. This may partly explain the limitations of size and confidence in the body of evidence.

[7] *The ability of particulate matter to generate ROSs contributes, along with other molecular and cellular pathways, to the induction of oxidative stress in lung target cells. Oxidative stress is a mechanism of particle toxicity. The ability of particulate matter to generate ROSs is also related to the composition and surface of the particulate matter.*

3.2 Conclusions by sources of outdoor ambient air particulate matter

Road traffic

In 2013, the REVIHAAP review concluded that there was sufficient evidence of the health effects of black carbon (mainly emitted by diesel vehicles in most urban environments) and likely associations between health and $PM_{2.5}$ emissions from road traffic and road dust (including crustal material). Levels of new evidence accumulated since REVIHAAP, from high to moderate depending on the type of emissions (e.g. traffic-related black carbon, traffic-related $PM_{2.5}$ emissions and road dust/crustal material), confirm the health effect of the "road traffic" source as a whole on the basis of bodies of evidence of human studies that lead to a high level of confidence and examine many health categories. However, the bodies of evidence for road traffic-related black carbon, diesel engine exhaust particulate matter and gasoline engine exhaust particulate matter were limited. Underpinning these results, the levels of evidence accumulated since REVIHAAP from animal experimental studies are low to moderate for the respiratory health effects (ultrastructural damage, respiratory function, lung remodelling) and the cardiovascular health effects (vascular function, coagulation, atherosclerosis lesions) of road traffic-related $PM_{2.5}$ emissions and diesel engine exhaust particulate matter. The highest levels of evidence for an adverse health effect in humans are obtained for road traffic-related black carbon (on respiratory health, cardiovascular health and all-cause mortality) and road dust (on respiratory health), based on broad bodies of evidence. Levels of new evidence accumulated since REVIHAAP are moderate and suggest an adverse effect of long-term exposure to $PM_{2.5}$ emissions from road traffic on neurological health and perinatal health, two health categories not mentioned in REVIHAAP. The conclusions for the "road traffic" source are consistent with the evidence obtained for some individual components, such as black carbon, organic carbon and some metals. Independently of the body of evidence analysed here on the effects of outdoor ambient particulate matter from road traffic, there is an extensive literature on the harmfulness of diesel engine exhaust and diesel particulate matter (exposure classified as carcinogenic by IARC) and gasoline engine exhaust (exposure classified as probably carcinogenic by IARC).

Combustion of coal and petroleum products

In 2013, REVIHAAP reported strong evidence of the health effects of coal combustion, based notably on evidence of an adverse effect of sulphate-rich particulate matter. Only mitigated associations were reported regarding the combustion of petroleum products. The evidence accumulated since REVIHAAP confirms the health effects of ambient particulate matter from these sources based on broad bodies of evidence of human studies, leading to a high level of confidence and examining several health outcomes. The levels of evidence range from high for coal combustion to moderate for petroleum-product combustion. These conclusions are consistent with the evidence obtained for some components assessed individually: sulphate (coal combustion tracer), nickel and vanadium (petroleum-product combustion tracers). In addition, there is an extensive literature, not assessed here, on the harmfulness of emissions from coal combustion, particularly for household combustion (cooking and heating) in developing countries (exposure classified as carcinogenic by IARC).

Biomass combustion

In 2013, REVIHAAP reported a likely association between particulate emissions from biomass combustion and health, based mainly on publications investigating the occurrence of health events during forest fire episodes. The evidence accumulated since REVIHAAP is inadequate and do not allow a firm conclusion to be drawn about an adverse health effect of outdoor particulate matter from biomass combustion, due to the limited body of evidence reporting inconclusive results. The body of evidence is likely to be limited due to the selection criteria used, favouring the inclusion of publications using statistical methods for source apportionment. Nevertheless, many associations between health and potassium, a tracer of biomass combustion, have been reported in the studies published since REVIHAAP. In addition, there is an extensive literature, not assessed here, on the harmfulness of emissions from biomass combustion, particularly for household combustion (cooking and heating) in developing countries (exposure classified as carcinogenic by IARC).

Industry

In 2013, REVIHAAP reported associations between the "industry" source category and health, but did not reach a firm conclusion about a level of evidence due to the heterogeneity of this source category, which may include a dominant source, a mixture of sources, or various combustion sources. The levels of evidence accumulated since REVIHAAP, from inadequate to low depending on the type of industry, do not allow a firm conclusion to be drawn about an adverse health effect of particulate matter emissions from industrial sources, due to a body of evidence leading to an insufficient level of confidence or inconclusive results. In addition, the heterogeneity of definitions of the "industry" source in the various publications makes the interpretation and comparison of the results difficult. Nevertheless, the potential health effects of this source category are consistent with the evidence obtained for the combustion of coal, the combustion of petroleum products and some individually-assessed metals (nickel and vanadium). In addition, there is an extensive literature, not assessed here, on the adverse effects on human health of environmental contamination by industrial sites (e.g. WHO Europe, 2014).

Hazardous waste sites

In 2013, REVIHAAP mentioned two publications that did not report clear association between residential proximity to hazardous waste storage sites and perinatal health. The evidence accumulated since REVIHAAP is inadequate and does not allow a firm conclusion to be drawn about an adverse health effect for this source category, due to a body of evidence consisting of a single publication reporting inconclusive results for many health outcomes. The body of evidence is likely to be limited due to the selection criteria used, favouring publications using statistical methods for source apportionment.

Agriculture

In 2013, REVIHAAP did not mention the health effects of outdoor ambient air particulate matter from agriculture. New evidence accumulated since REVIHAAP is non-existent (no human studies) or inadequate (in animal experimental studies), which does not allow any conclusion to be drawn about a health effect of ambient air particulate matter from this source category. The body of evidence is likely to be limited due to the selection criteria used, favouring publications using statistical methods for source apportionment (and in such publications, the application of these methods did not identify an agricultural source). In addition, there is an extensive literature, not assessed here, examining the health effects of occupational exposure to pesticides.

Desert dust

In 2013, REVIHAAP reported an increase in the number of adverse health events during air pollution episodes due to desert dust. The evidence accumulated since REVIHAAP is moderate and confirms the health effect of desert dust, particularly on the respiratory health of children, based on a body of evidence that is limited but leads to a high level of confidence.

Sea salt and sea spray

In 2013, REVIHAAP reported mitigated associations between sea salt and sea spray and health, and even suggested that there was no health effect. The evidence accumulated since REVIHAAP does not allow a firm conclusion to be drawn that sea salt and sea spray have an adverse health effect, which could support the evidence of no health effect, based on a broad body of human evidence.

4 ROAD TRAFFIC EMISSIONS – METHOD AND SUMMARY OF THE WG's WORK

4.1 METHOD

Simulations were performed to assess the impact of several scenarios of technological developments in the vehicle fleet on traffic emissions and air quality in the Île-de-France region and in metropolitan France as a whole.

To answer the question about the differentiated impact of technologies on road-traffic particulate emissions, an approach involving the simulation of pollutant emissions and concentrations in the Île-de-France region[8] and in metropolitan France as a whole was therefore developed and implemented, considering different scenarios of changes in the composition of the vehicle fleet (Figure **2**).

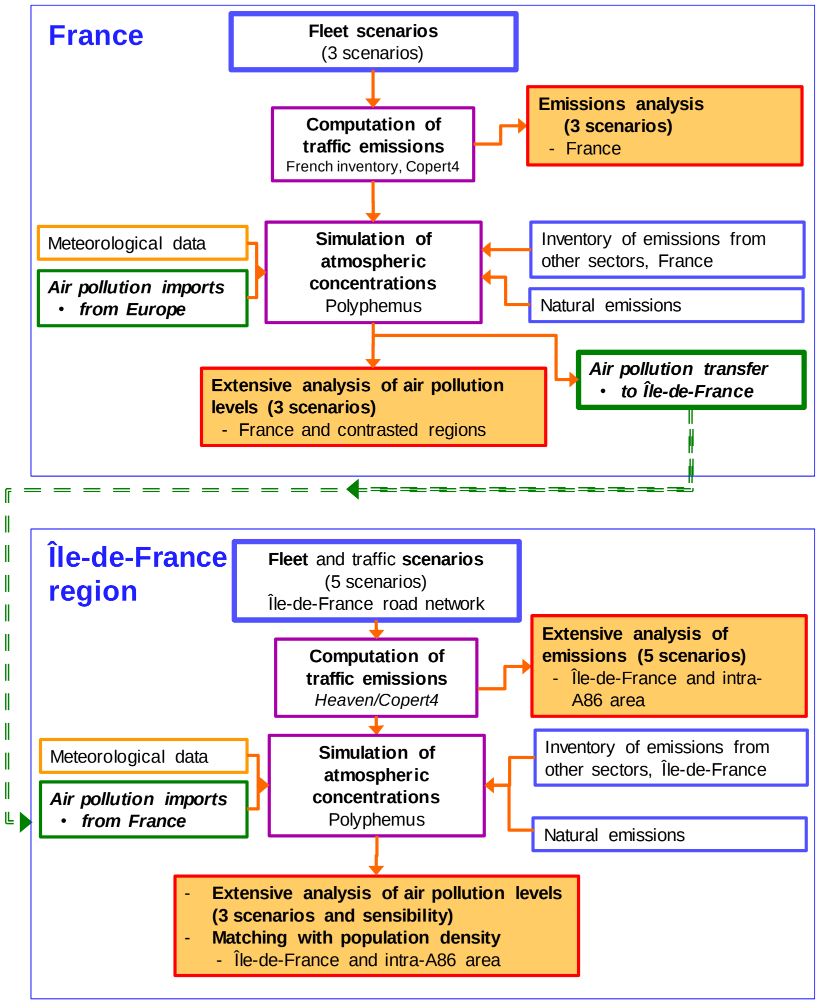


Figure 2: Diagram of the pollutant emission and concentration simulation process, for France (top) and Île-de-France (bottom)

[8] The Île-de-France region was chosen because of the availability of tools and data at a fine territorial scale, and due to the major pollution issue, while the analysis on the national scale enabled greater representativeness as well as an analysis according to places and contexts.

This approach combined existing tools: Airparif's Heaven platform and CITEPA's national inventory for calculating traffic pollutant emissions in Île-de-France and France (European COPERT4 methodology); the Polyphemus atmospheric concentration simulation platform for the regional scale. It also used numerous types of data: traffic modelled throughout the Île-de-France region, meteorological data, Île-de-France/France/European inventories of pollutant emissions from the various activity sectors, etc. Overall, the approach took emissions of both anthropogenic and natural pollutants into account, as well as imported emissions from larger scales (Europe to France, France to Île-de-France, see Figure 2). It integrated most known physico-chemical interactions between pollutants.

The scenarios of technological developments in vehicle fleet composition were derived from the current fleet compositions (Île-de-France and national, baseline situation, 2014 – for which detailed data on fleet, traffic and emission inventories were available). A model was used to simulate vehicle renewal and fleet development by 2025 according to the following assumptions:

- **DPF scenario or S1**: Generalisation of the diesel particulate filter (the various current technologies) and concomitant changes to emission regulations (Euro standards) by this date. This scenario constituted near steady development ("business as usual"), without any change in the balance between engine types (gasoline, diesel, electric), or between vehicle categories and vehicle sizes.
- **S1-elec. 2W scenario**: A variant of this first scenario was considered to study the sensitivity of the simulation results to volatile organic compounds (VOCs). This variant consisted in cancelling the exhaust emissions from motorised two-wheelers, which are high VOC emitters (motorised two-wheeled vehicles were then all assumed to be electric).
- **Gasoline scenario or S2**: A large decline in diesel engines in favour of gasoline engines for light-duty vehicles, obtained by assuming a continuous decrease in sales of light-duty diesel vehicles (from 60% in 2014 to 5% in 2025), with the same regulatory changes as for the DPF scenario.

In addition to the baseline situation (2014), these scenarios were simulated in terms of pollutant emissions and concentrations in the Île-de-France region (fine resolution) and throughout France.

Two other scenarios were simulated solely for emissions in the Île-de-France region due to the complexity of the simulations and calculation times:

- **Alternative Technologies scenario**: in addition to the steady development in the DPF scenario, strong promotion of electric vehicles on the urban road network alone, for all vehicle categories. This evolution of the urban fleet was reached assuming that 40% of cars and 60% of light-duty commercial vehicles sold in 2025 were expected to be electric, while all Euro 3 and earlier trucks and buses, and all two-wheeled vehicles of less than 250 cm^3 were replaced by electric vehicles on the urban road network. The fleet from the DPF scenario operated in the rest of the region (rural road network and motorways).
- **Ambition Air scenario**: 20-25% reduction in traffic and a similar fleet composition to that of the Alternative Technologies scenario in the highly urbanised intra-A86 area, while the fleet from the DPF scenario operated in the rest of the region, with no reduction in traffic.

Table 3 summarises the assumptions of these scenarios and gives some characteristics of the resulting fleet compositions (light-duty vehicles in Île-de-France).

Table 3: Vehicle fleet scenarios and their assumptions

Scenarios		**Assumptions**	**Characteristics – Ile-de-France (in % of traffic)**
Scenarios with pollutant emission and concentration simulation, for Île-de-France and France			
Reference	Year 2014	**Actual vehicle fleet composition**	73 % Diesel Light Duty vehicles • Of which 58 % without DPF 27 % Gasoline 61 % Euro 4 or before
DPF scenario (S1)	**Generalisation of the Diesel particulate Filter**	**“Business as Usual” evolution up to 2025 with:** • Renewal of the fleet towards the recent regulations (Euro 5 and 6) • Recent Diesel fitted with DPF • Distribution as regards vehicle types and sizes unchanged.	73 % Diesel Light Duty vehicles • **Of which 21 % without DPF** 27 % Gasoline **21 % Euro 4 or before**
S1-elec 2W	(sensitivity to VOC)	Ditto DPF, expect **2-wheelers changed to electric to decrease VOC emissions**	
Gasoline scenario (S2)	**Decline in the Diesel Light Duty vehicles**	**Decrease in Diesel light duty vehicle sales for Gasoline vehicles.** Diesel sales decrease: • From 60 % in 2014 to 5 % in 2025 • Renewal of the fleet towards the recent regulations (as for the DPF scenario)	43 % Diesel Light Duty vehicles • Of which 16 % without DPF 56 % Gasoline 8 % Euro 4 or before
Scenarios with pollutant emission simulation only, for Île-de-France			
Alternative Technologies scenario	**Electric vehicles in urban areas**	*Urban vehicle fleet only:* **Strong progression of electric vehicles** • 40 % of car sales and 60 % light commercial vehicles sales are electric in 2025 • 5 % of light duty vehicles sales are Diesel • Lorries and Buses Euro 3 and before, and 2-wheelers < 250 cm^3 are all replaced by electric vehicles *On rural roads and motorways: vehicle fleet from the DPF scenario (S1)*	*For the whole Île-de-France* 58 % Diesel Light Duty vehicles • Of which 16 % without DPF 31 % Gasoline **11 % Electric Light Duty Vehicles** 17 % Euro 4 or before
Ambition Air scenario	**Electric vehicles and traffic reduction in the Intra-A86 area**	**In intra-A86, traffic reduction / increase as follows:** • **-25 % for passenger car traffic,** • **-20 % for light and heavy commercial veh.** • **+50 % for motorised 2-wheelers** • **+75 % for urban buses and coaches** **And vehicle fleet corresponding to the Alternative Technologies scenario** *Outside intra-A86: Vehicle fleet from the DPF scenario (S1)*	*For the whole Île-de-France* 68 % Diesel Light Duty vehicles • Of which 21 % without DPF 27 % Gasoline 4 % Electric Light Duty Vehicles 20 % Euro 4 or before *In intra-A86* 50 % Diesel Light Duty vehicles • Of which 20 % without DPF 34 % Gasoline 16 % Electric Light Duty Vehicles 14 % Euro 4 or before

Figure 3**Erreur ! Source du renvoi introuvable.** illustrates the average fleet compositions for the whole Île-de-France region, resulting from these assumptions, considering traffic volumes on the entire road network and the dedicated fleet compositions applying to the urban and rural road networks, as well as to motorways and Paris ring-road.

Several assumptions and input data were kept invariant for all the scenarios, to specifically analyse the impact related to the technological options for the vehicle fleets. These invariants included weather conditions, populations and their geographical distribution, emissions from activity sectors other than traffic, traffic volumes (except for the "Ambition Air" scenario) and traffic conditions.

The simulation results were developed in relation to issues of exposure and health impacts. Differences between the scenarios were thus provided as regards average concentration values and also thresholds being exceeded, spatial variability and numbers of people exposed.

The interpretation of the results was based on a detailed "phenomenological" description allowing a better understanding of the mechanisms that can lead to an improvement or degradation in air pollution and of the issues at stake.

This simulation work was supplemented by a retrospective analysis of the changes in pollutant emissions and concentrations in France and Île-de-France, and by a summary of several impact assessment studies (urban mobility plan and restricted traffic areas in Île-de-France).

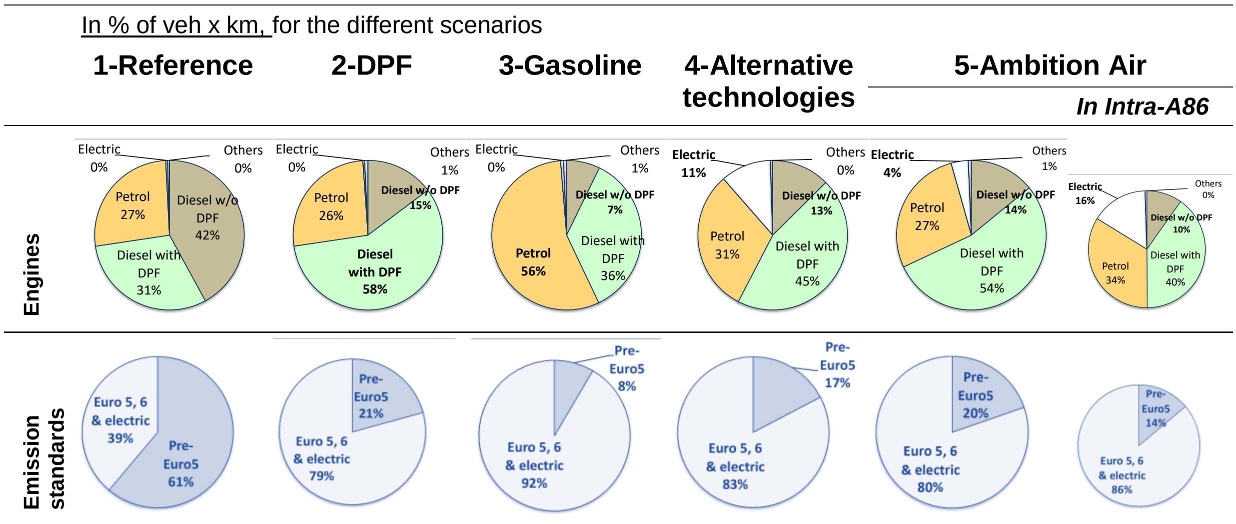


Figure 3: Light vehicles (cars and light commercial vehicles) fleet composition in the Île-de-France region and intra-A86 area, as regards engine types and emission standards

The pollutants considered in the simulations were:

- at source emission: particulates in mass and size classes (PM_{10}, $PM_{2.5}$, $PM_{1.0}$)[9], particle number (PN) and according to their type (black carbon - BC; organic matter - OM), gaseous pollutants (nitrogen oxides - NOx; nitrogen dioxide - NO_2; ammonia - NH_3; volatile organic compounds - VOCs; carbon monoxide - CO) involved in the formation of secondary aerosols and ozone (O_3), as well as CO_2 because of the climate issue;
- in the atmosphere (in concentrations): particulate pollutants broken down by mass and size classes ($PM_{2.5}$, PM_{10}), particle number (PN) and according to their type (BC, organic and inorganic fractions of PM_{10}), as well as the gaseous pollutants NO_2 and O_3.

A critical analysis was also conducted, justifying the methodological choices and assumptions while identifying their limitations and suggesting more extensive studies. The literature provided partial insight into the uncertainties, which can be large for certain emission factors. An analysis of emission factors illustrated the sensitivity of the simulations, such as the sensitivity of the formation of the secondary aerosols analysed with regard to the scheme for determining semi-volatile organic compounds (SVOCs).

In the end, the work presented in this framework constitutes a rather unique experiment through its use of complementary skills, resources and data to simulate atmospheric pollutant emissions and concentrations under different scenarios. The approaches and tools developed provide a

[9] PM_{10}, $PM_{2.5}$, $PM_{1.0}$: mass of particles with a median aerodynamic diameter less than 10 µm, 2.5 µm and 1 µm respectively.

framework that can be used for further work investigating the impact of scenarios of changes in traffic and other emission sources on air pollution and health.

4.2 SUMMARY OF THE WG's WORK

Important note: *Any comparison of this work with public policy impact assessments (restricted traffic zones, announcement of restrictions or bans on combustion-engine vehicles, etc.) should be avoided. This is because the scenarios simulated in this study compare different technological assumptions (or even traffic reductions) in a constant context (no demographic changes, or changes in other emitting sectors, etc.). They do not consider any changes in mobility behaviour, in emissions other than those from vehicle traffic, or in the economic context. They instead enable a study of air pollution's sensitivity to different technological developments in the motor vehicle fleet, and not a prospective study of air pollution in relation to public policies.*

1. Pollutant emissions (annual amounts, t/year)

Road traffic is currently a major challenge in terms of NOx, BC, OM, $PM_{2.5}$ and PM_{10}, especially in urban areas, with highly differentiated contributions according to the vehicle categories.

The Île-de-France simulations show the importance of traffic's contribution to pollutant emissions and identify the main challenges:

- Road traffic's contribution to total pollutant emissions (all sectors) in Île-de-France is high for NOx (58%), moderate for PM_{10} and $PM_{2.5}$ (20-25%), but high for BC (54%) and OM (37%); it is relatively limited for VOCs (11%) and NH_3 (9%). In the highly urbanised intra-A86 area, this contribution is higher for BC (58%), OM (43%) and NH_3 (94%).
- Within the road transport, cars predominate in traffic volume and pollutant emissions (71% of traffic, 40-50% of pollutant emissions studied); diesel light-duty commercial vehicles (LCVs) are less numerous (15% of traffic) but are still poorly equipped with particulate filters – they produce as many particles as cars and are even predominant for very fine particles ($PM_{1.0}$) or OM. Heavy vehicles (trucks, buses and coaches) (6% of traffic) contribute significantly to NOx emissions (36%) and less to particulate emissions (10-14%). Current motorised two-wheelers, which only account for 8% of traffic, are high emitters of VOCs (45%), along with gasoline-powered cars (41%) (Figure 4).

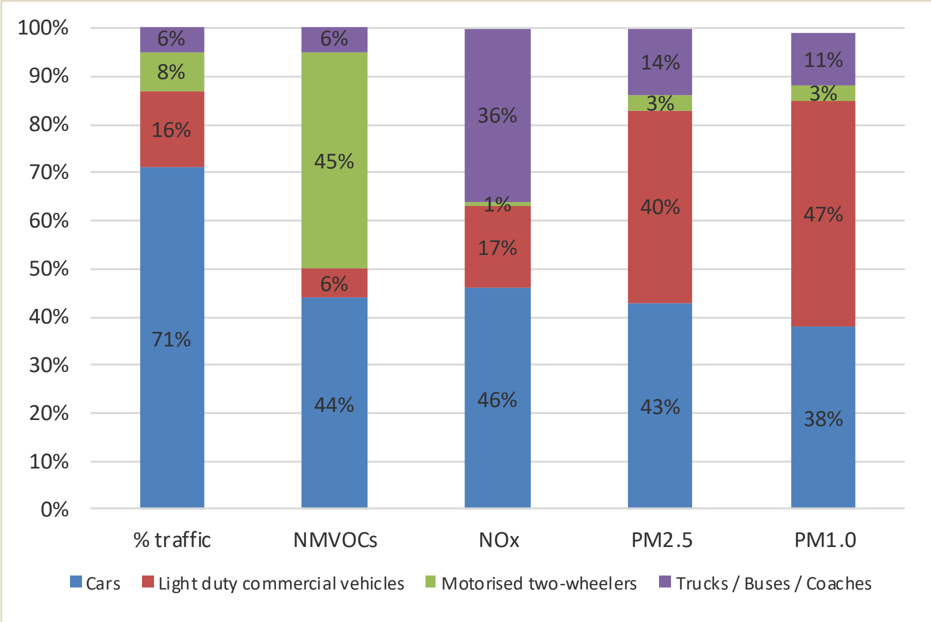


Figure 4: Breakdown of traffic (% of vehicles x km per year) and pollutant emissions (% of annual mass quantities) by vehicle category – baseline scenario, Île-de-France

Over a period of about ten years, the various technological scenarios lead to a sharp decrease (between -30 and -60%) in traffic pollutant emissions in Île-de-France and France.

- ***The promotion of light-duty gasoline-powered vehicles at the expense of light-duty diesel-powered vehicles, leading to accelerated fleet renewal (scenario S2), result in further reductions in particulate matter emissions but lower reductions in VOCs and NH_3.***
- ***In Île-de-France, the promotion of electric-powered vehicles in urban areas and, above all, the reduction in light-duty vehicle traffic in favour of public transport and two-wheelers would enable even greater reductions, especially in the urban and densely populated intra-A86 area.***

Compared to the baseline situation (year 2014), by 2025 all the technological scenarios significantly reduce traffic emissions from the fitting of DPFs and from regulatory changes (Figure 5). In Île-de-France, for example, the widespread use of particulate filters on diesel vehicles (DPF scenario) reduces traffic emissions: by 60% for combustion-related particulate matter ($PM_{1.0}$, BC, PN), by 40% for $PM_{2.5}$ and 30% for PM_{10} given that abrasion emissions (tyres, brakes, road) do not decrease, while the concomitant regulatory changes contribute to a reduction of 30% in VOCs, 50% in NOx and NO_2, and 36% in NH_3.

With regard to climate change, there is a 10% reduction in CO_2 emissions from road traffic in the Île-de-France region for the DPF (S1) and gasoline (S2) scenarios, with further reductions of 10% and 7% for the Alternative Technologies and Ambition Air scenarios, respectively.

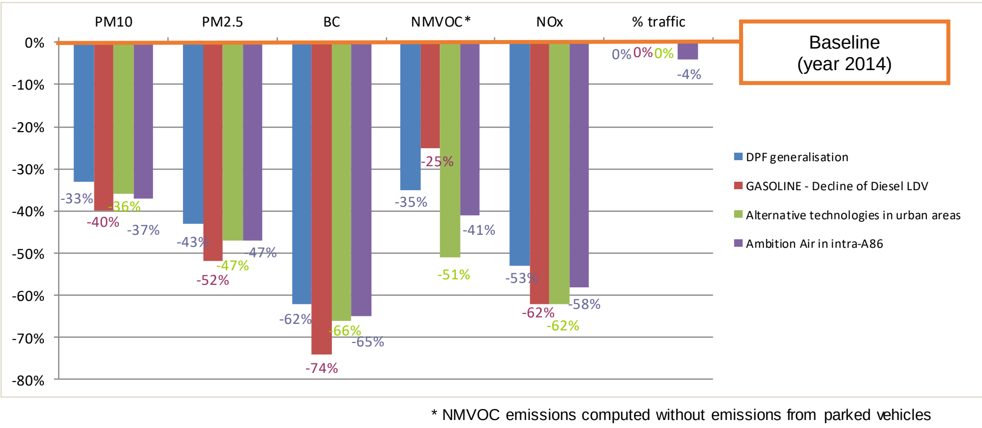


Figure 5: Annual traffic-related emissions (t/year) of PM_{10}, $PM_{2.5}$, BC, NMVOCs, NOx, and traffic (vehicles x km): Relative differences (in %) between the prospective scenarios and the baseline scenario (horizontal axis), Île-de-France

Taking into account all the activity sectors, the reductions in pollutant emissions according to the various scenarios are lessened in proportion to what the traffic emissions represent (Figure 6). Thus, the overall emission reductions by the DPF (S1) and gasoline (S2) scenarios are respectively 31% and 36% for NOx (instead of 53% and 62% for traffic emission reductions), and 33% and 40% for BC (instead of 62% and 74% for traffic emissions). The emission reductions for other pollutants are more muted: 11% and 13% for $PM_{2.5}$, 3% and 1% for VOCs, 7% and 8% for $PM_{2.5-10}$, and 2% and 3% for NH_3 for the Île-de-France region.

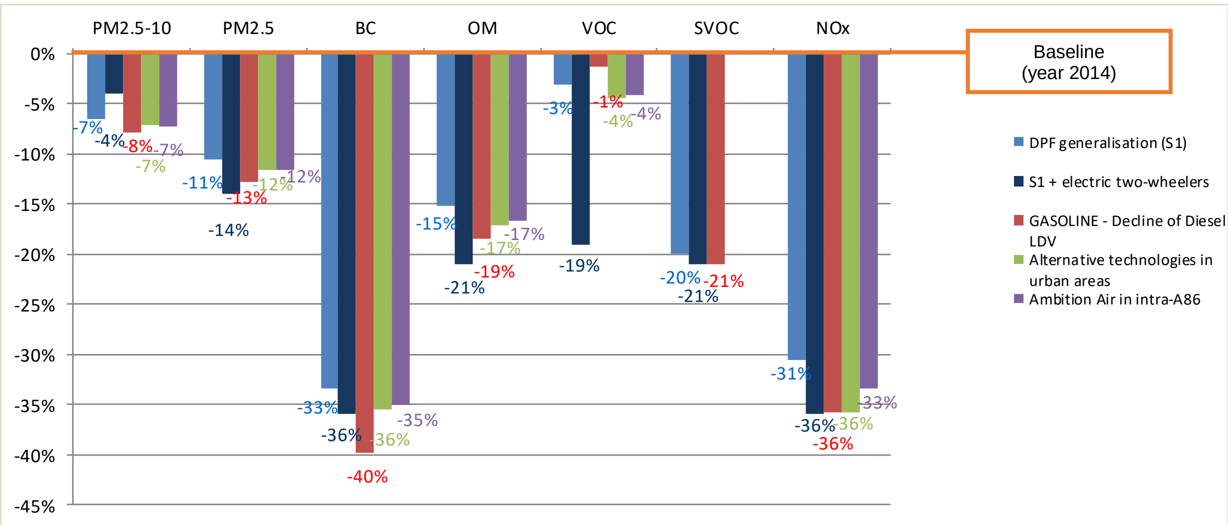


Figure 6: Comparison of total annual emissions from all activity sectors of $PM_{2.5-10}$, $PM_{2.5}$, BC, OM, VOCs, SVOCs and NOx in Île-de-France: Relative differences (in %) between the prospective scenarios and the baseline scenario.

Taking as the baseline the DPF scenario (S1), which is a near steady development scenario, the other technological options give the following results (Figure 7):

- A shift from light-duty diesel vehicles to gasoline vehicles, leading to accelerated fleet renewal (Gasoline or S2 scenario), has the overall result of further decreases of around 30% in combustion particulate emissions (BC), 10% to 15% in $PM_{2.5}$ and PM_{10} emissions, and 20% in NOx emissions, but also an increase of 15% in VOC emissions and 30% in NH_3 emissions.

- The Alternative Technologies (electric) and Ambition Air (reduced intra-A86 traffic) scenarios also result in further emission reductions in the Île-de-France region, smaller than those obtained under the Gasoline (S2) scenario for particulate matter, but more beneficial for CO_2 (greenhouse gases), VOC and NH_3.
- The improvements offered by the Alternative Technologies (electric) and traffic reduction scenarios are particularly marked in the intra-A86 area, which is a major local issue due to the much higher population densities in this urbanised area: reductions of 18% to 29% in combustion particulate emissions and 30% in gaseous pollutant emissions (except NH_3 and CO_2) with electric vehicles, and reductions of 34% to 43% in combustion particulate emissions and 20% to 44% in gaseous pollutants further tied to a traffic reduction of around 17% in this area.

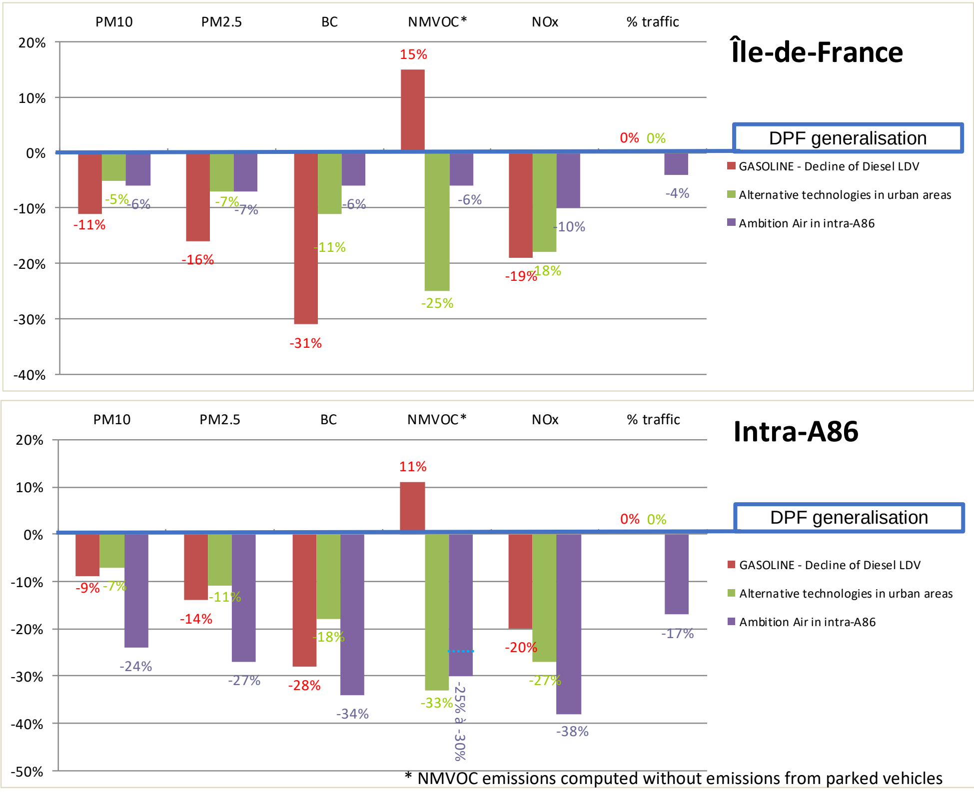


Figure 7: Comparison of traffic and traffic annual emissions of PM_{10}, $PM_{2.5}$, BC, NMVOCs, NOx: Relative differences (in %) between the prospective scenarios and the DPF steady development scenario (S1), Île-de-France (top) and intra-A86 (bottom)

2. Pollutant concentrations (annual averages and high values or "peaks")

As a reminder, pollutant concentrations were simulated over France and the Île-de-France region, considering only the DPF (S1), S1-elec. 2W (sensitivity to VOCs) and Gasoline (S2) scenarios as a complement to the baseline situation.

On average over the year, in France and Île-de-France, all the prospective scenarios lead to decreases in atmospheric concentrations of pollutants, compared to the baseline situation (2014).

- ***These decreases are more limited than those observed for emissions. They are large for pollutants emitted mainly by traffic (BC, NO_2), and more limited for particulate matter ($PM_{2.5}$) and its organic and inorganic fractions coming from transformation processes in the atmosphere.***
- ***For ozone, however, concentrations may increase in urban areas.***

Between the different prospective scenarios themselves, the variations in concentrations are quite small.

With the changes in regulations between the baseline situation (2014) and 2025 and the resulting reduction in emissions through the renewal of the fleet by that time, the different scenarios of technological developments in the vehicle fleet lead to reductions in pollutant concentrations. These reductions are relatively small and more limited than those observed for traffic emissions, due to the multitude of emission sources and – for particulate concentrations – due to their formation in the atmosphere by physico-chemical processes.

The differences between the prospective scenarios themselves are small because the differences in emissions between technologies are lessened by 2025:

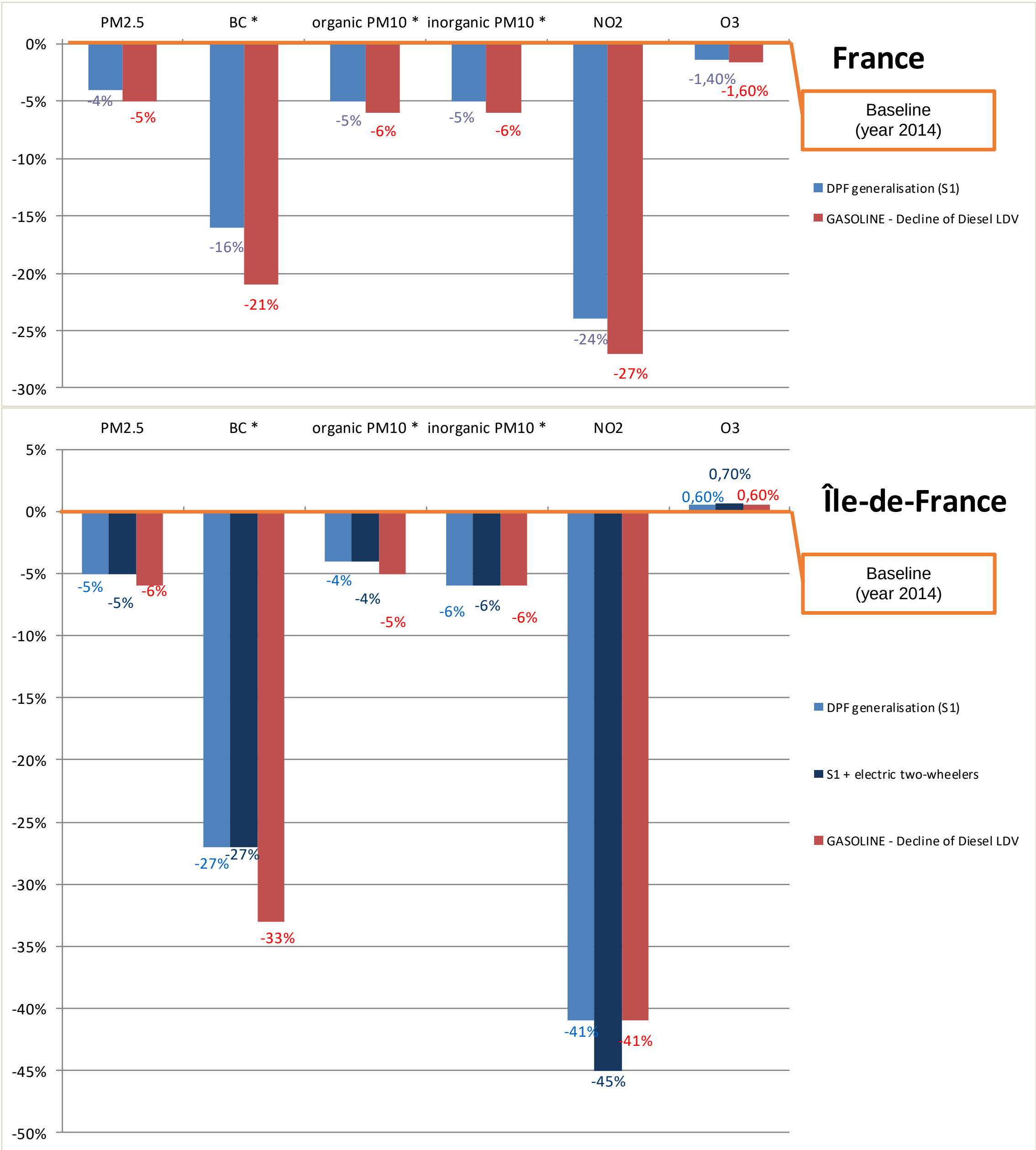
- For example, in the Île-de-France region, the sharp reduction in NOx emissions (39% for the Gasoline-S2 scenario and 35% for the DPF-S1 scenario) and the decrease in VOCs (5%) lead to a significant decrease in annual average concentrations of NO_2 (with large spatial variations ranging from -1% to -60% for the Gasoline-S2 scenario and from -1% to -54% for the DPF-S1 scenario). On the other hand, ozone concentrations tend to increase with disparities between the areas (in Île-de-France -4% to +27% for the Gasoline-S2 scenario and -4% to +23% for the DPF-S1 scenario).
- The reduction in $PM_{2.5}$ emissions (-14%) leads to a smaller decrease in concentrations (-3% to -12% depending on the location) in the Île-de-France region. Primary and non-reactive particulate compounds (BC), whose emissions decrease significantly with the prospective scenarios (-42% for the Gasoline-S2 scenario and -36% for the DPF-S1 scenario), are also significantly reduced in atmospheric concentrations (-17% to -56% depending on the location for the Gasoline-S2 scenario and from -13% to -47% for the DPF-S1 scenario).

Overall, for each of the DPF (S1) and Gasoline (S2) scenarios studied, it can be seen that:

- Except for O_3, whose concentrations increase in urban areas, emissions and atmospheric concentrations decrease for all other pollutants studied: BC, NO_2, $PM_{2.5}$, the organic and inorganic fractions of particulate matter, VOCs and SVOCs[10].
- Decreases in atmospheric concentrations of NO_2 (around -40% and -25% on average per year in Île-de-France and France) and BC (about -30% and -20% on average per year in Île-de-France and France) are greater than those of $PM_{2.5}$ and the organic and inorganic fractions of particulate matter (about -5% on average per year in Île-de-France and France). NO_2 and BC are pollutants to which traffic makes a dominant contribution compared to other activity sectors and for which the technological developments considered by the scenarios (particulate filters, promotion of gasoline vehicles) contribute markedly to reducing emissions.

As a reminder, these scenarios vary only in the technological composition of the fleet (engine types, pollution control technologies), while the other parameters are invariant (traffic, modes of travel, other activity sectors, weather conditions).

[10] Only the changes in emissions in t/year of VOCs and SVOCs were studied, and not the changes in atmospheric concentrations of VOCs and SVOCs.



* The simulated concentrations of particulate compounds (BC, organic and inorganic compounds) technically correspond to the PM_{10} fraction. In practice, they are almost entirely in the $PM_{2.5}$ fraction, as the condensation surface is much larger.

Figure 8: Comparison of annual average concentrations (µg/m³) of $PM_{2.5}$, BC, organic PM_{10}, inorganic PM_{10}, NO_2 and O_3: Relative differences (in %) between the prospective scenarios and the baseline scenario, France (top) and Île-de-France (bottom)

High concentrations (peaks) of air pollutants are reduced more sharply than annual average concentrations.

The decrease in high concentrations of air pollutants by the scenarios is greater than the decrease in annual average concentrations: in other words, the envisaged technological changes to the fleet are more likely to reduce the intensity of pollution peaks than to reduce annual pollution levels.

There is a decrease in the annual number of cases in which the WHO *daily* guideline value for $PM_{2.5}$ is exceeded (a reduction of about 15% in Île-de-France). On the other hand, the number of cases in which the WHO *annual* guideline value is exceeded remains constant and still concerns almost the entire region.

Ozone concentrations may increase in large urban agglomerations. This increase is a cause for concern because it indicates an increase in oxidants in the atmosphere, which may contribute to an increase in the formation of secondary compounds (inorganic and organic), if the precursor gases of these compounds are not reduced.

Variations in secondary pollutants[11] such as O_3, and inorganic and organic particulate compounds depend on the chemical regime of the atmosphere (via the formation of oxidants). This chemical regime is a characteristic of the region concerned, depending on the urbanisation level, and on the different sources and emission proportions of the different pollutants, including the presence or absence of biogenic emissions. The context may therefore promote a decrease in pollution related to a reduction in emissions in some cases, while conditions may be less favourable in other places. The chemical regimes governing the formation of O_3 and secondary compounds are largely controlled by the VOC/NOx ratio. Therefore, in the major cities of France (Paris, Lyon, Marseille, Lille, Bordeaux, Toulouse, Nantes, etc.) and in the north and east of metropolitan France, the formation of ozone and secondary compounds depends strongly on VOC[12] concentrations. Conversely, in the vicinity of regions with high biogenic emissions (Landes, Languedoc, Cévennes, Auvergne and Jura), this formation is highly dependent on NOx concentrations.

The scenarios therefore result in a decrease in ozone except in large cities where it increases, especially in winter (but for initially low concentrations) (Figure 9). In addition, increases or decreases in ozone concentrations are further accentuated by the Gasoline (S2) scenario compared to the DPF (S1) scenario.

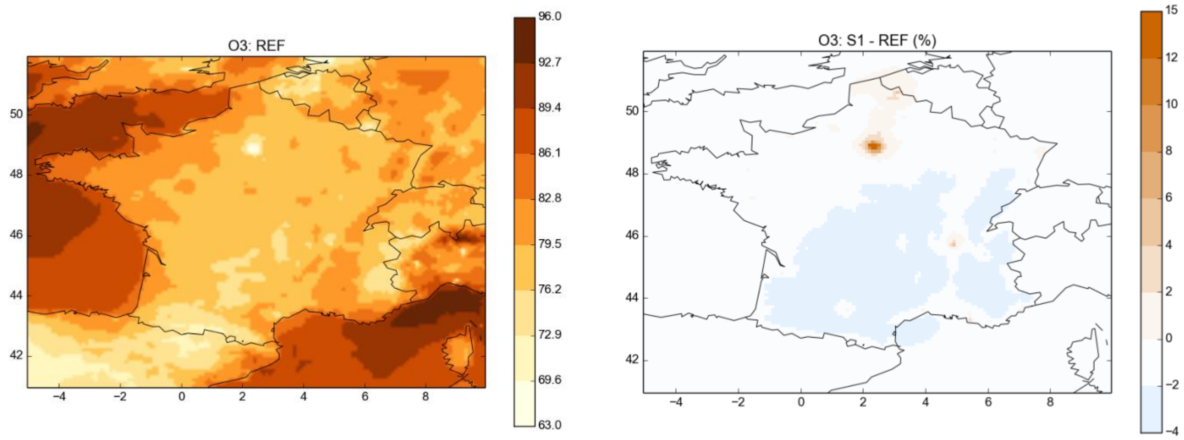


Figure 9: Concentrations of ozone (O_3) in France:

- **Annual average concentrations (in µg/m^3) in the baseline situation (left)**
- **Relative differences in concentrations (in %) between the DPF scenario (S1) and the baseline situation (right)**

[11] A secondary pollutant is not emitted directly but is formed when other pollutants (primary pollutants) react in the atmosphere (http://ec.europa.eu/health/scientific_committees/opinions_layman/en/pollution-air-interior/glossary/pqrs/primary_and_secondary_pollutants.htm).

[12] In a "limited VOC" or low VOC/NOx regime, a decrease in VOCs results in a decrease in ozone, while a decrease in NOx results in an increase in ozone.

For particulate matter concentrations, the scenario that promotes light-duty gasoline vehicles is slightly more favourable than the steady development scenario with generalisation of the diesel particulate filter.

For atmospheric particulate concentrations and emissions, the Gasoline (S2) scenario is always slightly more favourable than the near steady development in the DPF (S1) scenario (Figure 10). The difference is more pronounced for primary traffic particles (BC) than for particles including secondary compounds ($PM_{2.5}$, organic and inorganic fractions). The difference is also notable for NO_2.

This slight advantage of the Gasoline (S2) scenario over the DPF (S1) scenario is largely due to the differences in emissions between these technologies (80% and 60% of the reduction in $PM_{2.5}$ and BC emissions, respectively). It is also related to the accelerated vehicle fleet renewal with the Gasoline-S2 scenario, which results in higher proportions of more recent vehicles and vehicles equipped with DPFs: 92% of Euro 5 and Euro 6 vehicles and 7% of light-duty diesel vehicles without DPF in the urban fleet of light-duty vehicles in Île-de-France, compared to 79% and 15% respectively in the DPF (S1) scenario (Figure 3**Erreur ! Source du renvoi introuvable.** and Table 3). This accelerated fleet renewal therefore contributes partially to the gain in the Gasoline scenario (S2) (by 20% and 40% of the reduction in $PM_{2.5}$ and BC emissions, respectively), while the main reduction is due to the technology change from Diesel to Gasoline.

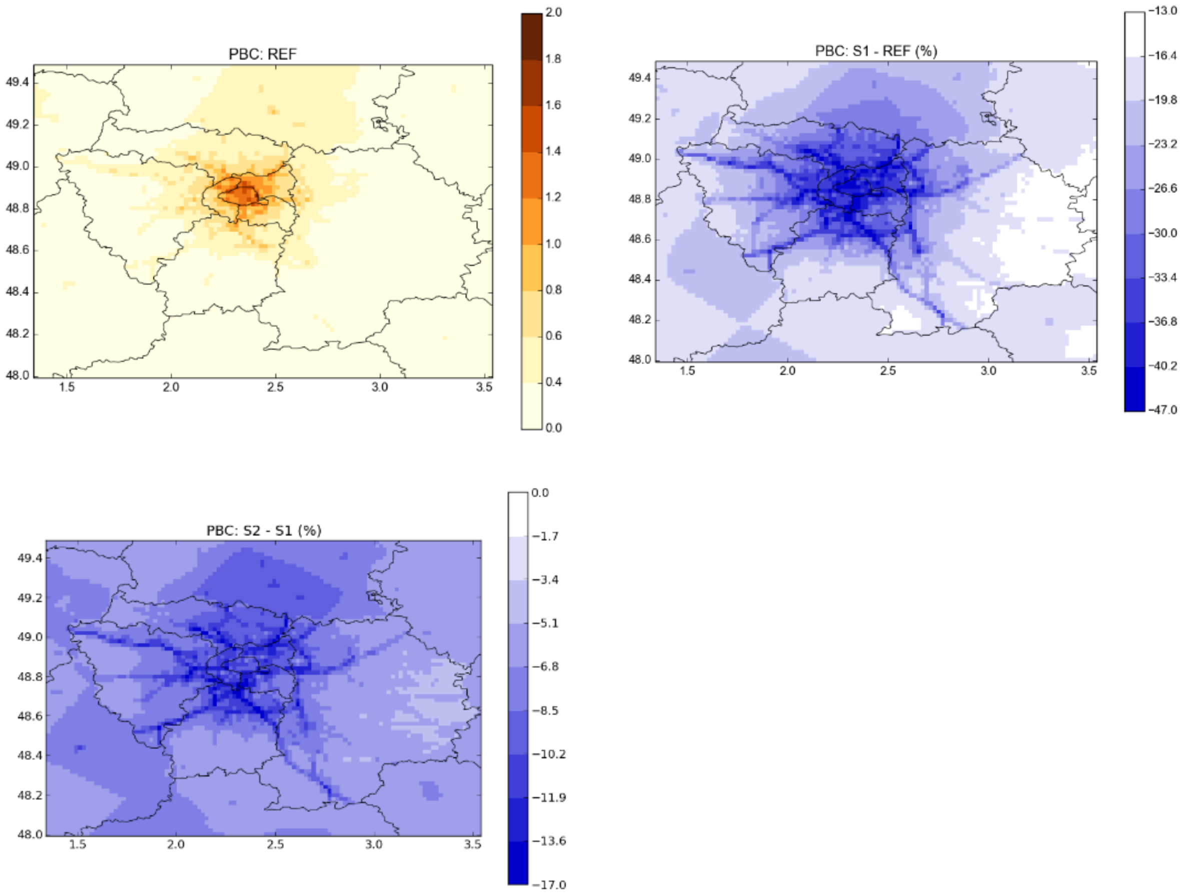


Figure 10: BC concentrations in Île-de-France

- **Annual average concentrations (in µg/m³) in the baseline scenario (top left)**
- **Relative differences in concentrations (in %) between the DPF and baseline scenarios (top right), and between the Gasoline scenario (S2) and the DPF scenario (S1) (bottom left)**

Although the processes of secondary particle formation differ from place to place and in relation to natural emissions and those from other sectors (constant here), all the prospective scenarios result in decreases in organic and inorganic particles in every case.

The decrease in particulate matter precursor[13] emissions induced by the prospective scenarios leads to a decrease in organic and inorganic particles concentrations, even in urban areas where oxidants may increase.

For the organic compounds of particulate matter, therefore, the scenarios induce a reduction in concentrations in urban areas, along major roads, but also near forests and natural parks (Figure 11); this reduction is due to the decrease in oxidants in the vicinity of forests and the decrease in precursor emissions in urban areas and along major roads. Similarly, replacing combustion engine two-wheelers by electric two-wheelers, in addition to the generalisation of diesel particulate filters (S1-elec. 2W scenario), leads to concentrations similar to those of the DPF (S1) scenario alone in the Île-de-France region, but to more significant reductions in the intra-A86 area, particularly for organic particles, due to the reduction in VOC emissions in this scenario. Indeed, this decrease in VOCs leads to a decrease in oxidants and therefore in secondary organic particles in the intra-A86 area and in Paris, where the regime is limited in VOCs. It should be noted that estimating the concentration of secondary organic particles in the scenarios remains uncertain due to uncertainties regarding traffic SVOC emissions.

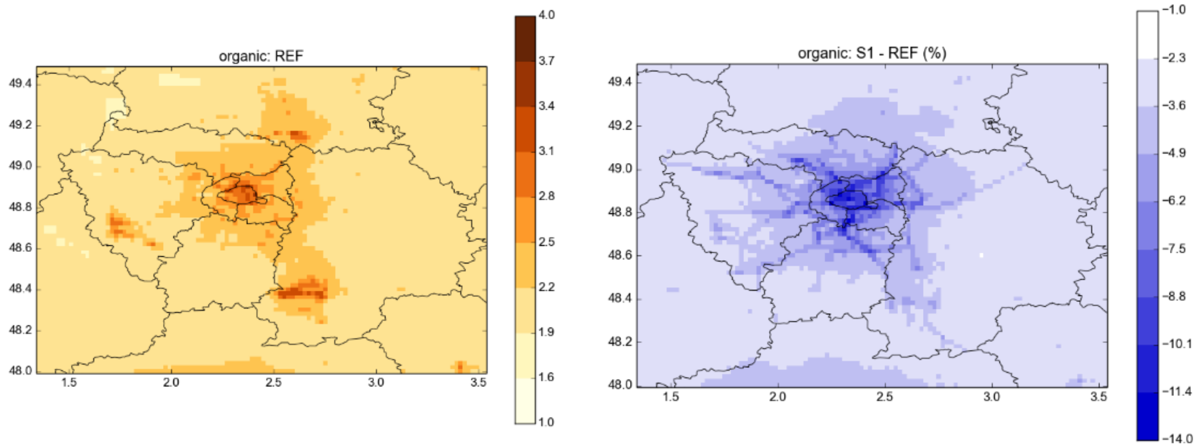


Figure 11: Concentrations of the organic fraction of particulate matter in Île-de-France:

- **Annual average concentrations (µg/m^3) in the baseline scenario (left)**
- **Relative differences in concentrations (in %) between the DPF scenario (S1) and the baseline situation (right)**

3. Population exposure

Cross-referencing pollutant concentrations with population densities – although indicative – shows an improvement in air quality in densely populated areas.

Although local pollution is not considered, the joint analysis of variations in simulated annual average pollutant concentrations (PM_{10} and NO_2) and resident population density makes it possible to estimate a potential impact on pollution exposure per 1 km^2 grid in Île-de-France.

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[13] NO_2, a pollutant more related to diesel engines, VOCs related to gasoline engines, especially motorised two-wheeled vehicles, SVOCs related to diesel and gasoline engines.

As the concentration decreases are greater in densely populated areas and along major roads, the air quality improvement is therefore more pronounced in the most populated areas. The largest gains are observed in the Gasoline scenario (S2), but the differences with the DPF scenario (S1) are small.

For PM_{10}, therefore, the entire Île-de-France population lives in a place where the annual average concentration in outdoor ambient air would decrease by at least 0.4 µg/m^3. A maximum decrease of at least 2 µg/m^3 is achieved for 0.4% of the population in the DPF scenario (S1) and for 1.6% of the inhabitants in the Gasoline scenario (S2).

For NO_2, there is a trend towards a large reduction in NO_2 concentrations for much of the population. Thus, 42% of the population benefits from a reduction of at least 10 µg/m^3 in the DPF scenario (S1) and 49% in the Gasoline scenario (S2). A maximum decrease of at least 18 µg/m^3 in annual average concentrations in outdoor ambient air concerns 1.4% of the population in the DPF scenario (S1) and 11% in the Gasoline scenario (S2).

4. Retrospective analysis

The simulation results are consistent with changes observed in the retrospective observations in France and Île-de-France.

The retrospective analysis show a decrease in emissions of particulate and gaseous pollutants from traffic and other sectors over the last two decades, mainly associated with pollution control systems and improved road traffic fuels, despite an increase in traffic and a greater number of diesel engines in the vehicle fleet. Primary particulate matter from road transport is mainly emitted by those diesel vehicles that are not fitted with particulate filters, with older vehicles making a major contribution to traffic emissions despite a relatively small number of kilometres driven (Figure 12).

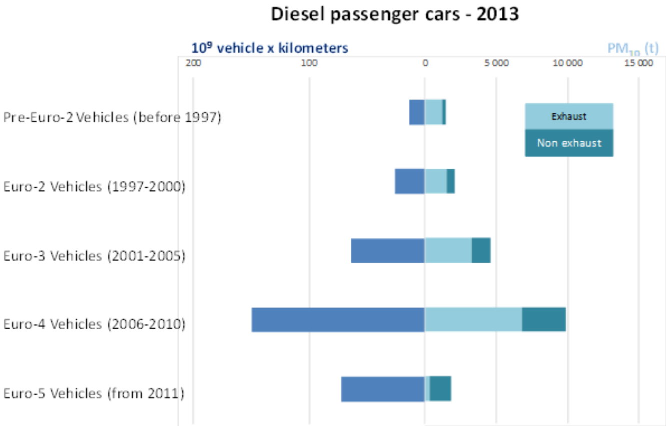

Figure 12: PM_{10} emissions and kilometres driven according to the Euro standards for diesel passenger cars (CITEPA 2013 estimate for the national fleet; CITEPA-OMINEA 2016)

Decreases in exhaust particulate emissions lead to the emergence of emissions related to wear (brakes, tyres, road) and resuspension, which become dominant in term of mass (Figure 13). However, this trend mainly concerns PM_{10} particles.

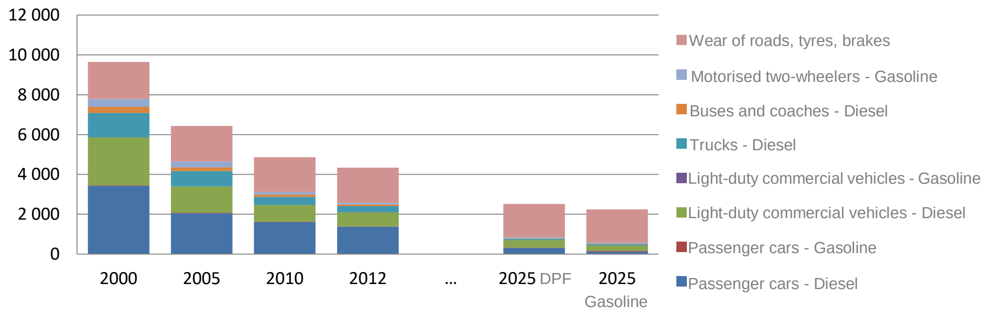

Figure 13: Changes in annual emissions (t/year) of PM_{10} particles from road traffic – Prospective scenarios *vs* 2000-2012 emissions, Île-de-France

Overall, the emission reductions are reflected in decreased concentrations (PM_{10}, $PM_{2.5}$, NO_2), although there are large disparities, especially near traffic, where there are still exceedances of the health standards set by European regulations (Directives 2008/50/EC and 2004/107/EC) in some parts of the country.

In Île-de-France, annual average particle concentrations (PM_{10}, $PM_{2.5}$) have decreased by 25% in 15 years and by 45% near traffic. In recent years, there has also been a slight decrease in total traffic, especially truck traffic (-20% between 2000 and 2012), with however a sharp increase in light-duty commercial vehicle and motorised two-wheeler traffic in urban areas.

In France, road traffic has increased by 1.2% per year on average in recent years, and grew at a faster rate in 2015 (+2.2%) and 2016 (+2.5%) (CCFA, 2017). This increase concerns not only passenger cars but also buses, coaches and heavy goods vehicles for freight transport. Traffic from the most modern cars (Euro 5 and above) accounted for 41% of total car traffic (excluding light-duty commercial vehicles) in 2016 (CITEPA, 2018). Despite their growth, alternative engine types (electric, hybrid) remain at a very limited level, with 21,758 electric passenger cars and 7,482 plug-in hybrid vehicles registered in 2016 (MTES, 2016).

5. Summary of results

In response to the second question of the request (p. 13), Table 4 and * PNC: particle number concentration
** The ranges presented include the variation values of all the pollutants to which they relate. In other words, these ranges do not refer to a specific pollutant.

Table 5 summarise the differentiated impacts of the prospective scenarios varying in the technological composition of the motor vehicle fleet (engine types, pollution control systems) on road traffic emissions and on atmospheric concentrations respectively, for the main particulate and gaseous pollutants.

These tables use arrows and colour codes to show the direction and intensity of simulated changes in road traffic emissions (Table 4) and atmospheric concentrations (* PNC: particle number concentration
** The ranges presented include the variation values of all the pollutants to which they relate. In other words, these ranges do not refer to a specific pollutant.

Table 5).

Table 4: Summary of the impact of the scenarios on emissions of particulate and gaseous pollutants from road traffic

		$PM_{2.5}$	PM_{10}	OM	PNC*	BC	NO_2	VOCs	NH_3	CO_2
Prospective scenarios compared to the baseline scenario (2014)	**DPF scenario (S1)** generalisation of the diesel particulate filter, "near steady development" until 2025	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓
	Gasoline scenario (S2) a decrease from 60% in 2014 to 5% in 2025 in sales of light-duty diesel vehicles in favour of gasoline	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓↓	↓	↓
Change in average annual traffic emissions in the intra-A86 area compared to the baseline scenario (t/year)**. ↓/↑: moderate decrease/increase: [8%; 15%]; ↓↓/↑↑: strong decrease/increase: [28%; 78%]										
Prospective scenarios compared to the DPF scenario (S1)	**Gasoline scenario (S2)** mechanically, renewal of the fleet accentuated with the gasoline scenario (S2) compared to the DPF scenario (S1) involving a lower proportion of pre-Euro 5 vehicles in the Île-de-France fleet (8% vs 21%)	↓	↓	↓	↓	↓	↓	↑	↑↑	=↗
	Alternative Technologies scenario urban: - change in the market to reach electric vehicle sales of 40% of passenger cars and 60% of light-duty commercial vehicles by 2025, and only 5% in diesel vehicles - Euro 3 and earlier trucks and buses, and two-wheeled vehicles <250 cm^3 all replaced by electric vehicles in 2025 outside urban areas: fleet for the DPF scenario (S1)	↓	↓	↓	↓	↓	↓	↓↓	=↘	↓
	Ambition Air scenario intra-A86 area: - fleet for the Alternative Technologies scenario - traffic reduction (-25% passenger cars, -20% light-duty commercial vehicles and trucks) offset by +75% diesel and electric bus traffic, +50% two-wheeled traffic (gasoline and electric) outside intra-A86 area: fleet for the DPF scenario (S1)	↓	↓	↓	↓	↓	↓↓	↓	↓	↓↓
Change in average annual traffic emissions in the intra-A86 area compared to the DPF scenario (t/year)**. =↘/=↗: equivalence or slight decrease/increase: [0%; 2%]; ↓/↑: moderate decrease/increase: [5%; 17%]; ↓↓/↑↑: strong decrease/increase: [21%; 24%]										

* PNC: particle number concentration

** The ranges presented include the variation values of all the pollutants to which they relate. In other words, these ranges do not refer to a specific pollutant.

Table 5: Summary of the impact of the scenarios on concentrations of particulate and gaseous pollutants

		$PM_{2.5}$	Organic PM_{10}	Inorganic PM_{10}	PNC*	BC	NO_2	O_3 urban	O_3 non-urban
Prospective scenarios compared to the baseline scenario (2014)	**DPF scenario (S1)** generalisation of the diesel particulate filter, "near steady development" until 2025	↓	↓	↓	↓	↓↓	↓↓	↑	=↘
	Gasoline scenario (S2) a decrease from 60% in 2014 to 5% in 2025 in sales of light-duty diesel vehicles in favour of gasoline	↓	↓	↓	↓	↓↓	↓↓	↑	=↘

Change in annual average air concentration compared to the baseline scenario (µ/m³)**

- organic $PM_{2.5}$ and PM_{10}, inorganic PM_{10} and PNC: ↓: moderate decrease: [3.3%; 6.2%] (variation in France and Île-de-France)
- BC and NO_2: ↓↓: strong decrease: [30%; 47%] for BC and [19 µg/m³; 25 µg/m³] for NO_2 (maximum variation in Île-de-France on urban areas)
- O_3: =↘: equivalence or slight decrease: [4%]; ↑: moderate increase: [15%; 30%] (maximum variation on urban or rural areas in France and Île-de-France)

		$PM_{2.5}$	Organic PM_{10}	Inorganic PM_{10}	PNC*	BC	NO_2	O_3 urban	O_3 non-urban
Gasoline (S2) scenario compared to DPF (S1) scenario	**Gasoline scenario (S2)** mechanically, renewal of the fleet accentuated with the gasoline scenario (S2) compared to the DPF scenario (S1): 8% vs 21% of pre-Euro 5 vehicles in the Île-de-France fleet	=↘	=↘	=↘	=↘	↓	↓	=↗	=↘

Change in annual average atmospheric concentration compared to the DPF scenario (µ/m³)**

- organic $PM_{2.5}$ and PM_{10}, inorganic PM_{10} and PNC: =↘/=↗: equivalence or slight decrease: [0.4%; 1.2%] (variation in France and Île-de-France)
- BC and NO_2: ↓: moderate decrease: [17%] for BC and [6 µg/m³] for NO_2 (maximum variation in Île-de-France on urban areas)
- O_3: =↘/=↗: equivalence or slight decrease/increase: [0.3%; 5%] (maximum variation on urban or rural areas in France and Île-de-France)

* PNC: particle number concentration

** The ranges presented include the variation values of all the pollutants to which they relate. In other words, these ranges do not refer to a specific pollutant. For $PM_{2.5}$, organic PM_{10}, inorganic PM_{10} and PNC, there is no strong decrease/increase (↓↓/↑↑), nor any equivalence or slight decrease/increase (=↘/=↗) for the comparison with the baseline scenario. For BC and NO_2, there is no equivalence or slight decrease/increase (=↘/=↗), nor any moderate decrease/increase (↓/↑) for the comparison with the baseline scenario. For O_3, there is no strong decrease/increase (↓↓/↑↑), nor any moderate decrease/increase (↓/↑) for the comparison with the DPF scenario.

5 ROAD TRAFFIC EMISSIONS – CONCLUSION OF THE CES "Air" and the WG on "Particulate matter"

The conclusions are presented below, distinguishing between:

- firstly, results derived purely from the simulations and their analysis;
- secondly, results placed into perspective in a more general context where the developments and challenges are not limited to the impact of vehicle technologies on air pollution (*text in italics*). These associated conclusions or recommendations are therefore based on an elicitation of the experts' statements by self-analysis in regard to the scenarios studied and the knowledge of their limits.

Relative importance of traffic and of the different vehicle categories regarding pollutant emission in ambient air

Road traffic is the main emitter of certain pollutants such as black carbon (BC), organic matter (OM) and nitrogen oxides (NOx) in urban areas. It also produces a significant proportion of $PM_{2.5}$ and PM_{10} and their precursor gases and is therefore a fairly strong contributor to urban air pollution. Passenger cars are predominant within the road traffic environment, but each of the other vehicle categories can play a major role regarding certain pollutants.

Reduction in simulated emissions with the various scenarios

The simulation of pollutant emissions and ambient air concentrations in the Île-de-France region and France by 2025 and under the "near steady development" scenario shows that traffic emissions decrease sharply (-30% to -60%), due to changes in emissions regulations (Euro standards), improvements in pollution-control technologies – particularly the near-generalisation of particulate filters on diesel vehicles – and the gradual renewal of the fleet. The scenario that promotes gasoline engines (56% light-duty vehicle traffic compared to 27% in the baseline situation and the DPF scenario (S1)) would result in an accelerated renewal of the vehicle fleet and further reductions in particulate matter and NOx emissions, but also a smaller reduction in VOC and NH_3 emissions.

Reduction in simulated atmospheric concentrations with the various scenarios

In a constant context (demographics, traffic, emissions from sectors other than transport), these reductions in simulated traffic emissions by the technological development scenarios are reflected in:

- a decrease in annual average concentrations (large for BC and NO_2);
- a decrease in the number of high-concentration episodes (except for ozone O_3 in urban areas), but still without achieving compliance with the WHO annual guidance values for $PM_{2.5}$;
- a possible but limited increase in O_3 concentration in urban areas.

In an actual changing context (including probable variations in other parameters), however, this improvement in air quality would be mitigated by an increase in traffic and other polluting activities in urban or suburban areas, related to urbanisation, if new *types of mobility are not promoted (car-sharing, car-pooling, active modes of transport, etc.), in addition to the strengthening of public transport networks. Conversely, it could be amplified by a reduction in emissions from other activity sectors (heating, industry, etc.) that also undergo technical improvements and by various local measures or policies in favour of air quality. It could also be amplified by a decrease in imported pollution when the global context is favourable to a reduction in anthropogenic emissions. These various aspects, as well as climate and demographic changes, have not been considered in this framework and should be studied.*

If they are not accompanied by traffic changes, therefore, technology developments may not be enough to achieve a sustainable improvement in air quality in urban agglomerations.

It should be noted that the more limited improvements observed for $PM_{2.5}$ and PM_{10} concentrations are related to:

- the high contribution of other sectors (combustion for heating and agriculture in Île-de-France). Coordinated air quality policies should therefore be promoted;
- traffic emissions being maintained by abrasion (tyres, brakes, road surface). These could be reduced thanks to improved braking systems and regulatory changes;
- the increase in oxidant concentrations in urban areas that promote the formation of secondary particles.

Technological scenarios and other levers for reducing air pollution from road traffic

Between the "steady development" with generalisation of the particulate filter and the scenario marking a shift from light-duty diesel vehicles to gasoline vehicles, the differences would ultimately be quite limited compared to those observed between 2014 and 2025.

A small (and therefore uncertain) benefit would be observed with the gasoline scenario (S2) with respect to pollution by particulate matter and NO_2 concentrations, for various reasons:

- firstly, for particulate matter, this benefit is partly due to a greater decrease in precursor gases, including NO_2, despite an increase in urban O_3 concentrations;
- secondly, part of the benefit of the gasoline scenario (S2) compared to the DPF scenario (S1) is related to the accelerated fleet renewal (which results in a lower proportion of light-duty diesel vehicles without a DPF and a higher proportion of recent Euro 5 and 6 vehicles). This accelerated fleet renewal is due to the significant shift in the breakdown between gasoline and diesel vehicles over a relatively short period.

Regardless of the technological options, the "accelerated" renewal of the fleet (through various incentives, restrictive measures, etc.) therefore appears as a potential lever for improving air quality in addition to the technological improvements in vehicles and to regulatory changes. However, the side effects of renewal must be considered (additional economic and environmental costs of vehicle construction and destruction, increased use of recent vehicles, possible inequities in incentives and scarcity of used vehicles, etc.).

Nevertheless, the emission simulations with the "Alternative Technologies" and "Ambition Air" scenarios reveal above all the potential of promoting non-polluting (electric) engine types. Even more, they reveal the potential of an ambitious reduction *in traffic in dense areas, contributing to a further reduction in emissions and anticipating a reduction in human exposure and local pollution.*

Technological options, as well as accelerated fleet renewal, must therefore be compared with other measures such as traffic control (low-emission zones, urban tolls, etc.), the promotion of public transport, active modes of transport, car-sharing, car-pooling and freight logistics (e-commerce, last mile delivery, urban logistics platforms), which offer benefits for air quality by potentially reducing the contribution of road traffic. However, the real effectiveness of these different measures remains to be assessed.

The guidelines and measures designed to improve air quality in France in the areas of road transport and mobility (national plan to reduce air pollutant emissions, National Conference on Mobility) and the guidelines for the development of "sustainable transport systems" (international work by the OECD, UNECE, WHO-Europe) could provide an interesting framework for analysis.

Measures to improve air quality can bring co-benefits such as reduced noise pollution or commuting time. More generally, measures specific to mobility should be part of the broader governance of towns and cities, integrating urban planning, transport, health, air and environmental quality, and quality of life.

However, objectively assessing the effectiveness of the measures remains very complex and insufficiently documented, and also requires going beyond the strict framework of pollution. Thus, electric or hydrogen engines, etc., which can be effective solutions for reducing local pollution and greenhouse gas emissions under certain conditions, must be assessed taking multiple implications into account (availability and sources of energy, materials, induced environmental impacts, etc.). "All-electric" transport by 2025 or even 2040 would then probably seem rather unrealistic.

Changes in the issues

This work has shown the importance of traffic in urban air pollution. Several changes can be anticipated and are discussed below.

Urbanisation and development of suburban areas (even without urban expansion) contribute to increased mobility needs and car dependency. Traffic control and the promotion of public transport, active modes of transport and car-pooling for commuters seem essential to contain the resulting increases in emissions.

Developing urban logistics based on light-duty commercial vehicles (at the expense of heavy vehicles) could significantly increase urban traffic and pollutant emissions. However, their already high contribution to pollutant emissions should be reduced by bringing regulations forward (requirements closer to those of cars) and by the relatively rapid renewal of the professional vehicle fleet. Fewer diesel engines and a shift towards natural gas for vehicles (NGV) are also expected. Lastly, due to the significant transfer of used light-duty commercial vehicles to the car fleet, incentive policies on light-duty commercial vehicles (LCVs) may prove to be strategic in terms of the overall development of the fleet.

Motorised two-wheeler traffic is already increasing considerably in some congested urban agglomerations. Its high contribution to VOC emissions is expected to decrease with regulatory changes and the promotion of electric motorised two-wheeled vehicles.

The decrease in actual road traffic emissions is generally lower than expected with regulatory changes, thus lessening the improvement in air quality. Focusing on compliance with approval and control procedures, sparked by recent scandals, seems likely to limit this risk for the future. The dismantling or disabling of pollution-control systems, or their malfunctioning and the degradation of emissions as the vehicle ages, should also decrease through the sophistication of vehicle pollution-control technologies and the strengthening of the pollution component of roadworthiness tests. New techniques for measuring emissions (on-board portable emissions measurement systems – PEMS, in situ measurements) and for identifying vehicles and encouraging eco-driving (Crit'Air stickers, connected stickers) should also help to improve knowledge and control of traffic emissions.

New forms of mobility (car-sharing, car-pooling, autonomous vehicles) and freight logistics (e-commerce, last mile delivery, urban logistics platforms) are expected to impact traffic, vehicle fleets and pollutant emissions, although it is not yet possible to assess their extent.

Regarding exhaust emissions of particulate matter from the automotive technologies currently on the market, there is now very little difference between the amounts of black carbon emitted by a diesel-powered vehicle and those emitted by a gasoline-powered vehicle. Nevertheless, the question of the difference in emissions of precursor gases to organic (semi-volatile organic compounds, SVOCs) and inorganic (NO_2, NH_3, etc.) secondary aerosols is still unresolved.

Regarding non-exhaust emissions of particulate matter from automotive technologies, they could decrease as a result of improved technologies and regulatory changes, but they essentially remain related to traffic volumes and not to technologies. Substituting combustion-engine vehicles by equivalent but heavier electric or hybrid engine vehicles would not guarantee a reduction in non-exhaust $PM_{2.5}$ and PM_{10} emissions because their greater weight would increase particulate matter emissions related to tyre-road contact and resuspension (Timmers et al., 2016).

Uncertainties and limitations

The simulation work presented in this study contains uncertainties (emissions, recent pollution-control technologies, precursors of secondary particles, spatial and temporal distribution of traffic and other polluting sources, etc.). Prospective changes are by nature uncertain, due to the fragility of some of the assumptions in the scenarios, and fail to take many aspects into account (changes in population, behaviour and lifestyles, etc.). The results do not predict the extent of local sources of ambient air pollution. However, they do provide a framework for analysing air quality trends, while allowing identification of issues and comparison of different scenarios by explaining the mechanisms of pollution.

The availability of high-quality data and observations (mobility, traffic, knowledge of emissions, etc.) is fundamental in this process.

In summary:

Road traffic is one of the main contributors to urban air pollution, through its emissions of particulate compounds and precursor gases.

With regulatory changes and improved pollution control technologies, traffic emissions will decrease sharply over a ten-year period, also leading – in an unchanging context – to a more moderate decline in annual average concentrations and episodes of high concentrations, and a possible but limited increase in ozone concentrations in urban areas. Technological developments alone are therefore not enough to achieve a sustainable improvement in air quality in urban agglomerations.

The comparison of technological scenarios shows a slight and uncertain advantage in promoting gasoline engines compared to the expected widespread use of diesel particulate filters, by reducing emissions of particles and precursors such as NO_2 and by accelerating renewal of the vehicle fleet.

In a changing context (greater urbanisation and mobility needs, increasing numbers of light-duty commercial vehicles and motorised two-wheeled vehicles, new regulations, new forms of mobility, etc.), greater benefits must be sought by reducing polluting traffic in densely populated areas, in conjunction with other measures to control traffic, promote public transport and active modes of transport, etc. A framework for assessing the effectiveness of these different measures is essential. It could be based on simulation, but requires the specification of prospective scenarios integrating the main demographic, climatic and energy changes and should consider the various activity sectors (residential, agriculture, etc.) including traffic.

6 RECOMMENDATIONS OF THE CES "Air" and the WG on "Particulate matter"

The recommendations have been divided into two areas: public policies, and research and assessment work to support decision-making.

6.1 Recommendations on the health effects of particulate matter in ambient air according to components, sources and particle size

1/ Public policies

i) Components of outdoor ambient air particulate matter

Considering the evidence of adverse health effects identified for the particulate components mentioned below, the WG and the CES recommend, as part of policies to monitor ambient air quality and reduce air pollutant emissions, that the following particulate components be given priority consideration:

- ultrafine particles (< 100 nm, number concentration),
- black carbon,
- and organic carbon.

Coarse particles ($PM_{2.5-10}$), for which there is evidence for health effects, are already indirectly taken into account in the currently regulated measurement of PM_{10} and $PM_{2.5}$. These recommendations do not call into question the relevance of measuring $PM_{2.5}$ and PM_{10} in the current surveillance system.

These recommendations on ultrafine particles and black carbon reinforce those made previously on the need to supplement and sustain the acquisition of data on these two indicators, as part of the Agency's work on emerging pollutants in ambient air (ANSES, 2018).

ii) Sources of outdoor ambient air particulate matter

Considering the evidence of adverse health effects identified for the sources mentioned below, the WG and the CES recommend that national and international efforts continue to reduce outdoor air pollution and/or population exposure related to the following sources:

- road traffic (including exhaust and non-exhaust emissions),
- coal combustion,
- combustion of petroleum products,
- biomass combustion,
- and desert dust.

Regarding particulate pollution from road traffic, the WG and the CES stress the importance of continuing efforts to reduce population exposure to black carbon, organic matter and ultrafine particles emitted into outdoor air, considering:

- the results of the collective expert appraisal showing strong evidence of adverse health effects associated with exposure to black carbon from road traffic particulate matter, organic carbon and ultrafine particles,
- the results of the collective expert appraisal showing decreases in atmospheric emissions and concentrations of black carbon, organic matter and ultrafine particles from road traffic, obtained through changes in emissions regulations (Euro standards), improvements in pollution-control technologies – particularly the near-generalisation of particulate filters on diesel vehicles – and the gradual renewal of the fleet, based on simulations from 2014 to 2025.

Regarding particulate air pollution from industries, it was not possible to reach a firm conclusion about health effects of this source category due to the heterogeneity of the emission sources and the insufficient quality of the corpus of assessed studies. Nevertheless, the WG and the CES point out that this limitation does not call into question the evidence accumulated from other bodies of literature on the harmful effects on human health of environmental contamination by industrial sites (e.g. WHO Europe, 2014); nor does it challenge the monitoring and control of emissions from industrial sources.

Lastly, in the present work, it was not possible to assess the evidence of health effects of other sources due to a lack of data: agriculture, shipping, airport pollution, natural sources such as pollen and plant debris, wind erosion, volcanic eruptions and biogenic emissions of volatile organic compounds (precursors to secondary organic aerosols) from the vegetation.

2/ Assessment work to support decision-making and research work

To allow for health risk assessments and health impact assessments of outdoor air pollution, the WG and the CES recommend deriving – or producing as necessary – exposure-risk functions for the following particulate pollutants, in order to include them in future assessments:

- ultrafine particles (< 100 nm, number concentration),
- black carbon,
- and organic carbon.

In terms of improving knowledge, the WG and the CES recommend pursuing research efforts on:

- the health effects of exposure to outdoor ambient air particulate matter by including exposure metrics other than PM_{10} and $PM_{2.5}$ mass, in order to develop other reference indicators (exposure-risk functions, ambient air quality standards, etc.) for particulate pollution,
- a metrological definition of secondary organic aerosols with a view, if possible, to harmonising and standardising this exposure metric,
- the predictive nature of the oxidative potential of outdoor ambient air particulate matter in terms of health effects, as well as the definition of this indicator, which is currently

measured by various tests under acellular conditions, with a view, if possible, to harmonising and standardising this exposure metric,

- the health effects of endotoxins in outdoor air,
- the health effects of outdoor air pollution from some as yet poorly documented anthropogenic sources such as agriculture, shipping and airport pollution.

6.2 Recommendations on the impact on air pollution of the technologies and composition of the motor vehicle fleet operating in France

1/ Public policies

The WG and the CES point out that several documents specify national guidelines and measures designed to improve air quality in the areas of road transport and mobility, such as the Ministerial Order of 10 May 2017 establishing the national plan to reduce emissions of air pollutants, as well as the summary of the thematic workshop on "Cleaner mobility" from the National Conference on Mobility in December 2017.

However, the WG and CES note that objective assessment of the effectiveness of these measures remains very complex and insufficiently documented, and requires assessment methods to be defined, including the definition of prospective scenarios. Moreover, the enforcement of several of these measures by local authorities requires calls for projects to be implemented and sustained (for example, calls for projects on "segregated public transport lanes" and "public transport and sustainable mobility").

In view of the very focused analysis carried out as part of the present expert appraisal and the current lack of information and of methods for assessing the actual effectiveness of the various air quality improvement measures, the WG and the CES stress the need to:

- enhance cross-sectoral coordination of air quality policies considering the contributions of different economic sectors[14] to ambient air pollution, especially particulate pollution;
- consider the issue of air pollution by road traffic in its entirety rather than think in terms of technological options and their impact on pollutant emissions alone;
- consider both local pollution and greenhouse gases;
- give joint consideration to technological and regulatory changes, the promotion of alternative technologies (electromobility) and the renewal of the motor vehicle fleet (all vehicle categories including motorised two-wheeled vehicles and light-duty commercial vehicles), but also and above all to the reduction in traffic being offset by greater use of public transport and active modes of transport in densely populated areas, as potential levers for reducing air pollution, local pollution and population exposure;
- take into account the pollutants contributing to particulate pollution as a whole in the development of public policies for air quality, given the high dependence of particulate concentrations on precursor gases (NO_2 and organic components);
- use concentrations of black carbon and nitrogen dioxide (NO_2) and particle number concentrations (PNCs) as exposure indicators in impact assessments and monitoring studies of air pollution generated by road traffic.

[14] Depending on the region, the dominant contributions to particulate pollution may come from the residential and service sectors, industry, road transport or agriculture.

2/ Assessment work to support decision-making and research work

In terms of simulation and assessment methods, the WG and the CES recommend:

- extending the simulation work to other particulate components (polycyclic aromatic hydrocarbons, metals), to more radical scenarios (e.g. 100% gasoline, targeted traffic reductions) or to additional scenarios, in order to observe the sensitivity of certain results (influence on ozone and secondary aerosols). Work on various specific improvements in assumptions or simulation input data would also be useful (ANSES, 2019b);
- developing and implementing tools to enable – in conjunction with the various existing air pollution simulation platforms – more local analyses and the specific study at higher spatial resolutions of local pollution induced by emission sources;
- developing methods for the comparative analysis of different air quality improvement measures – particularly those relating to road traffic – as well as the predictive assessment of the impact of public policies; these methods should include other activity sectors, road traffic and mobility, and take into account the changing context (e.g. climate, demography, energy, emerging technologies and services, behaviour, etc.), in the form of prospective scenarios (even simplified ones) to be developed;
- broadening the issues of assessing air pollution and reduction measures and policies, by integrating the most robust models and indicators on population exposure, exposure to local pollution and health effects.

In terms of knowledge acquisition, the WG and the CES recommend:

- experimentally characterising the emission factors of unregulated pollutants, secondary pollutant precursors and semi-volatile organic compounds for the various vehicle technologies, and investigating more specifically abrasion emissions (brakes, tyres, road surface) and resuspension of particulate matter;
- deploying observation campaigns (traffic) and surveys (mobility) in order to obtain reliable statistics as input data for simulations (fleet composition, speeds, traffic data and activity profiles of the various pollutant-emitting sectors, etc.) and gain a better understanding of behavioural changes.

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8 APPENDIX

Follow-up of the report updates

Date	Version	Page	Description de la modification
January 2019	01		First version of the ANSES report
August 2019	02	2-11	Bringing into conformity with the ANSES report format (list of keywords, presentation of the contributors, acronyms and abbreviations)

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